DESIGN CONSIDERATIONS FOR RESURFACING PAVEMENTS WITH CONCRETE

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The most common methods for determining concrete resurfacing thickness are reviewed, and the major factors affecting the design of concrete resurfacing are discussed. It is suggested that limitation of slab deflection is of great importance. Deflection at joints, cracks, and free edges is greater than deflection at some distance from those discontinuities. Based on laboratory data, maximum slab deflection for various methods of load transfer across joints or cracks is proposed. The methods of load transfer discussed are aggregate-interlock, dowels, and continuous reinforcement. The effect of load position and method of load transfer on slab deflection is noted, and the structural benefit of tied concrete shoulders is indicated. Values for the slab support capacity of subgrades, subbases, and existing pavements are suggested, and, based on concrete pavement performance at the AASHO Road Test, maximum allowable slab deflection was calculated to be 0.025 in. Equating slab depths determined by calculation and field performance made it possible to establish a relation between static loads and truck traffic. Concrete resurfacing thickness was then related to truck traffic, method of load transfer across transverse joints or cracks, shoulder type, and slab support. A design example is used to illustrate how concrete resurfacing thickness may be determined. The design and performance of some recent concrete resurfacing projects are considered. The need for a stress relief or leveling course for concrete resurfacing of both concrete and bituminous pavement is discussed. The use of the PCA roadmeter to determine present serviceability index and its application to concrete pavement and resurfacing design are indicated.

•THE MOST common procedure for determining concrete resurfacing thickness on an existing concrete pavement is that developed by the Corps of Engineers (1). Resurfacing thickness is related to required thickness of a new pavement, thickness and condition of the existing pavement, and bond between the resurfacing and the existing pavement. That design method indicates that direct or partially bonded resurfacing may be thinner than separated or unbonded resurfacing. That does not appear to be justified based on the performance of highway resurfacing projects.

The most common methods for determining the slab thickness of concrete resurfacing on bituminous pavement, and also on new concrete pavement, are those of the Portland Cement Association (PCA) and the American Association of State Highway Officials (AASHO) (2, 3). In those methods, slab thickness is related to anticipated axle loads, concrete flexural strength, and slab support capacity of material under the slab. It should be noted that for the same design conditions the PCA and AASHO methods generally indicate that different slab thicknesses are required!

Because the PCA and AASHO design methods are not in agreement and the Corps of Engineers design procedure must be related to one of those methods, a discussion of factors affecting concrete pavement design seems appropriate.

Concrete resurfacing is a means of strengthening, restoring smoothness of ride on, and providing an appropriate surface texture to both concrete and bituminous pavements.

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Pavements may be built initially with a concrete surface or be stage-constructed with concrete, i.e., be resurfaced with concrete. In both cases, the design of a concrete slab requires determination of maximum allowable slab deflection at joints, cracks, or free slab edges; load transfer method across joints or cracks; load position relative to joints, cracks, or free slab edges; support capability of the materials on which the slab will be placed; loads or traffic to which the slab will be subject; slab depth compatible with the above factors; joint or crack type and spacing; need for reinforcement between joints or cracks; and concrete quality.

The following discussion is an endeavor to indicate the relative influence of the above factors in the design of concrete resurfacing, which is, in reality, a concrete pavement having relatively good slab support.

SLAB DEFLECTION

Excessive slab deflection results in the type of distress often attributed to pumping, that is, faulting of joints and cracks and slab disintegration at the free edge of continuously reinforced concrete pavements. Deflection measurements indicate that the following equation, developed by Westergaard in 1926, adequately predicts interior slab deflection d_i:

$$d_i = P/8kl^2$$

where

P = load, lb;
k = subgrade modulus, pci;
$l^4 = Eh^3/[12(1 - \mu^2)k]$;
h = slab depth, in.;
μ = Poisson's ratio; and
E = elastic modulus of concrete, psi.

Values of l for a range of h and k values may be found in another report (4). Interior deflections may also be calculated by means of the PCA influence charts for single axles, tandem axles, and the like. In this discussion, load is considered to be a wheel load or half a single axle load. Interior deflections occur under loads applied approximately 5 ft from joints or free edges; however, all other conditions being equal, slab deflection at joints, cracks, and free edges is greater than at slab interiors. Figure 1 shows the approximate slab deflection if a given load is placed at various locations on a pavement (5, 6, 7, 8). The difference in joint deflection for the various methods of load transfer and shoulder type indicates that slab thickness can be varied with the method of load transfer and shoulder type. The difficulty of measuring slab deflection in the field because of slab warping or curling is recognized. However, if the relative deflection at the load points shown in Figure 1 for different slab depth, joint design, and loading is obtained at the same time on the same day, those data would be of use in analyzing field performance of various pavement designs.

LOAD TRANSFER METHOD

The method of load transfer across joints and cracks is a major factor affecting maximum slab deflection. It is assumed that load transfer across transverse joints or cracks is provided by either aggregate interlock, dowels, or reinforcement. Longitudinal joints may be tied or untied, doweled or undoweled. If a longitudinal joint is not tied or doweled, slab depth at the joint should be the same as if it were a free edge. Tied joints may be weakened plane, keyed, corrugated, or plain providing that an appropriate amount of steel is used across the joint. The nonpositive nature of load transfer across joints that are not tied or doweled should be recognized. However, concrete pavements with undoweled transverse joints can be designed so that joint faulting will not be excessive for a predetermined service life. It is assumed that the load transfer capability of doweled joints and continuous reinforcement is similar (Fig. 1 and Table 1). If continously reinforced concrete pavement (CRCP) is properly designed and constructed, there is evidence that continuous reinforcement is superior to dowels as a method of load transfer (9). The effect of various methods of load transfer on maximum slab deflection is given in Table 1 and shown in Figure 1.

EFFECT OF LOAD POSITION

The structural benefit of a concrete shoulder tied to the slab should be noted (Table 1 and Fig. 1). Laboratory data indicate that, if a load is at least 2 ft from a free edge, a significant reduction in free edge deflection results (5, 6, 7, 8). As an alternative to using a tied concrete shoulder, the lane width could be increased and corrugations placed in the outside 2 ft to discourage its use by traffic. A curb and gutter tied to the slab would produce the same result. The effect of load placement on concrete pavement behavior is also documented elsewhere (10). Concrete pavements are now usually built with a uniform slab depth, i.e., a rectangular cross section. That results in free edges being weaker than tied longitudinal joints. The economic as well as structural advantage of constructing slabs with a trapezoidal cross section or a thickened edge should be considered in locations where concrete shoulders are not appropriate.

SLAB SUPPORT

Concrete slabs may be placed on subbases, on existing pavements, or directly on subgrades. Subbases and existing pavement can provide a nonpumping, all-weather construction platform. If an all-weather construction platform is not considered mandatory, pumping may be prevented by limiting slab deflection. That is possible with or without a tied concrete shoulder or curb and gutter, provided that an appropriate slab depth is used.

Subbases and existing pavements also increase slab support, and that should be recognized in slab thickness determination (11, 12). In the PCA and AASHO methods for determining slab thickness, slab support is estimated in terms of the Westergaard modulus of subgrade reaction k. The choice of an appropriate k value requires some engineering judgment, for k values vary considerably with testing procedure and the time of the year when testing is done (13, 14). An extensive study of concrete pavement performance indicates that, for practical purposes, there are 2 subgrade categories (15):

1. Soils having an AASHO classification of A-1, 2, and 3, i.e., soils having good vertical drainage such as sand and gravel; and
2. Soils having an AASHO classification of A-4, 5, 6, and 7, i.e., soils having poor vertical drainage such as clay.

Subgrade k values of 50 and 150 are used for A-4, 5, 6, and 7 and A-1, 2, and 3 soils respectively to represent the subgrade in its weakest condition (2). Data given in Table 2 may be used to estimate the slab support k value of subbases and existing pavements composed of a variety of materials. Data given in Table 2 were developed from charts used by the California Division of Highways to determine the k value on top of unstabilized granular material and cement-treated aggregate subbase (12). Plate load tests on cement-treated subbase and bituminous concrete subbase indicate that cement-treated subbase has a significantly higher k value than bituminous concrete (16). However, in the absence of deflection measurements at the joints and cracks of concrete pavement placed on top of those materials, it is assumed that they have similar slab support capability. It is also assumed that portland cement concrete has a slab support capacity similar to that of cement-stabilized material and bituminous concrete. That is reasonable if the existing concrete pavement is structurally damaged, e.g., if it has excessive joint or crack faulting. In any event, the k value for design purposes should be chosen with due regard to the subgrade type, existing pavement design (thickness of structural components and load transfer method if concrete), existing pavement condition, and reason for resurfacing.

MAXIMUM ALLOWABLE SLAB DEFLECTION

Concrete pavement at the AASHO Road Test was subjected to known traffic, and the performance was documented in terms of present serviceability index (PSI), a measure of ride smoothness varying between 0 and 5. Concrete pavement sections at the AASHO Road Test had an initial PSI of approximately 4.5 and were considered to have failed when the PSI dropped to 1.5. The minimum subgrade k value at the AASHO Road Test was approximately 50 pci (AASHO A-6 soil), and granular subbase varied from 3 to 9 in. All transverse joints were doweled, and longitudinal joints were tied and keyed (13). The maximum calculated slab deflection, $3d_1$ (Table 1), was determined and related to PSI (Table 3). Data given in Table 3 indicate that very good performance resulted if the maximum calculated slab deflection did not exceed 0.025 in. Calculated slab deflection is generally greater than slab deflection measured in the field because of the effect of slab curling at joints, cracks, and free edges caused by continual daily temperature change from the bottom to the top of a concrete slab. A maximum allowable calculated slab deflection of 0.025 in. is used in this discussion.

LOADS AND TRAFFIC

After a maximum allowable slab deflection is chosen, it is possible to calculate slab thickness for a range of static loads. Static loads of 3,000 to 15,000 lb, representing single axle loads of 6,000 to 30,000 lb, are used. For practical application, slab thicknesses obtained by using static loads must be related to slab thickness requirement based on field performance under traffic.

An extensive study of the performance of concrete pavements having undoweled joints has been made by Brokaw (15). That study related pavement smoothness to heavy truck traffic, subgrade soil type, and pavement age for a range of slab depths. Based on slab depths determined from calculation (using a static load and assuming a slab support k value and a maximum allowable slab deflection) equated to required slab depths determined from field performance (PSI versus age relation), static loads were related to traffic (Table 4).

SLAB DEPTH RELATED TO TRAFFIC, LOAD TRANSFER, SHOULDER TYPE, AND SLAB SUPPORT

Data given in Table 5 are based on a maximum allowable calculated slab deflection of 0.025 in. They indicate the structural benefit of dowels, continuous reinforcement, concrete shoulders, and improved slab support. For a specific project, they show that several different concrete pavement designs are available and that the most appropriate one can be selected.

JOINT TYPE AND SPACING

The choice of joint type and spacing is of paramount importance if distress associated with joint movement such as spalling and pavement blowup is to be prevented. In general, if all transverse joints are contraction joints, the joint spacing should not exceed 30 ft; if all transverse joints are expansion joints, the joint spacing should not exceed 80 ft (17). Longitudinal joint spacing should generally not exceed 15 ft. If joint spacing and type are as suggested above and joints are doweled or tied, joint sealing is not required.

REINFORCEMENT

Slab reinforcement should be used in jointed pavement if the transverse joint spacing exceeds 12 ft (4-in. slab), 15 ft (5-in. slab), and 20 ft (6-in. or greater slab). In both jointed pavement and CRCP, overstressing of reinforcement must be prevented. Accordingly, dowels should not be excessively misaligned and should have a cladding such as Monel metal, stainless steel, or possibly plastic (17, 18). If CRCP will be subject to large slab temperature change, the use of "elastic joints" or an increase in the steel to concrete area ratio should be considered (19, 20).

Figure 1. Effect of load position and method of load transfer on slab deflection.

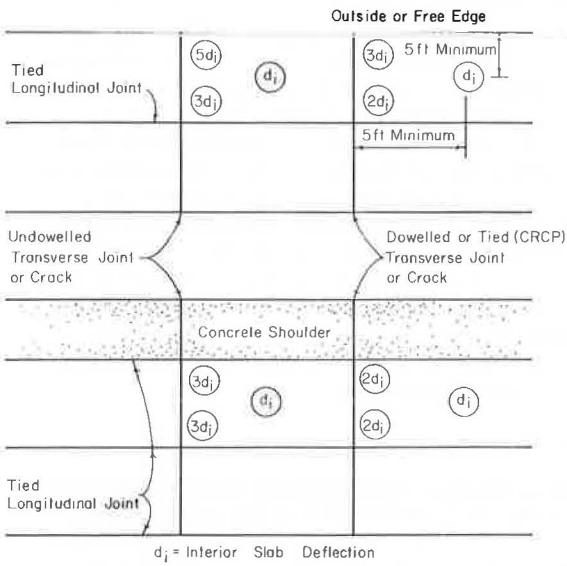

Table 1. Slab deflection related to transverse-joint load transfer method and shoulder type.

Load Transfer Method	Shoulder	Maximum Slab Deflection[a]
Aggregate interlock	Granular or bituminous material	$5d_i$
Aggregate interlock	Concrete[b]	$3d_i$
Dowels or continous reinforcement	Granular or bituminous material	$3d_i$
Dowels or continuous reinforcement	Concrete[b]	$2d_i$

[a]For location, see Figure 1.
[b]Concrete shoulders are same depth as slab at pavement edge. Longitudinal joints are tied. They may be weakened plane, keyed, corrugated, or plain.

Table 2. Slab support k values for 2 subgrade soils.

Material on Subgrade	Depth (in.)	Subgrade Soil: A-4, 5 6, and 7	Subgrade Soil: A-1, 2, and 3
	0	50	150
Granular base	6	75	200
Granular base	12 and more	125	250
Portland cement concrete, bituminous concrete, and cement-treated subbase[a]	4	125	250
	8 or more	250	500

[a]If there is 6-in. granular base beneath the 4-ft subbase, increase k by 50 pci; if 12 in. beneath, increase k by 100 pci.

Table 3. Maximum calculated slab deflection of concrete pavements at the AASHO Road Test.

Slab Depth (in.)	P[a] (lb)	k[b] (pci)	Least Number of Repetitions Carried by Failed Sections	Lowest PSI of Surviving Sections	Max Slab Deflection[c] (in.)
3.5	6,000	100	289,000	1.5-	0.059
5	9,000	100	291,000	1.5-	0.051
6.5	11,200	100	705,000	1.5-	0.043
8	15,000	100	768,000	3.4	0.043
3.5	3,000	50	1,114,000	3.7	0.042
5	6,000	75	725,000	3.1	0.040
6.5	9,000	100	1,114,000	1.8	0.035
5	6,000	100	1,114,000	3.3	0.034
3.5	3,000	75	1,114,000	4.0	0.034
9.5	15,000	100	1,114,000	2.2	0.033
8	11,200	100	1,111,000	4.6	0.032
11	15,000	75	1,114,000	4.0	0.031
8	9,000	75	1,114,000	3.9	0.030
9.5	11,200	75	1,114,000	3.7	0.028
6.5	6,000	75	1,114,000	4.1	0.027
2.5	1,000	50	1,114,000	4.2	0.023
6.5	6,000	100	1,114,000	4.2	0.023
2.5	1,000	75	1,114,000	4.4	0.019
9.5	9,000	75	1,114,000	4.5	0.017

[a]P = half single axle load.
[b]Subgrade k = 50 pci; subbase k estimated from Table 2.
[c]Max slab deflection = 3 d_i (see Table 1).

CONCRETE QUALITY

Concrete used in pavement must be adequately durable for the predicted service life. Concrete commonly used in pavements has a flexural strength of 500 to 700 psi (third-point loading at 28 days) or a compressive strength of approximately 3,500 to 4,500 psi at 28 days. In general, concrete of that quality has performed well, providing that air content was appropriate, the slab surface was not overfinished, and consolidation was adequate. However, particularly for heavily traveled pavement, the ability of high strength concrete (6,000 to 7,000 psi) to increase structural capacity and retain surface texture is worthy of future research (21).

DESIGN EXAMPLE

The subgrade is clay (AASHO A-6 soil), and the subbase is 6-in. granular material. The existing slab is 10-in. unreinforced slab with undoweled joints that have faulted excessively. The slab panels are uncracked (C = 1.0). k on top of the slab = 300 (Table 2). Average daily traffic on the design lane is 2,000 tractor semitrailers and combinations during a period of 30 years. The new pavement design is 9 in. of CRCP on 4-in. treated subbase. Resurfacing is to be CRCP with a stress relief course (unbonded). Resurfacing thickness by Corps of Engineers (1) method = $\sqrt{9^2 - 1.0 \times 10^2} = 0$. Resurfacing thickness by proposed method (Table 5) = 7 in. with bituminous shoulder or 5.5 in. with tied concrete shoulder.

RECENT RESURFACING PROJECTS

Since 1959, most of the highway resurfacing projects using concrete have been continuously reinforced, and most of those have been placed on a stress relief or leveling course (or both) of bituminous concrete. Those projects appear to be performing very well. During 1970-71, in Indiana and Georgia (Table 6), CRCP resurfacing was slip-formed directly over concrete pavement. The project in Indiana had 2 sections of 6-in. CRCP resurfacing, one placed directly on the existing slab and the other separated from it by a polyethylene bond breaker. The project in Georgia was placed directly on a concrete pavement and varied in thickness between 7 and 9 in. Also, CRCP resurfacing in Oregon and unreinforced concrete resurfacing in California were slip-formed directly over bituminous pavement without a leveling course.

The long-term performance of those projects will provide additional data on concrete resurfacing with and without a stress relief or leveling course. In general, a stress relief course is recommended prior to resurfacing with concrete. However, use of CRCP for resurfacing may allow the omission of a stress relief or leveling course, and that would reduce cost for a given pavement and shoulder depth and would minimize construction time.

Since the AASHO Road Test, relatively few data have been gathered on pavement PSI related to pavement age; and, as a result, meaningful documentation of pavement performance is lacking. After the development of the PCA roadmeter by Brokaw (22), a rapid method for measuring PSI became available, and engineers are now able to appraise with minimum effort the performance of pavements having a variety of designs. Before a pavement is resurfaced, its terminal PSI should be documented; after it is resurfaced, the new PSI should also be documented. By relating those data to traffic, slab support, and the like, one can determine performance and cost of pavement and develop realistic design methods.

SUMMARY

1. Existing methods for determining slab thickness of concrete pavement and resurfacing should be reappraised. A more logical design method is proposed.

2. In concrete pavement or resurfacing design, limitation of slab deflection is of great importance. Maximum slab deflection occurs where transverse joints or cracks intersect the outside or free edge of the pavement. If concrete shoulders are tied to the pavement, the free edge deflection is reduced.

Table 4. Relation between static loads and traffic.

Static Load (lb)	Slab Depth (in.): A-4, 5, 6, and 7 Subgrade[a]	Calculated k = 75[b]	A-1, 2, and 3 Subgrade	Calculated k = 200	ADTST[c] on Design Lane for 30 Years[d]
3,000	6	6.5	5	4.5	20
6,000	9.5	10	7.5	7	200
9,000	13	13	9.5	9.5	800
12,000	16	15.5	11	11	2,000
15,000	19	18	13	13	5,000

[a]Granular subbase was under all slabs. Maximum allowable slab deflection = 0.025 in. = $5d_i$.
[b]k values were estimated from data given in Table 2.
[c]Average daily tractor semitrailer and combination traffic.
[d]Terminal PSI = approximately 2.5.

Table 5. Slab depth related to traffic, load transfer, shoulder type, and slab support for maximum calculated slab deflection of 0.025 in.

ADTST on Design Lane for 30 Years	Transverse Joint Load Transfer[a]	Shoulder Type[b]	Slab Depth[c] (in.): k = 50	k = 150	k = 500
5,000	A	G or B	20.5	14.5	9.5
	A	C	14.5	10	7
	D or CR	G or B	14.5	10	7
	D or CR	C	11	8	5.5
2,000	A	G or B	17.5	12.5	8.5
	A	C	12.5	9	6
	D or CR	G or B	12.5	9	6
	D or CR	C	9.5	7	4.5
800	A	G or B	14.5	10	7
	A	C	10.5	7.5	5
	D or CR	G or B	10.5	7.5	5
	D or CR	C	8	6	4
200	A	G or B	11	8	5.5
	A	C	8	6	4
	D or CR	G or B	8	6	4
	D or CR	C	6	4.5	3

[a]A = aggregate interlock; D = dowels; and CR = continuous reinforcement.
[b]G = granular material; C = concrete; and B = bituminous material. Concrete shoulders are same depth as slab at pavement edge. Longitudinal joints are tied.
[c]Slab depth is that required at free edge or at longitudinal joint when adequately tied concrete shoulders are used. Slab depth must be sufficient to provide adequate cover for dowels or reinforcement.

Table 6. Highway projects for concrete resurfacing.

State	Route	Approximate Area (yd^2)	Year Built	Existing Concrete Slab (in.)	Resurfacing (in.)	Continuous Reinforcement	Paving Method
Texas	I-35	15,000	1959	7 + B[a]	7	0.56	Form
	I-35	120,000	1965	9	6 + B[c]	0.57	Slip form
Illinois	I-70	10,000	1967	10 + B	6 + B	0.7 and 1.0	Form
	I-70	10,000	1967	10 + B	7 + B	0.7 and 1.0	Form
	I-70	50,000	1967	10 + B	8 + B	0.6	Form
California	I-80	28,000	1968	8	8 + V[d]	0[f]	Slip form
	US-99	15,000	1968	4 + B	8	0	Slip form
	I-8	40,000	1969	8	6 + B	0	Slip form
	US-99	100,000	1971	Bituminous[b]	8½	0	Slip form
Indiana	I-69	15,000	1970	9	6	0.6	Slip form
	I-69	40,000	1971	9	6 + P[e]	0.6	Slip form
Arkansas	I-55	24,000	1971	9	6 + B	0.6	Form
Mississippi	I-20	30,000	1971	9	6 + B	0.6	Slip form
Georgia	I-75	45,000	1971	8	7	0.7	Slip form
	I-75	146,000	1971	8	8	0.6	Slip form
Oregon	I-80	66,000	1971	Bituminous	7 to 9	0.6	Slip form
Maryland	I-70	130,000	1972	9	6 + B	0.6	Form

[a]Original concrete slab was previously resurfaced with bituminous concrete.
[b]Original pavement was not concrete.
[c]A bituminous concrete layer was placed prior to concrete resurfacing.
[d]Various bond breakers were used.
[e]A polyethylene bond breaker was used.
[f]Joints were undoweled, and concrete resurfacing was unreinforced.

3. If deflection at the interior of a slab is d_i, the maximum slab deflection is approximately $5d_i$ for a pavement with undoweled joints and $3d_i$ for a pavement with doweled joints or reinforcement across cracks. The use of a tied concrete shoulder reduces the maximum slab deflection to $3d_i$ and $2d_i$ respectively. The maximum allowable slab deflection is calculated to be 0.025 in.

4. For design purposes, subgrade k values of 50 and 150 are appropriate for AASHO A-4, 5, 6, and 7 and A-1, 2, and 3 soils respectively. Subbases and existing bituminous or concrete pavements improve the slab support k value, and that improvement should be considered in the design process.

5. The calculated slab depth based on a maximum slab deflection is equated to the slab depth of pavements in service, and a relation between static loads and truck traffic is established.

6. Concrete pavement or resurfacing need not have a uniform depth cross section. Slab depth should be varied with due regard to truck traffic on design lane, load transfer method across joints, shoulder type, and slab support of existing pavement.

7. Concrete resurfacing projects in service indicate that a stress relief or leveling course is generally desirable prior to resurfacing concrete pavement, it may be possible to omit a stress relief or leveling course if the concrete resurfacing is continuously reinforced, and concrete may be slip-formed directly over bituminous pavement without a stress relief or leveling course.

8. The present serviceability index of existing pavement and resurfacing should be determined by means of the PCA roadmeter so that with a minimum of effort the true performance and cost can be determined and realistic design methods developed.

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