

THICKNESS DESIGN OF CONCRETE RESURFACING

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Many miles of the nation's highway system have reached or exceeded their design lives in terms of traffic loading. A large portion of the highway system is being revitalized as part of the federal government's 4R program. The 4R program consists of rehabilitation, restoration, resurfacing, and reconstruction. Because of its cost-effectiveness and functional benefits, resurfacing is and will continue to be an important part of the 4R program. Portland cement concrete has been used to resurface pavements for over fifty years. Concrete resurfacing provides a relatively low maintenance service life. There are basically four types of concrete resurfacing. These are bonded, directly placed, unbonded, and concrete resurfacing over an existing asphalt pavement. Concrete resurfacings have been designed in the past by experience or engineering judgment. Recognizing the inherent weaknesses in the existing design procedures, an investigation was sponsored by the Portland Cement Association to develop more rational concrete resurfacing design procedures. This paper presents new thickness design procedures for unbonded and bonded resurfacings. The procedures involve a pavement condition survey, non-destructive load testing at the pavement surface, evaluation of in-situ material properties of the existing pavement, and use of design charts to compute required resurfacing thickness. The unbonded and bonded concrete resurfacing procedures are based on providing a resurfaced pavement that is structurally equivalent to a full depth concrete pavement designed for anticipated future traffic.

Many of the 42,000 miles of the Interstate Highway System have reached or exceeded their design lives in terms of traffic loading. A large part of this system as well as many miles of the primary system needs to be revitalized. One of the most effective methods for rehabilitating highway pavements is concrete resurfacing.

Concrete has been used to resurface pavements for over fifty years. Performance data indicate that concrete resurfacing provides a service life of about 20 years with low maintenance cost and

that many resurfacings have provided 30 to 40 years of service. Improvements in construction equipment, application procedures, and selection of resurfacing type based on life-cycle cost rather than initial cost have resulted in increased use of concrete resurfacing.

There are basically four types of concrete resurfacing. These are bonded, unbonded, directly placed, and resurfacing over an existing asphalt pavement.

1. Bonded Resurfacing - With fully bonded resurfacing, measures are taken to ensure a complete bond with the existing pavement so that the overlay becomes an integral part of the base slab.
2. Unbonded Resurfacing - With unbonded resurfacing, a separation course is used to prevent the overlay from bonding to the existing pavement.
3. Directly Placed (Partially Bonded) Resurfacing - For partially bonded resurfacing, the new overlay of concrete is placed directly on the old pavement. No special attempt is made either to obtain or to break bond.
4. Concrete Resurfacing over an Asphalt Pavement - Concrete resurfacing is placed directly over an existing asphalt pavement.

New thickness design procedures have recently been developed by the Portland Cement Association for concrete resurfacing and for concrete overlays of asphalt pavements (1,2,3). This paper provides a summary of the design procedures for unbonded and bonded concrete resurfacings.

Background

Schematics of the different types of concrete resurfacing sections are shown in Fig. 1. The unbonded resurfacing technique requires use of an unbonding medium at the surface of the existing pavement. This medium, usually asphaltic concrete or sand asphalt, acts as a leveling course as well as a bond-breaker. The bond-breaking function reduces the risk of reflection cracking from the bottom slab. The use of a debonding medium also permits use of a jointing pattern for the resurfacing that does not have to match that of the existing concrete pavement.

A special case of unbonded concrete resurfacing is the directly placed concrete resurfacing. As the name implies, the directly placed resurfacing is placed directly on the existing concrete pavement without any attempt to obtain or break bond at the interface of the two layers. However, existing joints must be matched if the base pavement is jointed. In addition, adequate curing and timing of joint sawing are critical.

With a bonded resurfacing, the added concrete and the existing concrete pavement act together as an integral unit. The existing base concrete must be in sound structural condition, but can have surface distress such as shallow spalling and scaling. Interior slab cracking is permissible if potential reflection cracking is acceptable. Corner cracking should be repaired using full-depth tied patches. Existing joints must be matched, and surface preparation, curing, and timing of joint sawing are critical. Existing pavement surfaces are prepared for resurfacing by milling to remove unsound concrete. This is followed by sandblasting or water-blasting to remove dirt, oil, and other foreign material. A thin coating of a cement grout is applied to the prepared surface immediately ahead of the resurfacing placement.

Resurfacing Types

Unbonded concrete resurfacing may be plain, reinforced, continuously reinforced, or prestressed concrete. For directly placed surfacing, it is desirable to match the resurfacing type to the existing concrete pavement. Thus, a plain concrete directly placed resurfacing should be used only over an existing plain concrete pavement.

Plain concrete is the most commonly used bonded resurfacing. Plain concrete is used to resurface existing plain, reinforced, or continuously reinforced pavements. Joints in the resurfacing must match joints in the existing pavement. For use over continuously reinforced concrete pavements, the bonded resurfacing may not be provided with joints.

Existing Design Procedures

Extensive use has been made of the Corps of Engineers' procedure for design of concrete resurfacing. This procedure was developed for airfield pavements and is based on results from full-scale accelerated pavement testing. The procedure involves use of a coefficient to rate the condition of the existing pavement. This coefficient is primarily based on the amount of visible surface cracking. Its value has a significant influence on determination of the resurfacing thickness required. Because the rating is subjective, different engineers may rate a pavement differently thereby obtaining different thicknesses for the resurfacing.

The Corps of Engineers design equations for concrete resurfacing are:

$$t_o = ((t_t)^2 - c (t_e)^2)^{1/2} \text{ for unbonded resurfacing} \quad (1)$$

$$t_o = ((t_t)^{1.4} - c (t_e)^{1.4})^{1/1.4} \text{ for directly placed resurfacing} \quad (2)$$

$$t_o = t_t - t_e \text{ for bonded resurfacing} \quad (3)$$

where: t_o = required concrete resurfacing thickness, in.

t_t = required thickness for new full-depth pavement, in.

t_e = thickness of existing pavement, in.

c = pavement condition coefficient.

Example values of coefficient c follow (4):

$c = 1.0$ for existing pavement in good overall structural condition with little or no cracking

$c = 0.75$ for existing pavement with initial joint and corner cracking due to loading but without progressive structural distress or recent cracking

$c = 0.35$ for existing pavement that is badly cracked or shattered structurally

Use of the equation for bonded resurfacing implies that the concrete of the pavement has suffered no damage due to traffic or weathering and is therefore as strong as the concrete in a new pavement. However, this assumption cannot be generalized. Therefore, use of the cited equation cannot be expected to provide the most cost-effective solution.

The cited equations were developed specifically for plain concrete resurfacings of plain concrete pavements. For airfield pavements, the Corps of Engineers have developed modifications to account for resurfacing type, existing pavement type, and existing pavement flexural strength (4).

Recently an evaluation of the resurfacing design procedure used by the Federal Aviation Administration (FAA) was made by the Corps of Engineers (5). Several serious deficiencies were identified in the FAA procedure that uses the equation developed by the Corps of Engineers. These deficiencies and proposed improvements to the procedure are detailed in Reference 5.

Several studies have been funded in the past few years by the Federal Highway Administration (FHWA) to develop a rational design procedure for concrete resurfacing of highways. A procedure developed by Austin Research Engineers (ARE) uses linear-elastic layer theory to determine theoretical pavement stresses in the resurfacing (6). A modulus of elasticity value is assigned to the existing pavement based on extent of cracking. Fatigue life is then determined for several alternative resurfacing designs.

The ARE design procedure was not adopted by FHWA but was revised by Resource International, Inc. (7). A final report on the revised procedure is being reviewed by FHWA. The revised procedure requires nondestructive load testing and a condition survey of the existing pavement. Use of the procedure requires a mainframe computer or a large minicomputer.

Evaluation of Existing Pavement

As part of the design process for concrete resurfacings, a comprehensive evaluation of the existing pavement should be made. The evaluation program should consist of the following items:

1. Pavement condition survey
2. Nondestructive load testing
3. In-situ material evaluation

Condition Survey

Many highway agencies have developed comprehensive condition survey programs as part of their

pavement management systems. If a condition survey program has not been instituted by a highway agency, then evaluation procedures given in Federal Highway Administration's publication entitled, "Highway Pavement Distress Identification Manual," may be used (8).

The condition survey should identify type, extent, and severity of pavement distress. Distress types exhibited in concrete pavements are listed in Table 1. In a pavement condition survey, the pavement is divided into survey sections based on pavement design, construction history, traffic usage, and location. For small projects, the full length of the pavement in each section should be surveyed. For larger projects, each section may be divided into sample units consisting of about 10 to 20 slabs. Sample units from each section are then randomly selected. Use of a 25 to 50% sample is recommended. Exact sampling frequency should be based on site conditions and ease of access. For each sample unit, distress types, severity, and extent are recorded.

Distress severity is generally recorded as low, medium, or high. For a high severity distress, cause of distress should be identified and corrective measures taken. For example, if joint faulting is excessive, a program of joint subsealing may be warranted. Details of a joint subsealing program are given in Reference 9.

Load Testing of Existing Concrete Pavements

Need for load testing a pavement to be overlaid is based on site conditions and information developed during the condition survey. If the condition survey indicates existence of, or potential for, load-related distress, then load testing should be carried out to determine the severity of the problem. Load testing should be conducted at joints and cracks to determine absolute deflections at slab corners and relative deflections across joints and cracks. Results of load testing can be used to establish if loss of support exists and if load transfer across joints and cracks is adequate.

Load testing of existing concrete pavements may be conducted using a Benkleman beam, a Road Rater, or a falling weight deflectometer. Other non-destructive load testing equipment that imparts an 8,000 to 10,000 lb load on the pavement may also be used. Use of lighter load testing equipment is not recommended.

In-Situ Material Evaluation for Bonded Resurfacing

For bonded resurfacing projects, a detailed material testing program is recommended to evaluate the engineering properties of the existing pavement materials. Primary objectives of the material evaluation program are to identify the subgrade and subbase materials and to determine strength-related properties of the concrete. These data are needed for determination of the bonded resurfacing thickness.

The subgrade and subbase materials are identified and design moduli of subgrade reaction values at the subbase surface are established for the different sections of the project using procedures suggested in Reference 3. The modulus of subgrade reaction referred to is the Westergaard modulus of subgrade reaction and is equal to the load in pounds per square inch on a 30-in. diameter plate divided by the deflection in inches for that load. The modulus of subgrade reaction at the surface of the subbase may also be back-calculated from results of nondestructive load testing, if performed.

For the existing pavement concrete, it is necessary to obtain representative values of the flexural strength and the modulus of elasticity. Because it is not practical to obtain beam specimens from the pavement, it is recommended that splitting tensile tests be made on pavement cores.

The splitting tensile test consists of loading in compression a concrete cylindrical specimen placed on its side. Load is increased until failure by splitting along the vertical diameter takes place. The vertical diameter of the core under test should correspond to the transverse axis of the core in-place. The test should be conducted in accordance with procedures of ASTM Designation: C 496, "Splitting Tensile Strength of Cylindrical Concrete Specimens." Splitting tensile strength of the specimen is calculated as follows:

$$f_t = \frac{2P}{\pi ld} \quad (4)$$

where:

f_t = splitting tensile strength, psi

P = maximum applied load, lb

l = specimen length, in.

d = specimen diameter, in.

One core should be taken every 300 to 500 ft. Cores should be obtained at midslab and about 2 ft from the outside lane edge. Core diameter should be nominally 4 in. or more. Bottom of cores may be trimmed, but not more than 1/2 in.

For each section, the effective value of the splitting tensile strength is determined as follows:

$$\text{Design } f_{t_e} = \bar{f}_t - 1.65s \quad (5)$$

where:

f_{t_e} = effective splitting tensile strength for the section

$\bar{f}_t$ = average value of the splitting tensile strength for the section, psi.

s = standard deviation of the strength values for the section, psi.

Obtaining the effective value of the splitting tensile strength using the above cited equation implies that only 5% of the pavement section has splitting tensile strength less than the effective value.

The design flexural strength value for a section is then obtained using the following relationship:

$$f_r = AB f_{t_e} \quad (6)$$

where:

f_r = design flexural strength, psi

f_{t_e} = effective splitting tensile strength, psi

A = regression constant

B = damage factor equal to 0.9

Values of A reported in the literature range from about 1.35 to about 1.55. When available, a value of A based on local experience should be used. In the absence of local experience, a value of A of 1.45 is suggested.

The constant B , equal to 0.9, is used to relate the strength of a concrete specimen obtained about 2 ft away from the outside lane edge to that of

concrete at or near the outside lane edge. It is assumed that concrete at or very near the outside lane edge experiences higher stresses due to traffic loading than concrete away from the outside lane edge. Thus, concrete at or near the outside lane edge will exhibit more micro-cracking due to "fatigue" damage and therefore will exhibit lower strength.

The modulus of elasticity of the existing concrete pavement may be determined by testing concrete cores in accordance with procedures of ASTM Designation: C469, "Static Modulus of Elasticity and Poissons Ratio of Concrete in Compression," or by using the following approximate relationship:

$$E_C = D f_R \quad (7)$$

where:

E_C = design modulus of elasticity for the section, psi

f_R = design flexural strength

D = constant = 6,000 to 7,000

Analysis of Unbonded Resurfacings

An ideal analysis of a two-layer unbonded resurfacing section requires that the characteristics of each layer be properly considered. Thus, for an existing pavement slab, parameters to be considered should include slab thickness, slab length, slab cracking, load transfer across joints, load transfer across cracks, and concrete quality. For the resurfacing, parameters to be considered include slab thickness, slab length, load transfer across joints, and concrete quality. In addition, proper characterization of the support under the existing slab should be made.

A two-layer resurfaced pavement system can be analyzed using the finite element technique or using the elastic layer system technique. The finite element technique allows a more realistic modeling of the pavement components, material properties, loading system, and boundary conditions. Wheel loads can be considered at any location on the pavement and any finite size of the pavement slabs can be analyzed. In the elastic layer approach, only infinitely long slabs and circular loaded areas can be analyzed. Thus, the elastic layer approach can be used for analysis of only the interior load condition for an infinitely long and wide pavement system.

Computer program JSLAB developed by the Construction Technology Laboratories for the Federal Highway Administration was used for analysis of unbonded resurfacings. Program JSLAB is a finite element program that can analyze jointed concrete pavement sections consisting of a one-layer or two-layer slab system (10). Wheel loads can be input at any location on the slab. Thus, edge, corner, and joint loading can be analyzed. The analysis of an overlay section consisting of two unbonded layers is done by directly adding the plate stiffness matrix for each of the two layers. No consideration is made of the influence, if any, of the intermediate debonding medium.

Analysis of an unbonded overlay system was conducted for the following conditions:

Load type: 18,000 lb single axle load

Load placement: shoulder edge

Resurfacing slab:

Modulus of elasticity: 5,000,000 psi

Slab length: 20 ft

Existing pavement:

Modulus of elasticity: 3,000,000;

4,000,000 psi

Crack spacing: 5 ft

Cracks in the existing pavement were modeled using soft elements. Wheel load at the edge was placed directly over a crack in the existing pavement. Details of the loading and crack location are shown in Fig. 2.

To check the sensitivity of variable modulus on stress and deflection, analysis were made with modulus of elasticity of existing pavement concrete of 3,000,000 and 4,000,000 psi. Results of stress calculations are given in Table 2. The following trends can be observed from the analysis results:

1. Stress and deflections decrease as the thickness of the existing pavement increases. This effect is more significant for thinner resurfacing than for thicker resurfacing layers.
2. Stresses decrease only slightly with an increase in the modulus of elasticity value of the existing pavement. This effect is even less pronounced for thicker resurfacing when a stiffer subbase/subgrade support exists.

The influence of crack/joint spacing in the existing pavement was determined for spacings of 5, 7, and 10 ft. Analysis results indicate that although stresses and deflections are larger when a crack is present in the existing pavement, the presence of additional cracking in the existing pavement does not further increase the magnitude of stresses and deflections.

An analysis was also conducted for the case of no cracking in the existing pavement. This case simulates an existing pavement with little slab cracking and with reasonably good load transfer across joints and cracks. In addition, any loss of support along joints in the existing pavement is assumed to have been corrected by undersealing. Analysis results are given in Table 3 for the case of modulus of elasticity of the existing pavement of 4,000,000 psi. Analysis results indicate that resurfacing stresses are higher when cracking is present in the existing base slab than when no cracking is present.

It should be noted that the analysis results were for the case of completely debonded layers. However, in some cases some interaction may exist at the interface of the resurfacing and the leveling course and/or at the leveling course and the existing pavement. For such cases, calculated maximum stresses in the concrete resurfacing may be slightly lower.

Design Procedure for Unbonded Resurfacings

A simplified design procedure is presented for unbonded resurfacings. The procedure is based on results of pavement analyses conducted using the finite element computer program JSLAB.

Design Concept

The design concept for unbonded resurfacings is based on providing a resurfaced pavement such that the base slab plus the unbonded resurfacing is structurally equivalent to a new full depth concrete pavement designed to carry the anticipated

future traffic. This implies that the resurfaced pavement will provide a service life that is equivalent to that provided if a new full-depth concrete pavement were to be constructed.

For unbonded resurfacing, the premise of structural equivalency is based on ensuring that the stress that may develop in the unbonded resurfacing is equal to or less than the critical stress. The stress equivalency concept is illustrated in Fig. 3.

Stress data developed using Program JSLAB were used to prepare design charts for determination of unbonded resurfacing thickness. These charts are applicable to existing concrete pavements having effective modulus of elasticity values ranging from about 3,000,000 to about 4,000,000 psi.

Design charts are presented for three cases of existing pavement conditions. These cases are as follows:

- Case 1 - Existing pavement exhibiting a large amount of midslab and corner cracking; poor load transfer at joints and cracks.
- Case 2 - Existing pavement exhibiting small amount of midslab as well as corner cracking; reasonably good load transfer at cracks and joints; localized repairs performed to correct distressed slabs.
- Case 3 - Existing pavement exhibiting small amount of midslab cracking; good load transfer at cracks and joints; loss of support corrected by undersealing.

The design chart for Case 1 was developed using data from analysis of resurfacing sections incorporating a crack in the existing pavement directly under the edge load. The design chart for Case 3 was developed using data from analysis of resurfacing sections with no cracking in the existing pavement. The design chart for Case 2 condition was interpolated between Case 1 and Case 3 conditions. The design charts are given in Figs 4, 5, and 6 for Cases 1, 2, and 3, respectively.

Resurfacing Thickness

The first step in the design process involves determination of the thickness of a full-depth new concrete pavement that would be needed for the anticipated future traffic. The support condition used to determine the thickness of the full-depth concrete should be equal to that for the existing concrete pavement. This requires knowledge of the following design parameters:

1. Future design traffic
2. Design support condition (modulus of subgrade reaction)
3. Concrete flexural strength

The full-depth concrete pavement thickness can be determined using procedures of the Portland Cement Association (11), the American Association of State Highway and Transportation Officials (AASHTO) (12), or using a locally applicable procedure.

Design charts in Figs. 4, 5, and 6 are then used to compute the thickness required for the unbonded resurfacing. Use of the design charts is illustrated in Fig. 4. It should be noted that the minimum resurfacing thickness provided by the design charts is 6 in. Use of a thinner unbonded resurfacing is not recommended.

Representative values of resurfacing thickness determined from Figs 4, 5, and 6 are summarized in Table 4. These thicknesses are listed for different values of existing pavement thickness and equivalent full-depth concrete pavement thickness. It is seen that the resurfacing requirement ranges from 0.5 to about 3 in. less than an equivalent full-depth new concrete pavement. The determination of the actual resurfacing thickness is influenced by the condition and thickness of the existing base pavement.

To compare results given by the design charts with the Corps of Engineers design equations for unbonded resurfacing, resurfacing thicknesses were computed for values of pavement condition coefficient, c , of 0.35, 0.6, and 0.8. These results are presented in Table 5. It is seen that the resurfacing thicknesses listed in Table 5 agree closely with those listed in Table 4. This indicates that the characterization of the existing pavement in terms of Cases 1, 2, and 3 as recommended in the design procedure closely simulates existing pavement condition coefficient, c , values of 0.3 to 0.5, 0.5 to 0.7, and 0.7 to about 0.9, respectively.

Resurfacing with Tied-Concrete Shoulder

When a tied-concrete shoulder is used in conjunction with the resurfacing, then resurfacing thickness may be reduced by 1 in. provided a minimum resurfacing thickness of 6 in. is used. This recommendation is based on results of a field evaluation of pavement sections with tied-concrete shoulder in Minnesota (13). Results of the field evaluation indicate that only one-half the number of design 18-kip equivalent single-axle loads need to be considered for concrete pavements incorporating a tied-concrete shoulder. This results in a reduction of 1 in. in the required mainline slab thickness obtained using the AASHTO design procedure (12).

Design Procedure for Bonded Resurfacings

The design procedure for bonded resurfacing is applicable to projects where pavement strengthening is required to carry the anticipated future design traffic or when the load carrying capacity of an existing bonded resurfacing needs to be checked.

Design Concept

The design procedure for bonded resurfacing is based on providing a pavement such that the base slab plus the bonded resurfacing is structurally equivalent to a new full-depth concrete pavement designed to carry the anticipated future traffic. This implies resurfaced pavement will provide a service life that is equivalent to that provided if a new full-depth concrete pavement were to be constructed.

The premise of structural equivalency is based on ensuring that the critical normalized stress that may develop in a pavement with bonded resurfacing is equal to or less than the critical normalized stress in a new concrete pavement with similar support conditions. Normalization is done with respect to concrete flexural strength. The structural equivalency concept for bonded resurfacings is illustrated in Fig. 7. Thus, the design procedure requires knowledge of the following parameters for the resurfaced and full-depth pavements:

1. Design flexural strength
2. Critical tensile stress

For determination of critical tensile stresses, moduli of elasticity for the existing concrete pavement and for the new concrete pavement are needed. Program JSLAB was used to determine critical tensile stresses for the case of edge loading in a full-depth concrete pavement and in an existing pavement with bonded resurfacing.

The computed critical tensile stresses were then used to prepare design charts for determination of bonded resurfacing thickness. These design charts are applicable for the following conditions:

1. Modulus of elasticity of full-depth concrete pavement of 4,000,000 to 5,000,000 psi
2. Flexural strength of full-depth concrete pavement of 600 to 650 psi
3. Value of constant D of 6000 to 7000 in the following relationship for the existing concrete pavement: $E_c = Df_r$

Design charts shown in Fig. 8 have been prepared for the following three categories of existing pavement concrete flexural strength:

1. Existing pavement concrete flexural strength ranging from 425 to 475 psi
2. Existing pavement concrete flexural strength ranging from 476 to 525 psi
3. Existing pavement concrete flexural strength ranging from 526 to 575 psi

Charts have not been prepared for existing pavement concrete flexural strength values lower than 425 psi and for flexural strength values over 575 psi. For cases when flexural strength values are lower than 425 psi, the large theoretical thickness requirements may not warrant use of bonded resurfacing. Also, an existing pavement with such low flexural strength may already exhibit distress that would not warrant use of bonded concrete resurfacing. In such a case, use of a directly placed or an unbonded concrete layer should be considered.

For the case when flexural strength of the existing pavement concrete is over 575 psi, then the resurfacing thickness required should equal the difference between the required full-depth pavement thickness and the existing pavement thickness plus the depth of surface milling or scarification.

It should be noted that the maximum bonded resurfacing thickness recommended is 5 in. When bonded resurfacing thickness exceeds 5 in. for highway application, then use of a directly placed or an unbonded concrete resurfacing may be a more cost-effective solution. In addition, use of bonded resurfacing less than 2 in. is not recommended for highway pavement strengthening.

Resurfacing Thickness

The first step in the design process involves determination of the thickness of a full-depth new concrete pavement that would be needed for the anticipated future traffic. The support condition used to determine the thickness of the full-depth pavement should be equal to that for the existing pavement. The thickness determination is done using the procedure discussed in the section on the design of unbonded concrete resurfacing.

Design charts given in Fig. 8 are then used to determine the total thickness of the existing pavement plus the bonded resurfacing, t_t . Use of the design charts is illustrated in Fig. 8. After the

total thickness of the existing pavement plus bonded resurfacing, t_t , is determined, the actual as-constructed resurfacing thickness is determined as follows:

$$t_o = t_t - t_e \quad (8)$$

where

- t_o = as-constructed resurfacing thickness, in.
- t_t = total thickness of existing pavement and bonded resurfacing obtained from the design charts, in.
- t_e = existing pavement thickness after milling or scarification, in.

Sample Problem

A sample problems is presented to illustrate use of the design procedure for bonded resurfacings. Assume the following design parameters have been determined for the pavement section to be overlaid:

Existing concrete pavement thickness after milling, $t_e = 7.5$ in.
 Average splitting tensile strength, $\bar{f}_t = 430$ psi
 Standard deviation for splitting tensile strength tests, $s = 50$ psi
 Modulus of subgrade reaction = 100 pci

Parameters for new concrete pavement:

Design thickness = 10 in.
 Design flexural strength = 600 psi
 Design modulus of elasticity of concrete = 4,000,000 psi
 Design modulus of subgrade reaction = 100 pci

Design flexural strength of the existing concrete pavement is computed as follows:

$$\begin{aligned} \text{Effective tensile strength} \\ &= 430 - 1.65 (50) \\ &= 358 \text{ psi} \end{aligned}$$

Using a value of 1.45 for regression constant

$$\begin{aligned} \text{A. Design flexural strength} &= 1.45 (0.9)(358) \\ &= 466 \text{ psi} \end{aligned}$$

Using Fig. 8, the total thickness of the existing pavement and the resurfacing, t_t , should be 11.5 in.

The as-constructed resurfacing thickness is then determined as follows:

$$\begin{aligned} t_o &= t_t - t_e \\ &= 11.5 - 7.5 \\ &= 4.0 \text{ in.} \end{aligned}$$

Thus, for the design example, a 4.0 in. thick bonded resurfacing would be required.

Summary

The Portland Cement Association has developed procedures for thickness designs of unbonded and bonded concrete resurfacing. These procedures require a pavement condition survey, nondestructive load testing, in-situ material evaluation, and use of charts to determine unbonded resurfacing thickness.

Acknowledgments

Work was performed in the Engineering and Resource Development Division of the Construction Technology Laboratories (CTL), a Division of the

Portland Cement Association, under the direction of Dr. W. G. Corley, Divisional Director, and Mr. B. E. Colley, Director of the Transportation Development Department.

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Table 1. Concrete Pavement Distress (From Ref. 8).

Distress Type	Description
Corner Break	Cracks that intersect a joint at a distance less than 6 ft on either side of the corner
D-Cracking	Series of closely spaced crescent-shaped hairline cracks appearing at slab surface along transverse and longitudinal joints caused by freeze-thaw damage to certain types of aggregates
Faulting	Difference in elevation across a joint or crack
Longitudinal Cracking	Cracks parallel to the center line of the pavement
Transverse (Diagonal) Cracking	Cracks caused by combination of drying shrinkage, temperature and moisture variations in the slab, and traffic loading
Popouts	Loss of part of aggregate particle from the pavement surface due to freeze-thaw action, expansive aggregates, or nondurable aggregates
Pumping	Ejection of water and fine material through joints and cracks under traffic loading
Reactive Aggregate Action	Map cracking due to aggregate reactivity (alkali-silica or alkali-carbonate)
Scaling	Wearing of the slab surface, generally caused by freeze-thaw action
Spalling	Partial depth breaks along slab edges usually within 2 ft of the joint or crack

Table 2. Results of Unbonded Overlay Section Analysis (Crack in Existing Pavement Under Load).

k, pci	t _o , in.	t _e , in.	σ , psi	
			E _e = 3,000,000 psi	E _e = 4,000,000 psi
100	6	0	517	517
		6	441	426
		8	394	378
		10	358	344
	8	0	342	342
		6	316	310
		8	293	284
		10	270	260
	10	0	248	248
		6	238	235
		8	226	221
		10	212	205
300	6	0	425	425
		6	360	346
		8	317	303
		10	284	271
	8	0	279	279
		6	258	252
		8	238	229
		10	217	208
	10	0	202	202
		6	194	191
		8	184	180
		10	173	167

Notes: k = modulus of subgrade reaction
t_o = resurfacing thickness
t_e = existing pavement thickness
 σ = maximum resurfacing stress
E_e = modulus of elasticity of existing pavement

Table 3. Results of Unbonded Overlay Section Analysis (No Crack in Existing Pavement Under Load).

k, pci	t _o , in.	t _e , in.	σ , psi
100	6	0	517
		6	334
		8	240
		10	176
	8	0	342
		6	275
		8	223
		10	175
	10	0	248
		6	220
		8	192
		10	161
300	6	0	425
		6	276
		8	200
		10	149
	8	0	279
		6	225
		8	183
		10	146
	10	0	202
		6	180
		8	158
		10	134

Notes: k = modulus of subgrade reaction
t_o = resurfacing thickness
t_e = existing pavement thickness
d = maximum edge deflection
 σ = maximum resurfacing stress

Table 4. Representative Values of Resurfacing Thickness.

t_n , in.	t_e , in.	Resurfacing Thickness, in		
		Case 1	Case 2	Case 3
8	8	6.8	(6.0)	(6.0)
	7	7.2	6.0	6.0
	6	7.6	6.8	6.0
10	9	9.0	7.0	(6.0)
	8	9.2	7.8	6.0
	7	9.4	8.8	8.0
12	9	11.5	10.4	9.0
	8	11.7	10.8	10.0
	7	11.8	11.2	10.8

Notes: t_n = equivalent full depth new pavement thickness
 t_e = existing pavement thickness
 Cases 1, 2 and 3 refer to condition of existing pavement described in the text
 Values in parentheses indicate minimum thickness requirement of 6 in.

Table 5. Resurfacing Thickness Determined Using Corps of Engineers' Equation.

t_n , in.	t_e , in.	Resurfacing Thickness, in		
		$c = 0.35$	$c = 0.6$	$c = 0.8$
8	8	6.5	(6.0)	(6.0)
	7	6.8	(6.0)	(6.0)
	6	7.2	6.5	6.0
10	9	8.5	7.2	6.0
	8	8.5	7.9	7.0
	7	9.1	8.4	7.8
12	9	10.8	9.8	8.9
	8	11.0	10.3	9.6
	7	11.3	10.7	10.2

Notes: t_n = equivalent full depth new pavement thickness
 t_e = existing pavement thickness
 c = pavement condition coefficient
 Values in parentheses indicate minimum thickness requirement of 6 in.

Figure 1. Concrete resurfacings.

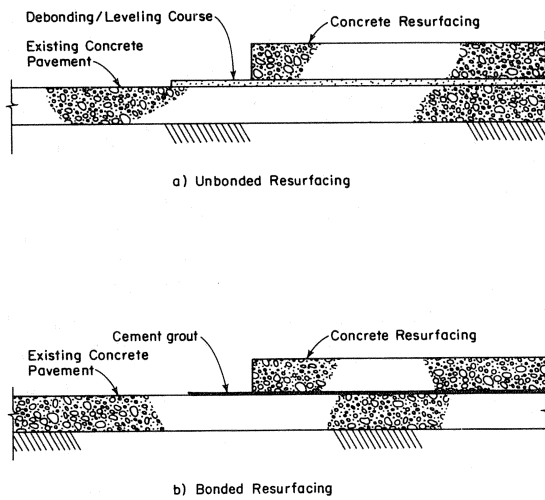


Figure 2. Loading details for pavement analysis.

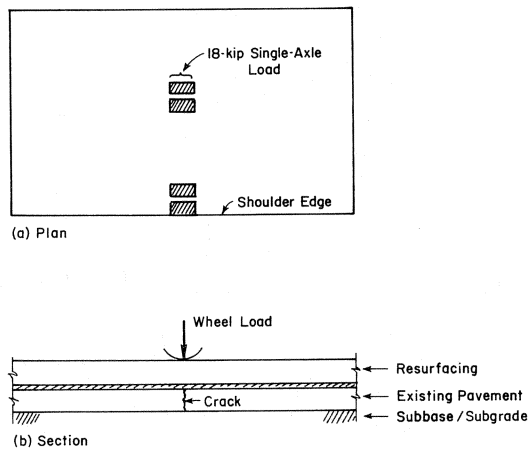
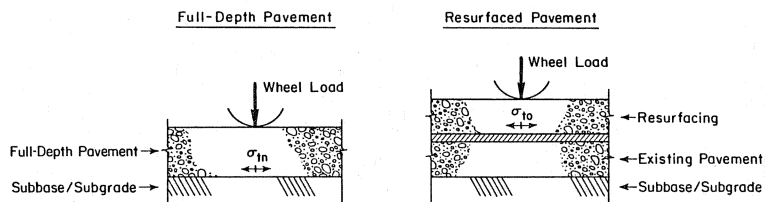


Figure 3. Stress equivalency concept.



Resurfaced pavement to be structurally equivalent to full-depth pavement designed for anticipated future design traffic.

Thus, $\sigma_{to} < \sigma_{tn}$

where: σ_{to} = critical edge stress in resurfacing

σ_{tn} = critical edge stress in full-depth pavement

Figure 4. Design chart for Case 1 condition of existing pavement.

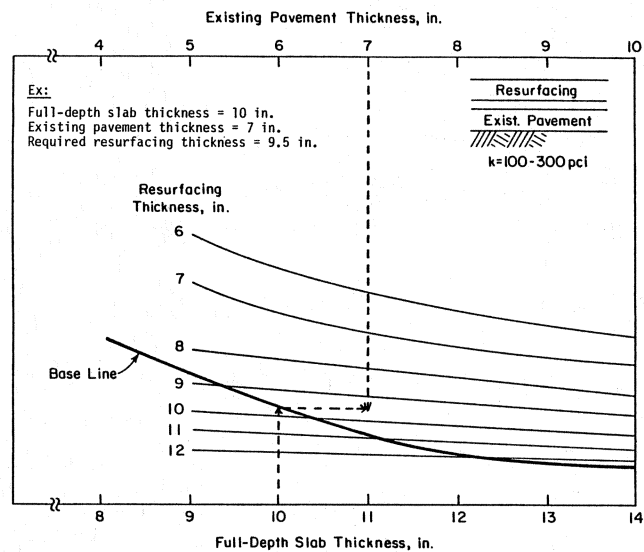


Figure 5. Design chart for Case 2 condition of existing pavement.

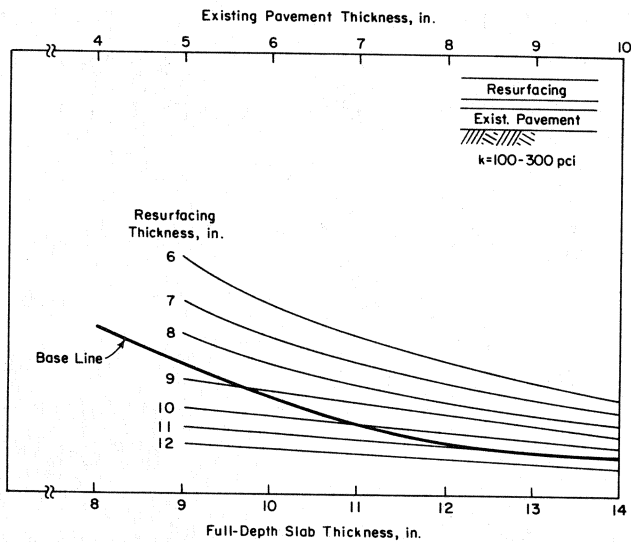


Figure 6. Design chart for Case 3 condition of existing pavement.

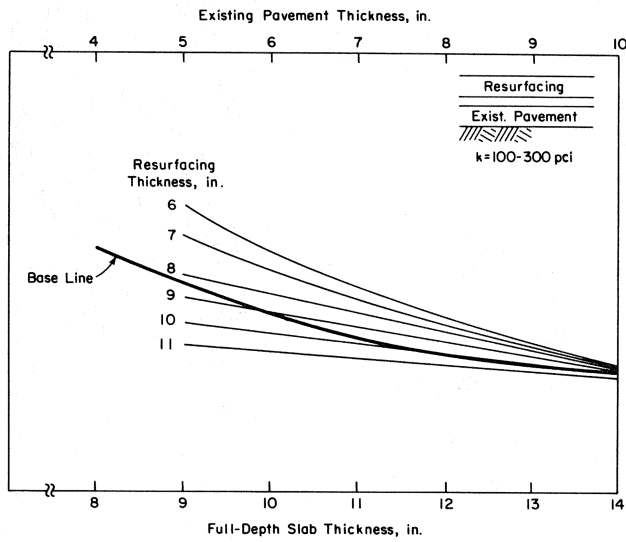
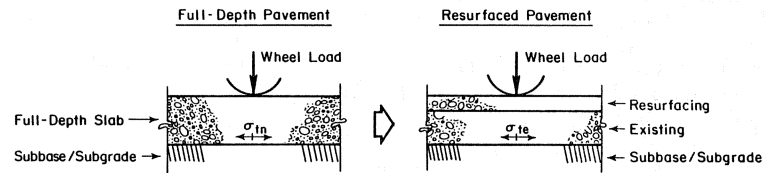


Figure 7. Stress equivalency concept.



Resurfaced pavement to be structurally equivalent to full-depth pavement designed for anticipated future design traffic.

$$\text{Thus, } \frac{\sigma_{te}}{f_{re}} < \frac{\sigma_{tn}}{f_{rn}}$$

where

σ_{te} = critical edge stress in resurfaced pavement

σ_{tn} = critical edge stress in full-depth pavement

f_{re} = flexural strength of existing pavement concrete

f_{rn} = flexural strength of full-depth pavement concrete

Figure 8. Design chart for bonded resurfacing.

