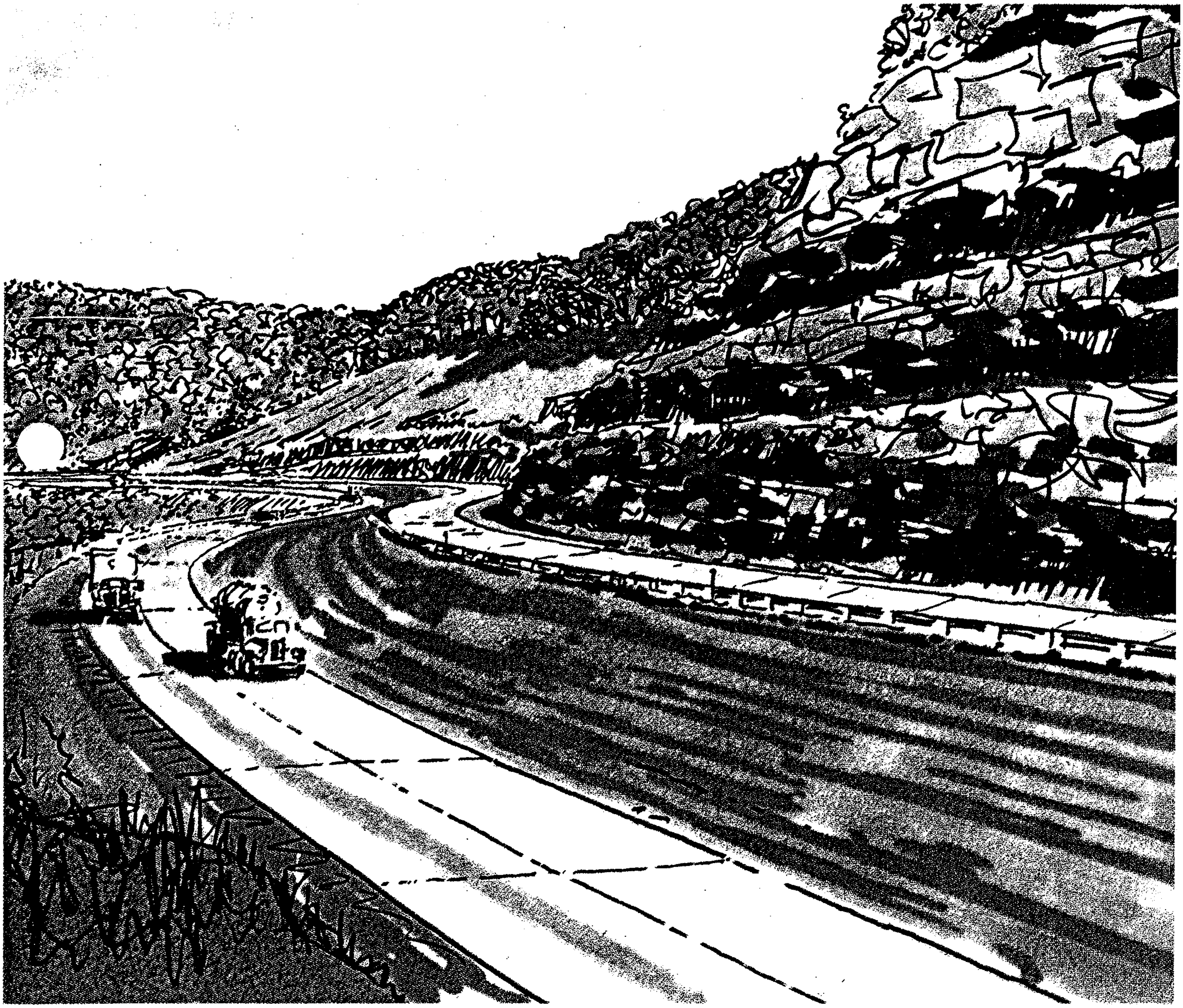
Jointed Concrete Pavements Reinforced With Welded Wire Fabric



Wire Reinforcement Institute, Inc.
McLean, Virginia

JOINTED CONCRETE PAVEMENTS

REINFORCED WITH WELDED WIRE FABRIC

A manual on the design, construction, and maintenance of jointed, reinforced pavement

Prepared under direction of the Paving Fabric Committee, Wire Reinforcement Institute

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FOREWORD

The Wire Reinforcement Institute is privileged to make this manual available to all interested in the design, construction, and maintenance of pavements for highways and airports.

Jointed reinforced pavements are used extensively for expressways, highways, streets, airports, and other pavements. Their overall performance record has been excellent. There are literally tens of thousands of miles of jointed reinforced pavements in service today. Incidentally, many miles of these pavements are what one might describe as being overworked. They were built when our knowledge of subbases, subgrades and joints was limited. In addition, many highways are carrying far more traffic than was ever anticipated. Truck traffic and truck loads have also increased dramatically. We feel that jointed reinforced pavements are a good investment. They perform well and are competitive in initial cost and on an annual cost basis.

This manual contains the current state of the art in the design of jointed pavements. It discusses many aspects of both design and maintenance. Special emphasis is given to joint design which is an integral part of jointed pavement design.

The Wire Reinforcement Institute wishes to thank the Portland Cement Association for permission to use and reprint the following: Design Charts for Single-Axle and Tandem-Axle Loads; Form for Calculation of Concrete Pavement Thickness; Chart on Interrelationship of Soil Classification and Bearing values; and drawings of joints.

ABOUT THE AUTHOR, MR. L.D. CHILDS

The Wire Reinforcement Institute commissioned Mr. L.D. Childs, P.E., to prepare this manual. He spent eight years as Physical Research Engineer with the Michigan Department of State Highways. Mr. Childs then joined the Portland Cement Association, retiring recently as Principal Research Engineer. Mr. Childs was principal consultant on the development of NCHRP #19 entitled, Design, Construction and Maintenance of PCC Pavement Joints (1973). Mr. Childs has been active in both the American Concrete Institute and Transportation Research Board and has presented numerous papers to both of these organizations.

JOINTED CONCRETE PAVEMENTS—REINFORCED WITH WELDED WIRE FABRIC

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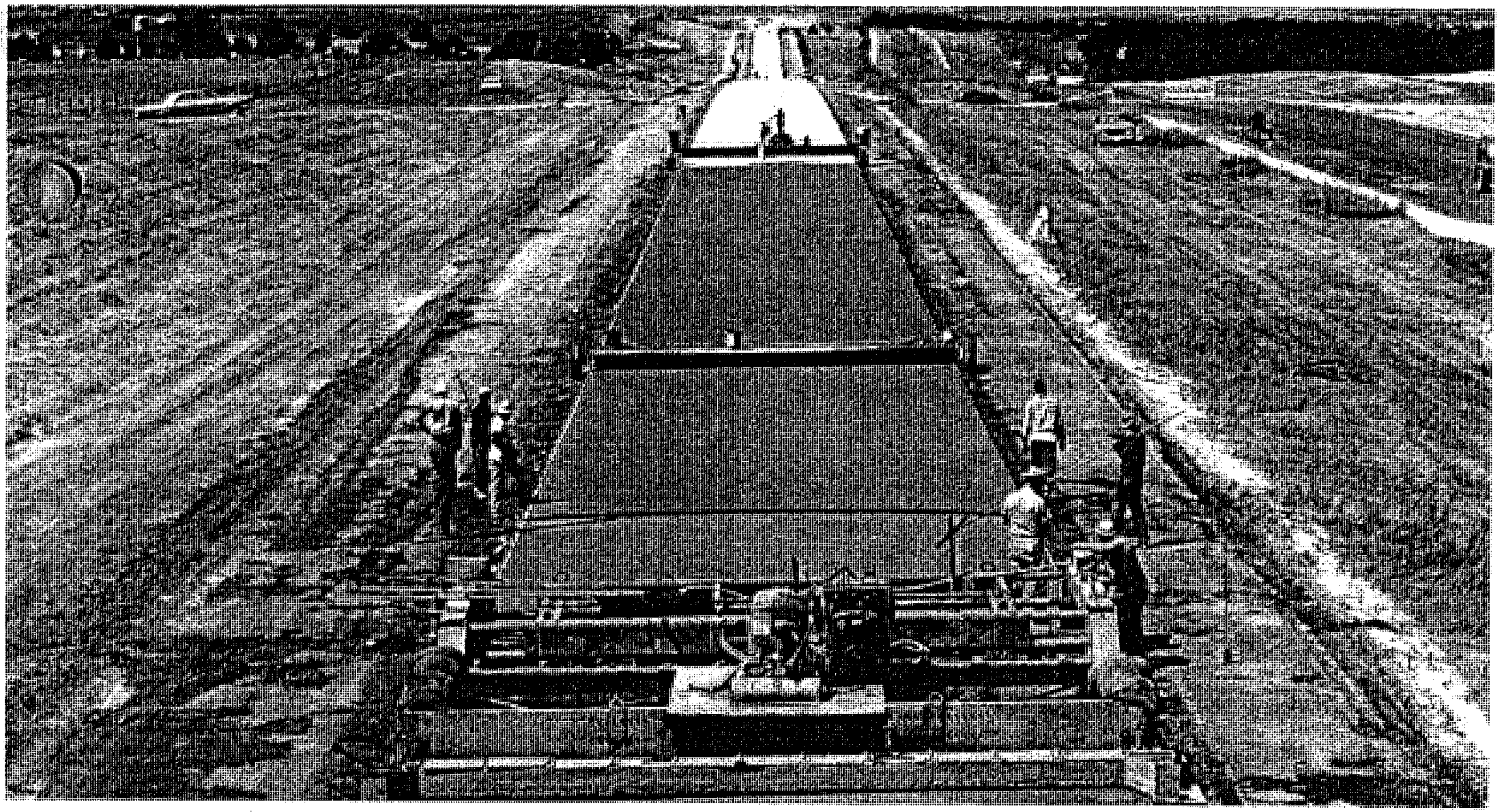


JOINTED CONCRETE PAVEMENTS—REINFORCED WITH WELDED WIRE FABRIC

1. SUMMARY OF PAVEMENT FUNDAMENTALS

The purpose of a pavement is to facilitate the movement of vehicles between point of origin and destination. This is accomplished by the construction and maintenance of a firm, smooth surface with good geometry for safety of operation and long life to justify the cost of construction.

1.1 BASIC PAVEMENT COMPONENTS — Components of a concrete pavement contributing to its serviceability are the supporting soil, subbase, the concrete slab, the reinforcing steel, the load transfer devices — dowels and tiebars — at the joints, and the joint sealants. Each of these must be optimized or designed for best performance to insure adequate pavement life.

1.1.1 Soils — The support given to the concrete slab by the soil is a most important factor in pavement design. This varies with soil type, moisture content, and degree of compaction. Roads are usually routed to avoid organic deposits and cross-hauling is often used to cover poor soils with materials less sensitive to moisture and frost. Pavements for heavy traffic require bases or subbases of granular or treated soils to be placed between subgrade and slab to improve the support factor and uniformity and also to reduce moisture sensitivity.

1.1.2 Concrete — The slab is designed with thickness sufficient to withstand the imposed traffic and of quality to resist the climatic conditions of exposure. It also must have a surface texture to provide adequate friction between tire and slab to assure safe operation on a wet surface. Slab length should minimize joint load transfer deterioration and preserve the joint seal. Quality concrete is designed with a good gradation of sound aggregates and in frost areas the concrete must be air-entrained.

1.1.3 Steel — All pavements except those with very short slab lengths (usually less than 20 feet) require distributed steel to prevent the opening of random cracks. Transverse cracks are the result of accumulation of friction between the slab and subbase or supporting soil, of curl, and of load stresses.

Tensile stresses from friction are induced when the concrete slab contracts due to shrinkage, or a reduction in temperature, and the ends are pulled toward the center. Curl stresses are caused by differences in top and bottom temperatures of the slab causing one surface to contract more than the other. Load stresses result when an axle load deflects the slab.

The reinforcing steel in a concrete slab may be either smooth welded steel wire fabric conforming to ASTM A 185 or welded deformed steel wire fabric conforming to ASTM A 497. Both are of high quality steel with yield strengths of 65,000 psi and 70,000 psi respectively for smooth and deformed wire fabrics.

1.1.4 Load transfer — Short plain concrete slabs are often built without doweled joints, depending upon aggregate interlock for load transfer. This is suitable for streets with little truck traffic but heavy trucks cause joint deflections—particularly when support is inadequate—resulting in aggregate abrasion and eventual loss of load transfer.

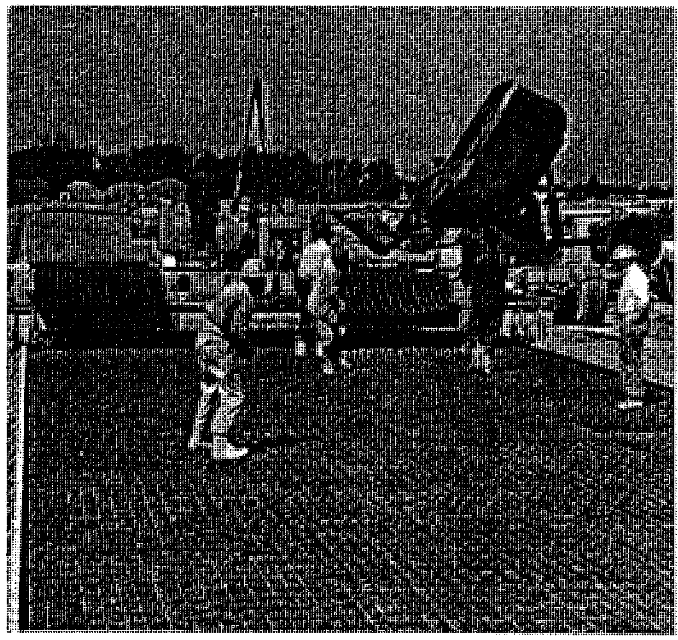
When joints open more than 0.03 to 0.04 inches, dowels are required. These are usually smooth round steel bars or structural tubing with capped ends of lengths of 18 inches or more. Coatings are used to prevent bond to concrete and to inhibit corrosion. Dowels are usually on 12-inch centers and aligned carefully to prevent binding.

1.1.5 Sealants — A joint sealant prevents water and deicing agents from damaging dowels and the subbase. Sealants also keep particles highly resistant to compression from filling the joints and restricting joint movement. Therefore an effective sealant must adhere to the joint walls and cohere and remain extensible when the opening is greatest in cold weather. This requires 1) the selection of a material to meet the specific temperature requirements, 2) control of joint opening by limiting slab length, and 3) design of a suitable reservoir to contain sufficient sealant to meet the extensibility demands.

1.2 PAVEMENT TYPES, SUITABILITY, AND RELATIVE COSTS — Climate, traffic, underlying soil, terrain, and other intangibles cause pavements of different designs to have different success records in various regions. This has prompted the development of several types of pavements to meet these needs. Although first costs differ considerably, the cost per year of service—or annual costs—is most important.

1.2.1 Plain pavements — Pavements without steel and with short slabs separated by weakened-plane transverse joints are usually the cheapest to build. The slabs are so short that the irregular joint surface produced when cracking occurs offers sufficient interlock to transfer traffic loads across the joint. Such pavements are suitable for some residential streets and parking areas with good bases and drainage and little truck traffic. When used on primary roads the joints quickly deteriorate.

1.2.2 Pavements with welded wire fabric — Slabs longer than those in plain pavements are practical when the concrete is reinforced with steel. Although transverse cracks occur, the steel restricts the width of crack opening and assures load transfer through aggregate interlock. Joints require dowels to transfer load because joint faces separate beyond aggregate interlock capability. The cost is slightly greater than that for plain pavements (some plain pavements are doweled) because of the added steel and dowels, but fewer joints are built. Serviceability exceeds that of plain pavements for similar traffic and maintenance is reduced. A great bulk of the highways use this type of pavement.



Formed concrete paving project. This is two-course work reinforcement being placed after first pass.

1.2.3 Continuously reinforced pavements — Transverse joints are eliminated by the construction of continuously reinforced pavements. These employ welded deformed wire fabric or reinforcing bars spliced to form the continuous reinforcement over long lengths. Steel is heavier than in jointed slabs but cost is partially compensated by elimination of joints except at project ends. First cost exceeds that of jointed reinforced slabs but maintenance is reduced, making this construction suitable for urban use where maintenance delays would be costly.

1.2.4 Prestressed pavements — Prestressed pavements are long lengths of concrete cast over pretensioned steel, or with tubes or conduits through which cables are post-tensioned to keep the hardened concrete in compression. Sufficient prestress is required so that friction, contraction, shrinkage, and creep losses are overcome and a residual prestress is maintained. This ideal concept is expensive and only experimental segments have been built.

2. FACTORS AFFECTING PAVEMENT DESIGN

All factors affecting pavement life affect its design. Those over which there is control are the design parameters. These parameters may vary with ambient conditions or materials and experience may sometimes be very important in their selection.

2.1 TRAFFIC — The flow of vehicles over a highway is important for two reasons. First, the road must have proper geometry to expedite this flow in as safe a manner as possible. Second, the number of heavy axle vehicles using the road is a prime factor in determining slab thickness. In the first case, traffic capacity is calculated on the basis of prior studies. Factors are terrain, sight distance, ratio of trucks to passenger cars, and peak densities. In the second case the truck traffic must be categorized by axle type and weight and the contribution of each weight-group frequency to concrete fatigue must be determined.

Traffic data are obtained from loadometer surveys or traffic counts. For capacity studies it is necessary to know the average daily traffic (ADT) as well as average daily truck traffic (ADTT). The figures are then adjusted by a growth factor for the planned pavement life. A convenient table for this calculation is Table 1, taken from a Portland Cement Association (PCA)[1] publication. The percentage of trucks in peak hours, T_{ph} is computed by assuming $T_{ph} = 2/3\ T_{adt}$ where T_{adt} is the ratio of ADTT to ADT expressed in percent. Table 2 from American Association of State Highway and Transportation Officials (AASHTO)[2] shows whether a two-lane road is adequate. If not, ADT less ADTT is converted to hourly volume and checked against Table 3.

TABLE 1

PROJECTION FACTORS FOR COMPOUND ANNUAL GROWTH

Compound Annual Growth Rate, %	Projection Factor	
	20-Year Pavement Life	40-Year Pavement Life
1	1.2	1.2
2	1.5	1.5
3	1.8	1.9
4	2.2	2.5
5	2.7	3.2
6	3.2	4.1

If a traffic count only is available, one may use the formula

$$ADT = \frac{100P}{100 + T_{ph}(j-1)} \times \frac{5{,}000\ N}{KD}$$

where P = passenger cars per lane per hour from Table 3

N = total number of traffic lanes in both directions

j = number of cars equivalent to one truck (4 in rolling terrain, 2 on level terrain)

K = design hour volume as percent of ADT (15 for rural, 12 for urban)

D = percent traffic in heaviest traveled lane peak (67 for rural, 60 for urban)

T_{ph} = percent of trucks in peak hours

2.1.1 A calculation of capacity. Assume a traffic count of 8,260 vehicles with 1,095 trucks in both directions. Design for a 20-year life with a growth rate of 3-1/2 percent. Table 1 gives a 2.0 projection factor which was determined by interpolation.

TABLE 2

CAPACITY, VEHICLES PER HOUR (vph) FOR FREE FLOW ON TWO-LANE ROADS

Terrain	% of Project With Sight Distance Under 1500 Ft.	vph for Indicated Tph, %		
		0	10	20
Level	0	900	780	690
	20	860	750	660
	40	800	700	620
Rolling	0	900	640	500
	40	800	570	450
	60	720	510	400
	80	620	440	350

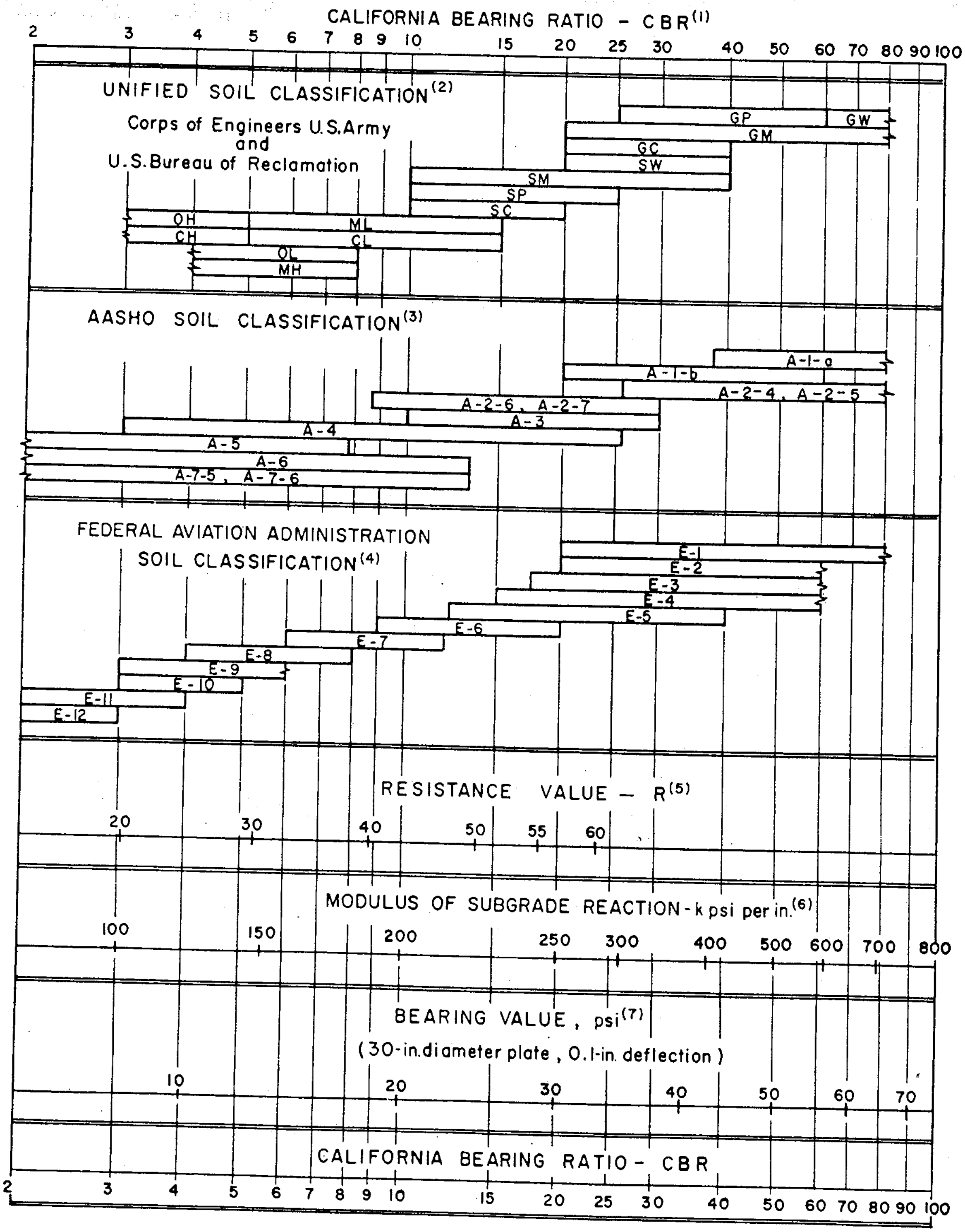
TABLE 3

MULTILANE CAPACITIES

Highway Category	Passenger Cars Per Lane Per Hour
Urban Fwy—Full Access Control	1500
Suburban—Full Access Control	1200
Rural Fwy—Partial Access Control	1000
Rural Major—Moderate Cross Traffic	700—900
Rural Major—Considerable Cross Traffic	500—700

All Above data—Ref. 1

[1]See item 1 in bibliography (page 39). Subsequent reference numbers refer to bibliographic list.



(1) For the basic idea, see O. J. Porter, "Foundations for Flexible Pavements," Highway Research Board *Proceedings of the Twenty-second Annual Meeting*, 1942, Vol. 22, pages 100-136.

(2) "Characteristics of Soil Groups Pertaining to Roads and Airfields," Appendix B, *The Unified Soil Classification System*, U.S. Army Corps of Engineers, Technical Memorandum 3-357, 1953.

(3) "Classification of Highway Subgrade Materials," Highway Research Board *Proceedings of the Twenty-fifth Annual Meeting*, 1945, Vol. 25, pages 376-392.

(4) *Airport Paving*, U.S. Department of Commerce, Federal Aviation Agency, May 1948, pages 11-16. Estimated using values given in FAA *Design Manual for Airport Pavements*.

(5) F. N. Hveem, "A New Approach for Pavement Design," *Engineering News-Record*, Vol. 141, No. 2, July 8, 1948, pages 134-139. *R* is factor used in California Stabilometer Method of Design.

(6) See T. A. Middlebrooks and G. E. Bertram, "Soil Tests for Design of Runway Pavements," Highway Research Board *Proceedings of the Twenty-second Annual Meeting*, 1942, Vol. 22, page 152. *k* is factor used in Westergaard's analysis for design of concrete pavement.

(7) See item (6), page 184.

FIGURE 1

APPROXIMATE INTERRELATIONSHIPS OF SOIL CLASSIFICATIONS AND BEARING VALUES

Then design ADT = 2 x 8,260 = 16,520

Design ADTT = 2 x 1,095 = 2,190

$$T_{adt} = \frac{2{,}190}{16{,}520} = 13 \text{ percent}$$

$$T_{ph} = 2/3 \times 13 = 9 \text{ percent}$$

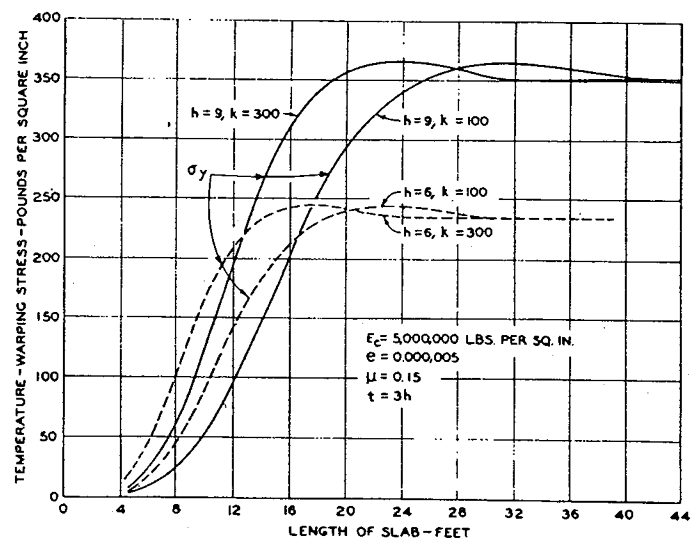
Vehicles per hour in both directions V_{ph} = 690. Using Table 2, the capacity for vehicles per hour for a two-lane road can be checked. By interpolation in Table 2 for T_{ph} = 9 and V_{ph} = 690, it is found that a two-land road in level terrain is satisfactory if no more than 40 percent of the project has sight distances less than 1,500 ft.

2.2 CLIMATE — Although the likelihood of poor driving weather is a factor in pavement geometry, extremes of temperature and rainfall are important in the design of pavement slabs. Cycles of freezing and thawing require the use of air-entrained quality concrete. Frequent rainfall, snow, or icing require that surface textures be rough and durable. Ditches, culverts, and other drainage features must remove water quickly to prevent subgrade saturation. Wet subgrades greatly reduce load-bearing ability and many are susceptible to pumping; in winter they increase chance of frost-heave and consequent slab cracking from sub-slab pressures. Excess moisture in granular bases has been instrumental in the occurrence of "D" cracks in concrete.

Dryness may be detrimental also. When pavements rest on subgrades of fine silt or marl, the tendency for moisture to collect beneath the slab causes these soils to swell and disturb pavement grade. Temperature extremes from day to night cause high curl stresses and large slab movements that test the extensibility of joint sealants.

2.3 SOILS AND SUBBASES — It has been suggested that some obviously detrimental soils can be avoided by route selection, but for the most part little can be done with subgrades except to try to prevent hostile environments. Thus it is necessary to provide the best drainage possible. In new right-of-way construction, it may be possible to bury poor soils under layers of better soils during the grading.

For highway engineering purposes, soils are classified by a combination of gradation and plasticity index (PI). Soils of coarser gradations (granular materials) have low PI and do not absorb much water. The fine grained soils (silts and clays) have high PI and change volume appreciably as water content changes. The preferred soils are granular, or those with large granular fractions.



Ref. 13

FIGURE 2

CALCULATED EDGE STRESS FROM TEMPERATURE

TABLE 4

HIGHWAY SUBGRADE MATERIALS

General Classification	Granular Materials (35% or less passing No. 200)							Silt-Clay Materials (More than 35% passing No. 200)			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5; A-7-6
Sieve Analysis: Percent passing: No. 10 No. 40 No. 200	50 Max. 30 Max. 15 Max.	– 50 Max. 25 Max.	– 51 Min. 10 Max.	– – 35 Max.	– – 35 Max.	– – 35 Max.	– – 35 Max.	– – 36 Min.	– – 36 Min.	– – 36 Min.	– – 36 Min.
Characteristics of fraction passing No. 40 Liquid limit Plasticity index	– 6 Max.		– N.P.	40 Max. 10 Max.	41 Min. 10 Max.	40 Max. 11 Min.	41 Min. 11 Min.	40 Max. 10 Max.	41 Min. 10 Max.	40 Max. 11 Min.	41 Min. 11 Min.
Group Index	0		0	0		4 Max.		8 Max.	12 Max.	16 Max.	20 Max.
Usual Types of Significant Constituent Materials	Stone Fragments Gravel and Sand		Fine Sand	Silty or Clayey Gravel and Sand				Silty Soils		Clayey Soils	
General Rating as Subgrade	Excellent to Good					Fair to Poor					

Ref. 4

2.3.1 Indicators of soil support — In addition to the preference for soils with good volume stability, it is advantageous if they offer good support to an applied load. For highway use it is not as important that support be high as it is that support be uniform. The support value, however, indicated by subgrade modulus k, is a parameter in thickness design and higher k values permit thinner slabs. It seems obvious that the k determined from tests on a base course built on a high-k subgrade will be greater than that on a like base on a low-k subgrade. Figure 1 from PCA[3] relates three methods of soil classification and four methods for evaluating support. Table 4 gives the AASHTO[4] method of designation of soils for highway use.

2.3.2 Disturbed soil and recompaction — When soils are disturbed their volumes are affected. Certain western shales swell when overburden is removed and delays must be planned until stability is attained. Conversely, peat densifies under surcharge because water is forced out. When soils from cuts are placed in fills for leveling purposes, the fill soil must be compacted at —or close to—optimum moisture content and in shallow lifts in order that the embankment be free from settlement. Also, embankment slopes are critical and vary with soil type.

2.3.3 Bases and subbases — The layer of select material placed between slab and subgrade is called a subbase or base course. Its function is to improve the support value of the soil and make it more uniform than can be attained by the many subgrade soils encountered, in order to reduce the sensitivity of the foundation to water and to control pumping. Natural bases are either open-graded with interlocking granular material having gradation gaps that allow small voids through which water may drain readily, or dense-graded with a gradation that includes sufficient small particles to pack solidly and form a water-shedding layer. Open-graded subbases are used over well-drained granular subgrades. Dense-graded subbases are used over highly water-sensitive subgrades.

The beneficiation of support is related to base thickness and type of material. Some examples from laboratory studies[5] are given in Table 5.

Beneficiation of k by bases may be accomplished also by treating the materials with cement, bitumen, lime, or other materials. These become water-shedding layers because of the material gradations and cementing action of the binder. A greater proportion of fines is used in these bases, thus obviating the need for the less plentiful granular materials. Treatments of soils must contain sufficient cementitious material to form durable bases under prevailing climatic conditions. Examples of k values obtained from tests[6] on cement-treated soils are shown in Table 6. Values for bitumen treated and lime treated materials are averages from various literature sources[7]. Good mix designs are described in the literature. Lime is most effective for treating upper subgrade layers of clays or soils with pH less than 7.

TABLE 5

EFFECT OF UNTREATED BASE ON FOUNDATION k

Material	Depth, In.	In-Place Density, pcf	30-in. Plate k - pci
Silty-clay subgrade	48	111	90
Dense gravel base	3 6 9	129 130 132	120 145 170
Open gravel base	5 10 15	132 137 135	130 200 225
Dense crushed stone	5 10 15	127 129 126	150 170 180
Open crushed stone	5 10 15	118 112 114	145 170 190

Ref. PCA Jour. 1960

TABLE 6

EFFECT OF TREATED BASE ON FOUNDATION k

Base Material	Depth, In.	Representative k, pci	Source
Soil-cement base	3 6 9	180 330 450	Ref. 6
Asphalt-treated lean subbase	3 5 7	130 210 290	Field Tests (St. Louis)
Lime-treated clay subbase	6 12 18	140 180 230	Lab. Extrapolation

3. SLAB STRESSES AND DEFLECTIONS

It has been mentioned that slab curling stresses are induced by temperature differentials, friction stresses by changes in average slab temperature, and load stresses by axle loads. From tests and theory, load stresses in modern pavements with good load transfer are greater for wheels at slab edges some distance from the joint. As deflection is convex downward, the bottom of the slab is in tension. If curling stresses and friction stresses also develop bottom slab tension, the allowable concrete strength is exceeded and a crack occurs.

3.1 CURL — Attempts to measure stresses due to slab curling or warping have been unrewarding. Maryland[9] and Illinois[10] attempted direct measurements of strain. Harr and Leonards[11] calculated stress from deflections. Results of the latter method were in close agreement with earlier calculations by Westergaard[12]. Typical results published by the American Concrete Institute (ACI)[13] are shown in Figure 2.

Although in theory a slab should curl up with the top surface in tension and the bottom in compression, and should curl down with stress reversal, observations have shown that downward curl as such does not occur. At an early age the top of the concrete loses moisture but the bottom retains moisture. Therefore the initial "flat" or normal shape of the slab is that produced by a shortening of the top elements. The soil continues to subject the bottom to a humid atmosphere throughout the pavement life and this normal shape persists. For downward curl, with bottom temperature cooler than top, the slab must be forced from this upward dished shape, through the "flat" position before a downward dishing and edge support can occur. Thus tensile curl stresses in the bottom of the slab are small.

3.2 FRICTION STRESSES. These stresses are caused by friction between the concrete slab and the subbase or subgrade and they can be considerable. Since concrete is relatively weak in tension, friction stresses are important as the slab shortens due to shrinkage or temperature changes. They are particularly critical at an early age when concrete strength is low; at later ages they may add to load stresses to accelerate concrete fatigue. Although Friberg[14] has proposed that when a slab moves over a base the friction coefficient for small movements inward from slab ends varies, and only the coefficient for large movements is constant, most designers continue to use the simple constant coefficient with the assumption that frictional force varies directly with normal pressure. The the drag or tensile stress (s_f) in the concrete midway between the ends of a slab of length L feet with friction coefficient F is s_f = 0.52 FL where the assumed concrete density is 150 pcf. Under this assumption, a 100 foot slab on a base developing a friction coefficient F=2 could develop a tensile stress s_f = 104 psi during contraction.

The values for the coefficient of friction vary considerably. There have been instances where treated base material bonded to the concrete. This has been evident when part of the base came up when the concrete was cored. If bonded, then we should assume that the treated base is part of the slab and include the total thickness in calculations for steel areas.

The friction coefficient normally varies from 1 to 2 on natural soils. Many designers use an arbitrary figure of 1.5. The friction factor can be reduced by using plastic film. When treated bases are used, however, the coefficient is much greater and very high values have been measured[15] on small test specimens. Covering treated subbases with wax-type curing compounds may be a practical, economical method of reducing friction. There is a need for additional research in friction factors with the advent of treated bases, plastic films and spray-on compounds.

3.3 LOAD STRESSES — Investigations on load stresses in concrete slabs have been numerous. Contributions have been made by Older, Spangler, Westergaard, Fox, Scrivner, Goldbeck, Bradbury, Pickett, Ray and many others. A current method of calculating stress caused by axle loads is an adaptation of the Westergaard[16] edge stress equation to solution by Pickett and Ray[17] influence charts. Results of many assumed loads have been arranged in nomogram form by Packard[1] as shown in Figures 3 and 4. Variables in the solutions are axle configuration (single or tandem), weight, support by the soil and base (foundation modulus - k), and slab thickness, h. Assumed constants are concrete elastic modulus (E_c = 4 million psi), Poisson's ratio (r = 0.15), and tandem axle spacing.

The slab stress (flexural) due to load is obtained by entering the proper axle configuration chart at the bottom of the given load intensity in kips; moving upward along or between the sloping lines to the selected k in pci; processing vertically upward to the sloping line indicating slab thickness, h, in inches; and finally moving horizontally left to the stress index where the calculated flexural load stress is read directly in psi.

3.4 SLAB DEFLECTIONS — The vertical movements of slabs transversed by loaded axles vary with the state of curl and foundation support. This is more critical at joints and corners than at other locations. With slabs curled concave upward, as on cool nights or after a rain shower, corners may move downward from their upward curled position several times the magnitude of movement produced when corners are resting firmly on the base. These "high joints" may be noticed as they are crossed but are not structurally detrimental if load transfer units are effective and the base is firm and dry. Under adverse conditions of moisture on susceptible bases the downward pressure at the joint may force suspended soil out from beneath the slab and cause support loss.

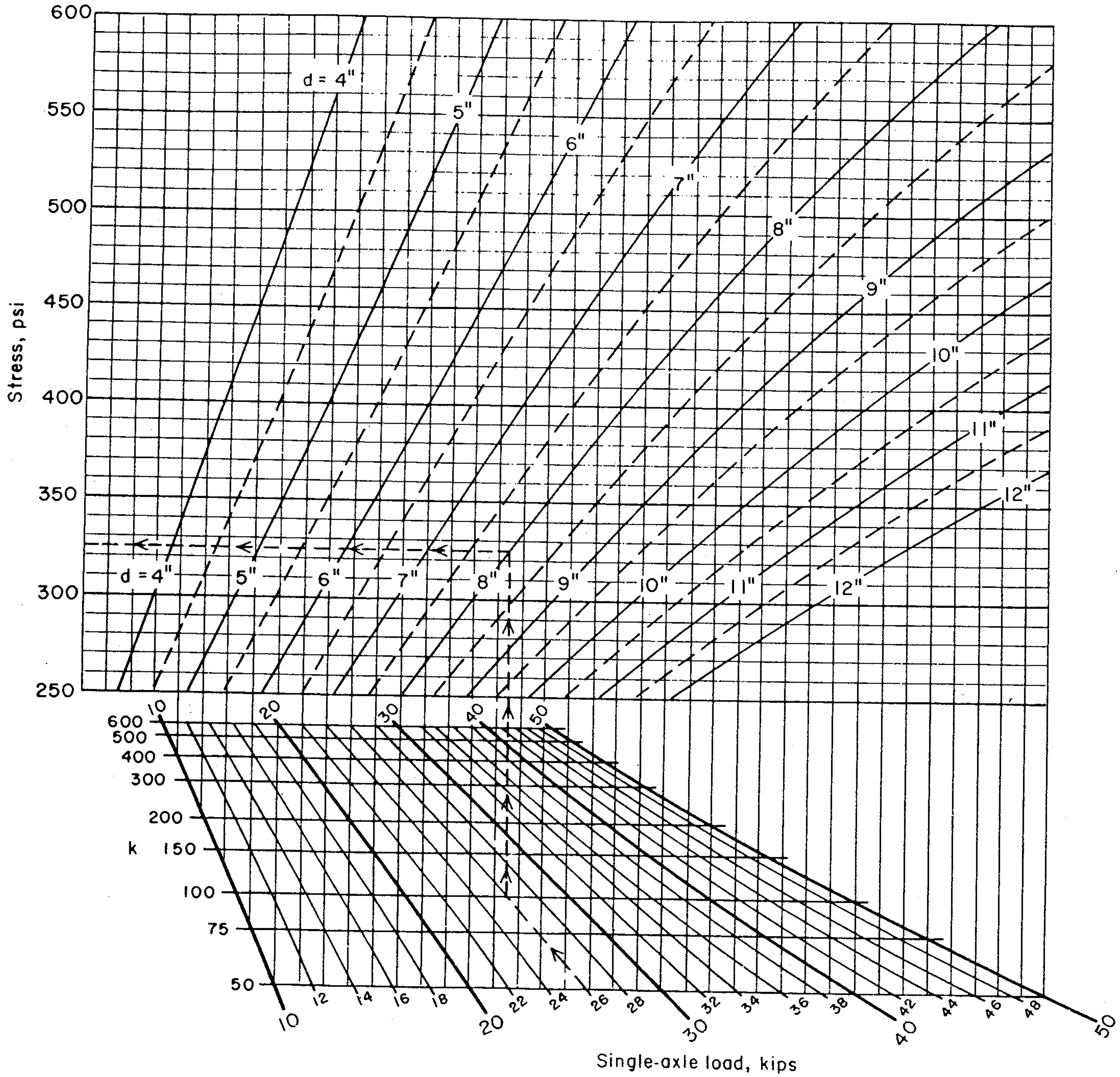


FIGURE 3
DESIGN CHART FOR SINGLE-AXLE LOADS

As deflections from loads are normally reduced as support is increased, it is expedient to provide the best support obtainable with available materials within the cost structure. Although uniformity of support may be a greater factor in preservation of pavement life than high support, it is usually easier to preserve uniformity with strong bases than with foundations of poorer materials.

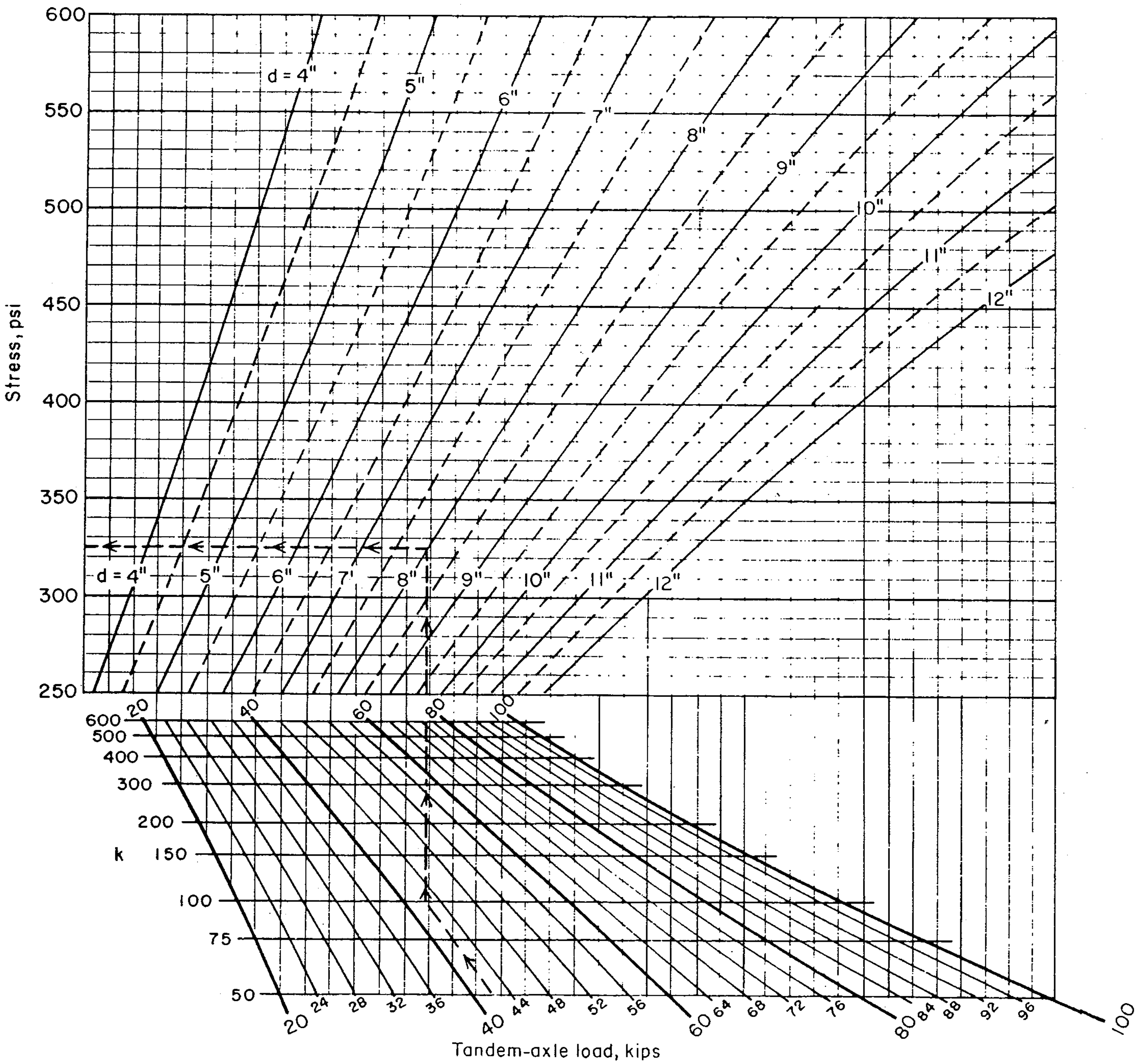


FIGURE 4
DESIGN CHART FOR TANDEM-AXLE LOADS

4. PAVEMENT THICKNESS DESIGN

The design of pavement thickness may be based on the rate of concrete fatigue as proposed by PCA[1] or on the rate of reduction of servicability as suggested by AASHTO[18]. The PCA method classifies truck traffic by axle weight and frequency, calculates the portion of available fatigue used by each group, and sums these portions to determine whether fatigue is exhausted. The AASHTO method reduces truck traffic to equivalent 18-kip axle loads and frequency and uses a nomogram of a semi-empirical model to calculate slab thickness. The design procedure selected for this brochure follows PCA recommendations. Figure 5 is a form to assist in calculating thickness of a concrete pavement. Exhibit A* is an extra form and has no printing on its back side. It may be cut out and photocopied if additional forms are needed. This form was developed by the Portland Cement Association.

The steps for the design calculations are as follows:

1. Determine the axle weights and their corresponding anticipated repetitions.
2. Increase each axle weight group by a selected load safety factor.
3. With the prevailing foundation support k and a trial concrete thickness find the stress induced by each load group.
4. Divide this stress by the design concrete flexural strength (MR) to obtain the stress ratios.
5. Determine the allowable repetitions to failure at each stress ratio.
6. Divide the anticipated repetitions by the allowable repetitions to find the portion of fatigue resistance used at each increment.
7. Add the percentages and compare with total allowable fatigue. If the full load capacity was experienced by the pavement for its total life and concrete did not improve in strength with age, the total allowable fatigue would be 100 percent; however, under the two favorable conditions of light traffic at early age and increasing concrete strength, "total fatigue" values as high as 125 percent are permitted.

If the allowable total fatigue is exceeded a new calculation must be made, usually with increased slab thickness. If the road is still in the planning stage it may be prudent to consider the economics of a stronger foundation such as a treated base, or a higher quality concrete mix. Conversely, if only a small portion of the allowable fatigue resistance is consumed, the calculations are repeated with a reduced trial thickness.

4.1 TRUCK LOADS AND FREQUENCY — If a loadometer survey is available for the design road, or one considered to be similar, the truck weight and frequency data are separated into the single and tandem axle categories, then further into weight groups and frequencies. The weight groups begin with the heaviest loads and descend consecutively in 2,000 pound increments to the legal load. Smaller values than the legal limit are unnecessary because at this load the number of applications must be unlimited.

If only a traffic count is available, or if the traffic is difficult to forecast, the count may be increased by a generous growth factor in the first case, or the road may be designed for capacity in the second case. In either instance the distribution of ADTT may be estimated from typical distributions as shown in the PCA manual[1] or tables of probable axles per thousand trucks such as calculated by AASHTO[19] or by Robbins and Warnes[20].

4.1.1 Axle load distribution calculations — assume that we wish to design a two-lane rural primary road through level terrain with good sight distances. If the projected ADT were 16,520 and ADTT = 2,190 we find in the discussion (Section 2.1.1), that capacity would be adequate providing no more than 40 percent of the road had sight distance less than 1,500 feet. In 20 years we would anticipate that 2,190 x 365 x 20 = 16 million trucks would use the road. We can obtain an estimate of the axle grouping from Table 7. Dividing total truck traffic by 1,000 and multiplying by the probability constant gives the axle distribution of Table 8.

4.2 MATERIALS — Support offered by the foundation is represented by subgrade modulus k. In truth this should be called foundation modulus because it represents the combined efforts of subgrade and base to support the slab. It may be measured with a 30-inch diameter plate on the surface of the base as in American Society for Testing Materials (ASTM) Designation 1196, or estimated from soil types and conditions. If the subgrade is well-drained and well-compacted material, the k value on top of the base will be of the order shown in Tables 5 and 6.

Concrete strength is that indicated by 3rd-point flexure tests on 6- x 6- x 30-inch beams manufactured from the selected materials and cured under conditions simulating those of the slab. In northern States, with numerous freeze/thaw cycles, the aggregate must be select with very little chert or porous material and the mix should contain about 6 percent entrained air. The design should produce a mix with modulus of rupture (MR) at 28 days of at least 600 psi. Sufficient silica sand fines should be

*See Exhibit A between pages 14 and 15

CALCULATION OF CONCRETE PAVEMENT THICKNESS
(Use with Case I Single & Tandem Axle Design Charts)

Project ______________________________

Type ______________________________ No. of Lanes ______________

Subgrade k ____________ pci., Subbase ______________________________

Combined k ____________ pci., Load Safety Factor ______________ (L.S.F.)

PROCEDURE

1. Fill in Col. 1,2 and 6, listing axle loads in decreasing order.
2. Assume 1st trial depth. Use 1/2-in. increments.
3. Analyze 1st trial depth by completing columns 3,4,5 and 7.
4. Analyze other trial depths, varying M.R*, slab depth and subbase type.**

1	2	3	4	5	6	7
Axle Loads kips	Axle Loads X L.S.F. kips	Stress psi	Stress Ratios	Allowable Repetition (Table 9) No.	Expected Repetitions No.	Fatigue Resistance Used*** percent

Trial depth ____________ in. M.R.* ____________ psi k ____________ pci

SINGLE AXLES

TANDEM AXLES

* M.R. Modulus of Rupture for 3rd pt. loading.

** Cement-treated subbases result in greatly increased combined k values.

*** Total fatigue resistance used should not exceed about 125 percent.

FIGURE 5

TABLE 7

PROBABLE OCCURRENCE OF AXLES OF DESIGNATED WEIGHT PER 1000 TRUCKS

Axle Load KIPS	County Rural Average	Main Rural Highway			State Urban Highways		
		Light	Average	Heavy	Light	Average	Heavy
Single Axles							
8	209.0	–	155.0	–	–	–	182.0
10	217.0	383.0	274.0	–	–	207.0	231.0
12	218.0	383.0	309.0	316.0	209.7	207.0	231.0
14	65.3	97.2	72.0	70.1	57.9	74.6	64.5
16	55.4	97.2	72.0	70.1	57.9	61.9	51.2
18	56.3	104.0	43.4	60.2	40.3	38.2	39.2
20	24.3	28.0	14.2	48.2	18.2	29.3	27.2
22	13.8	4.95	5.02	31.8	6.64	16.8	16.0
24	–	1.98	2.66	17.9	3.39	7.80	11.0
26	–	0.23	0.97	6.60	0.08	1.82	6.09
28	–	0.05	0.21	1.98	0.08	0.58	2.47
30	–	0.05	0.21	1.98	0.09	0.58	2.47
32	–	–	0.08	0.30	0.05	–	0.18
34	–	–	0.08	0.30	0.05	–	0.18
36	–	–	0.04	0.15	–	–	0.07
Tandem Axles							
12	46.2	–	117.0	–	75.4	–	42.1
14	35.7	–	59.2	–	42.0	–	44.5
16	35.7	–	59.2	–	42.0	–	44.5
18	32.1	–	59.3	–	41.1	–	44.6
20	14.5	92.0	76.6	–	29.8	–	23.9
22	14.4	92.0	76.6	–	29.8	–	24.0
24	21.9	92.0	75.7	–	30.0	26.1	24.0
26	28.7	112.0	108.0	–	45.2	31.3	25.3
28	23.7	112.0	108.0	60.8	45.2	31.3	27.3
30	27.4	112.0	108.0	60.8	45.3	31.3	27.3
32	28.1	167.0	57.0	51.2	45.5	34.0	33.4
34	27.7	41.6	20.1	45.4	13.8	24.7	28.2
36	18.5	8.32	8.91	41.2	23.0	17.8	23.8
38	10.5	2.52	5.99	25.7	20.7	8.93	17.4
40	4.6	1.30	2.97	15.3	–	5.86	14.4
42	–	0.74	1.61	10.5	–	4.86	9.30
44	–	0.12	1.03	5.46	–	4.52	7.00
46	–	0.28	0.64	2.48	–	1.42	5.04
48	–	–	0.17	1.61	–	1.04	2.30
50	–	–	0.17	1.61	–	1.04	2.30
52	–	–	0.02	0.38	–	0.29	0.73
54	–	–	0.02	0.38	–	0.29	0.73
56	–	–	0.01	0.25	–	0.15	0.47
58	–	–	–	0.11	–	–	0.20
60	–	–	–	0.11	–	–	0.20

included to avoid the development of slippery surfaces during wet weather.

4.3 FACTOR OF SAFETY — In the PCA design method the pavement thickness design is based on concrete 28 day strength and ultimate load density. As concrete continues to gain strength with age, and as the early load densities are approximately half of the ultimate used for design, an intangible factor of safety exists. However, for rural highways, the axle loads are upgraded 10 percent (and on heavily traveled roads and interstate routes 20 percent), by introducing load safety factors (LSF) of 1.1 and 1.2 respectively.

TABLE 8

PROBABLE AXLE DISTRIBUTION

Single Axles		Tandem Axles	
Load Group KIPS	Expected Repetitions	Load Group KIPS	Expected Repetitions
36	640	56	160
34	1,280	54	320
32	1,280	52	320
30	3,360	50	2,720
28	3,360	48	2,720
26	15,350	46	10,200
24	42,600	44	16,200
22	80,000	42	25,800
20		40	47,500
		38	95,800

4.4 A SAMPLE PROBLEM — As previously mentioned there are seven steps in calculating concrete thickness design. Figure 6 shows the steps in a sample problem:

1. The axle loads and expected repetitions of Table 7 are entered on the work form in columns 1 and 6 in descending order of weight down to weights close to legal limits.
2. Column 1 figures are multiplied by LSF = 1.2 and entered in column 2 because our capacity analysis showed that the road would be carrying near capacity traffic after 20 years.
3. Using k = 100 pci and a trial depth of 9 inches, the stresses induced by the loads of column 2 were found from the charts of Figures 3 and 4. Use of these charts is shown by the dashed, arrowed lines.
4. The stress ratios of column 4 were calculated by dividing each stress of column 3 by 620, the indicated MR for the project.
5. In Table 9, the number of load repetitions to failure for each stress ratio are noted. These are entered in column 5 at the corresponding ratios.

TABLE 9

REPETITIONS TO FATIGUE FOR INDICATED STRESS RATIOS

Stress Ratios	Allowable Repetitions	Stress Ratios	Allowable Repetitions
.51	400,000	.69	2,500
.52	300,000	.70	2,000
.53	240,000	.71	1,500
.54	180,000	.72	1,100
.55	130,000	.73	850
.56	100,000	.74	650
.57	75,000	.75	490
.58	57,000	.76	360
.59	42,000	.77	270
.60	32,000	.78	210
.61	24,000	.79	160
.62	18,000	.80	120
.63	14,000	.81	90
.64	11,000	.82	70
.65	8,000	.83	50
.66	6,000	.84	40
.67	4,500	.85	30
.68	3,500		

Unlimited repetitions permitted for stress ratios of 0.50 or less.

6. The expected load repetitions of column 6 are less than those allowed in column 7 so only a portion of the fatigue resistance is used at each load increment. This portion, expressed in percent, is the ratio of the column 6 number to column 5 number, and is entered in column 7.
7. The sum of all the column 7 numbers is the total fatigue used. We note here that the sum is 104. As the total fatigue resistance should not exceed 125 percent, we conclude that for the imposed conditions a 9-inch concrete slab is proper.

4.4.1 A computer solution — The foregoing procedure has been programmed for computer solution and memory banks have been stored at various locations for time-sharing operations. The program, known as PCCHWY, is described by Robbins and Warnes [21]. Several traffic conditions are stored, ranging from residential streets to interstate free-

CALCULATION OF CONCRETE PAVEMENT THICKNESS
(Use with Case I Single & Tandem Axle Design Charts)

Project Rural Primary Highway

Type Jointed Reinforced No. of Lanes 2

Subgrade k ________ pci., Subbase CTB

Combined k ________ pci., Load Safety Factor 1.2 (L.S.F.)

PROCEDURE

1. Fill in Col. 1, 2 and 6, listing axle loads in decreasing order.
2. Assume 1st trial depth. Use 1/2-in. increments.
3. Analyze 1st trial depth by completing columns 3, 4, 5 and 7.
4. Analyze other trial depths, varying M.R*, slab depth and subbase type.**

Trial depth 9 in. M.R.* 620 psi k 100 pci

1 Axle Loads kips	2 Axle Loads X L.S.F. kips	3 Stress psi	4 Stress Ratios	5 Allowable Repetition (Table 9) No.	6 Expected Repetitions No.	7 Fatigue Resistance Used*** percent
SINGLE AXLES						
36	43.2	410	0.66	6,000	640	11
34	40.8	395	0.64	11,000	1,280	12
32	38.4	378	0.61	24,000	1,280	5
30	36.0	358	0.58	57,000	3,360	6
28	33.6	340	0.55	130,000	3,360	3
26	31.2	324	0.52	300,000	16,350	5
24	28.8	304	<0.50	unlimited	42,600	
22	26.4	<300			80,000	
20	24.0					
TANDEM AXLES						
56	67.2	415	0.67	4,500	160	4
54	64.8	403	0.65	8,000	320	4
52	62.4	390	0.63	14,000	320	2
50	60.0	377	0.61	24,000	2,720	11
48	57.6	365	0.59	42,000	2,720	7
46	55.2	352	0.57	75,000	10,200	13
44	52.8	340	0.55	130,000	16,200	12
42	50.4	324	0.52	300,000	25,800	9
40	48.0	310	0.50	unlimited	47,500	
38	45.6	300			95,800	
36						

* M.R. Modulus of Rupture for 3rd pt. loading.

** Cement-treated subbases result in greatly increased combined k values.

*** Total fatigue resistance used should not exceed about 125 percent.

FIGURE 6

This extra sheet may be removed to photocopy form. Cut along line.

EXHIBIT A

CALCULATION OF CONCRETE PAVEMENT THICKNESS
(Use with Case I Single & Tandem Axle Design Charts)

Project ______________________________

Type ______________________ No. of Lanes __________

Subgrade k __________ pci., Subbase ______________________

Combined k __________ pci., Load Safety Factor ______________ (L.S.F.)

PROCEDURE

1. Fill in Col. 1, 2 and 6, listing axle loads in decreasing order.
2. Assume 1st trial depth. Use 1/2-in. increments.
3. Analyze 1st trial depth by completing columns 3, 4, 5 and 7.
4. Analyze other trial depths, varying M.R*, slab depth and subbase type.**

1	2	3	4	5	6	7
Axle Loads kips	Axle Loads X L.S.F. kips	Stress psi	Stress Ratios	Allowable Repetition (Table 9) No.	Expected Repetitions No.	Fatigue Resistance Used*** percent

Trial depth __________ in. M.R.* __________ psi k __________ pci

SINGLE AXLES

TANDEM AXLES

* M.R. Modulus of Rupture for 3rd pt. loading.

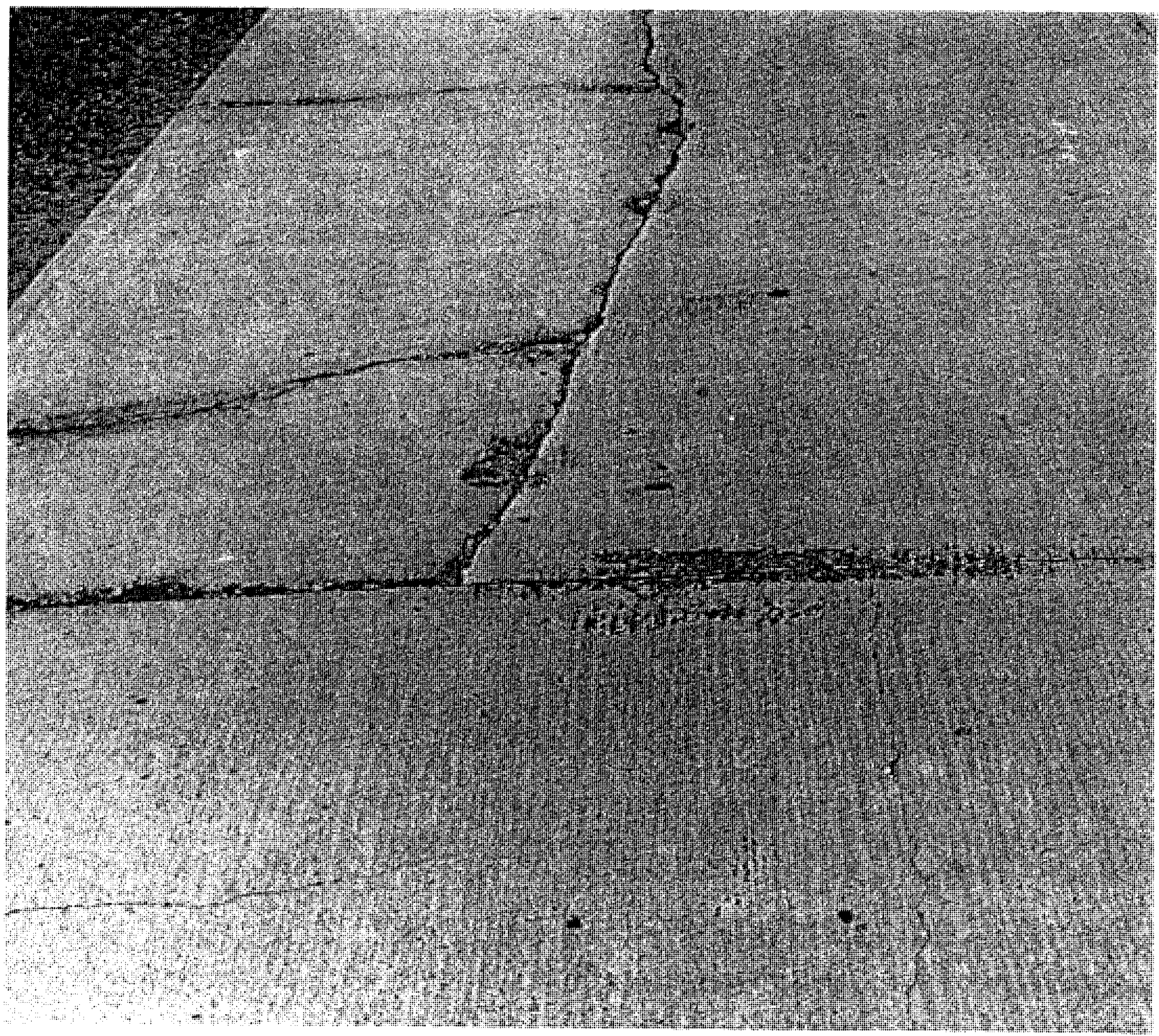
** Cement-treated subbases result in greatly increased combined k values.

*** Total fatigue resistance used should not exceed about 125 percent.

ways. The tediousness of the details encountered in the calculator solution as outlined in Section 4.4.1 are avoided, and much time is saved.

4.5 MODIFICATION OF THICKNESS — Pavement depths obtained by the outlined procedure require no modifications for plain concrete pavements with light traffic, or pavements with distributed steel for all traffic conditions. However, plain pavements for heavy traffic need added thickness or stronger bases to reduce joint deflection and abrasion and preserve aggregate interlock effectiveness.

The photo below gives an excellent illustration of the value of welded wire fabric and how it works. The plain pavement is above the transverse joint and the reinforced pavement below. This pavement was 22 years old when the photo was taken. Both sections are only 4-1/2-in. thick. It was constructed in Greene County, Iowa under the direction of Mr. C.A. Elliott, Greene County Highway Engineer. Note how closely the fabric is holding the cracked sections together. The reinforcement is 6x6 – W2.9xW2.9 [6 gauge]. The test sections included two - 4-1/2-in. thick sections reinforced with fabric and two sections each of 4-1/2-in., 5-in., 5-1/2-in. and 6-in. plain concrete. Mr. Elliott said, "The best section with the best performance to date, is the 4-1/2-in. section with mesh."



5. SLAB LENGTHS AND STEEL CROSS-SECTIONAL AREAS

A number of factors affect the choice of slab length. Plain slabs must not crack nor lose load transfer at joints. Slabs reinforced with steel may crack, but the joints must not open excessively to destroy the seals or overtax the load transfer devices at the joints.

5.1 PLAIN CONCRETE SLABS — When no reinforcement is used, the slab length must be such that curling stresses are low and the joint opening preserves aggregate interlock if the pavement is to perform satisfactorily. Tests[23] have shown that aggregate interlock is ineffective in load transfer when the joint opening exceeds 0.04 in. Slabs contract from temperature drop and shorten from drying shrinkage so joint opening, inches (w) can be expressed $w = 12L\,(eT + d)$

L = slab length

e = temperature contraction coefficient (use $e = 0.000004$ in./in./F° to allow for foundation restraint)

T = temperature drop F°

d = shrinkage — about 0.00005 in./in./in mature concrete

Thus, for a 60°F temperature drop L = 11.5 feet if w does not exceed 0.04 inches. Even if shrinkage were not considered, L = 14 feet. Curling stresses in these lengths could vary from 100 to 250 psi depending on thickness and base support. A survey shows plain slabs in the U.S. and Canada vary in length from 15 to 30 feet. Some States use repeat patterns such as 13-18-19-12-ft. to break up the rhythm of close joint spacings.

5.2 REINFORCED CONCRETE SLABS

The amount of steel used in jointed, reinforced concrete pavements is relatively low, usually in the range of 0.05 to 0.20 percent. The primary purpose of the reinforcement is to hold the cracks closely together so that aggregate interlock can function properly. The reinforcement covers the entire slab area and ties it into one unit. As the slab contracts, the steel reinforcement also shortens and keeps both longitudinal and transverse cracks together, permitting effective aggregate interlock performance. The use of welded wire fabric reinforcement thus permits longer panels and reduces the number of joints—which is a decided advantage.

Pavement reinforcement is not considered to be structural; however, there is some residual structural capacity added when slabs are reinforced.

TABLE 10

NUMBER TRANSVERSE JOINTS PER MILE

Transverse Joint Spacing (Feet)	Transverse Joints Per Mile	Lin. Ft. Transverse Joints Per Mile (2 Lanes–24 Ft. Wide)
12	440	10,560
15	352	8,448
18	293	7,032
20	264	6,336
25	211	5,064
30	176	4,224
40	132	3,168
50	106	2,544
60	88	2,112
70	75	1,800
100	53	1,272

Some recognition of this is given in the U.S. Army Corps of Engineers work[33] which permits a reduction of thickness when a minimum amount of reinforcement is used.

The traditional subgrade drag theory is used to determine the amount of steel reinforcing needed. The tensile stress, s_f, due to drag was shown in Section 3.2. The area of steel, A_s, with the allowable working stress, f_s, must balance the area of concrete, A_c with a tensile or drag stress, s_f. The formula to determine the amount of steel per lin. ft. is

$$A_s = \frac{FL\ 6.25h}{f_s}$$

A_s = Cross-sectional area of steel (sq. in.) per lin. ft.

F = Coefficient of friction

L = Panel length (or width if appropriate), ft.

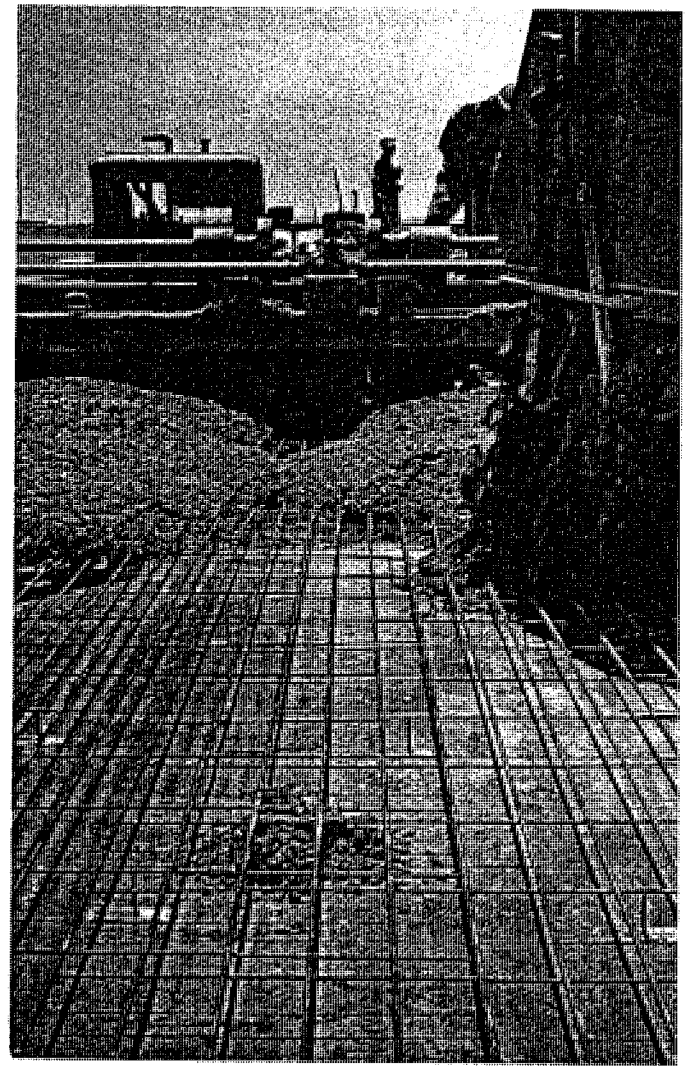
h = Slab thickness, in.

f_s = Working stress of steel, psi

The coefficient of friction (F) is discussed in Section 3.1. Many designers use a coefficient of friction figure of 1.5 or 2.0 for pavements. The working stress of the steel is usually 0.67 or 0.75 times the yield strength of the steel in psi. The yield strength of smooth welded wire fabric is 65,000 psi and deformed fabric has a yield strength of 70,000 psi. Further discussion on working stress and yield strength can be found in Section 6.3.

Thus, for a given steel working stress and foundation friction coefficient, thicker and longer slabs require more steel. For optimum economical design the slab lengths should be calculated by increasing length and steel weight and decreasing the required joints for a project length until minimum costs are attained consistent with good performance. Since joint costs are relatively high and very long slabs have not proven easy to maintain, it is important to weigh these two factors carefully before establishing final joint spacing.

A practical length for slabs with reinforcement is a function of the joint sealant. The reservoir holding the sealant over a joint must be properly designed so that the joint will perform properly. The sealant must adhere to the walls of the reservoir and have sufficient extensibility to remain intact as the slabs shorten, causing the width of the reservoir to increase. A 100-ft. joint would open according to equation in Section 5.1: w = 12 x 100 (0.000004 x 60 + 0.00005) = 0.35 inches. If a hot poured sealant were used, at freezing temperature it would have an extensibility of only about 10 percent. The original joint reservoir would then have been 3.5 inches. A



Chaired welded wire fabric for a highway. Welded wire fabric puts muscle in concrete pavements.

plastic sealant with 25 percent cold weather extensibility requires a 1.4 inch reservoir. At slab length 50 feet and half the movement the plastic sealant reservoir would be only 0.7 inches. Large reservoirs are not desirable because they allow imbedment of hard particles that can cause stress concentrations when the joints close in hot weather; they also downgrade rideability.

The subgrade drag theory formula is used also in calculating transverse steel. Here, L is lane width in feet if a center joint with tie bars is specified, or L is full width if the lanes are cast at the same time and steel fabric continues through the longitudinal joints.

6. WELDED WIRE FABRIC REINFORCEMENT

6.1 DESIGNATION — Welded wire fabric is prefabricated reinforcement consisting of parallel series of high-strength, cold-drawn wires welded together in square or rectangular grids. Each wire intersection is electrically resistance welded by a continuous automatic welder. Pressure and heat fuse the intersecting wires into a homogeneous section and fix all wires in their proper position. Welded smooth wire fabric bonds to concrete by the positive mechanical anchorage at each wire intersection. Welded deformed wire fabric utilizes both wire deformations and welded intersections for bond and anchorage. Both types of fabric are used for reinforcement.

Welded wire fabric is made in both sheets and rolls. Pavement fabric is invariably in sheet form.

The spacings and sizes of wires are identified by "style." A typical style designation is 6 x 12 — W8 x W6. This denotes a welded wire fabric in which:

Spacing of longitudinal wires is 6"

Spacing of transverse wires is 12"

Size of longitudinal wires is W8 (Nominal area= 0.08 sq. in.)

Size of transverse wires is W6 (Nominal area = 0.06 sq. in.)

The typical style with deformed welded wire fabric would be 6 x 12- D8 x D6.

6.2 SPECIFICATIONS—Welded smooth steel wire fabric is produced to ASTM Specification A 185. The wire used in the manufacture of this fabric is produced to ASTM Specification A 82. This cold-drawn wire has the following minimum properties:

Yield strength	65,000 psi
Tensile strength	75,000 psi

Welded deformed steel wire fabric is produced to ASTM Specification A 497. The deformed wire is produced to ASTM Specification A 496. This cold-drawn deformed wire has the following minimum properties:

Yield strength	70,000 psi
Tensile strength	80,000 psi

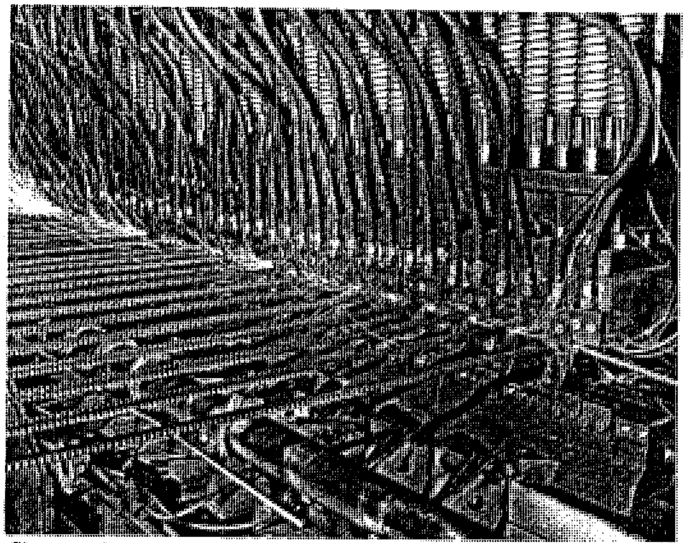
6.3 ALLOWABLE STRESSES—The design of reinforced concrete is based upon the yield strength of the reinforcing steel. In simple terms, the yield strength may be considered as the load limit below which the steel can be stretched and still return closely to its original length when the load is released. It follows that if the loads gave permanent elongations, the cracks in the concrete would be permanently open to permit corrosion, infiltration, and eventual failure. Therefore, reinforced concrete design provides that the loads should not exceed the yield strength and due to the nature of the material a factor of safety is assessed. Because structural safety is not involved, a design safety factor of 1.33 to 1.50 is usually assigned. This gives allowable stresses of about 2/3 to 3/4 of the minimum specified yield strength:

Welded smooth wire fabric (ASTM A 185) —	43,000 psi or $0.67f_y$ 48,750 psi or $0.75f_y$
Welded deformed wire fabric (ASTM A 497) —	47,000 psi or $0.67f_y$ 52,500 psi or $0.75f_y$

These values may be reduced where width of cracks in the paving is to be controlled to prevent corrosive infiltration from deicing chemicals applied to pavements.

6.4 STANDARD PRACTICES — Wire Sizes, Spacings, Laps, Clearance. As the fabric is subjected to bending stresses as well as tensile stresses at cracks, it is recommended that longitudinal wires be not less than W4 or D4 size. Similarly the transverse wires should be not less than W4 or D4. To provide generous opening between wires to permit placement and vibration of concrete, it is recommended that the longitudinal wire spacings be not less than 4 inches nor more than 12 inches. Similarly the transverse wire spacings should be not less than 4 inches nor more than 24 inches.

Transverse wire spacings may be controlled by the fabric-producing equipment. All machines making paving fabric can produce 12-in. spacings. Others can produce spacings of 16-, 18-, 20- and 24-in. This



Close-up of transverse and longitudinal wires being welded in fabric machine. Equipment is sophisticated and precise.

factor should be considered when preparing specifications.

As the dimensions of the concrete pavement slab are usually greater than the producing or shipping dimensions of the welded wire fabric, the fabric is usually installed with end and side laps. The end laps should be about 30 times the longitudinal wire diameter but not less than 12 inches. The side lap should be about 20 times the transverse wire diameter but not less than 6 inches. In reinforcing the concrete slab the reinforcement should extend to about 2 inches from the slab edges but not more than 6 inches from the slab edges. The depth of the reinforcing fabric should not be less than 2-1/2 inches from the top of the slab nor more than mid-depth. To demonstrate the selection of styles of fabric, Tables 12 through 17 outline the fabric

TABLE 11

WIRE SIZES, WEIGHTS AND STEEL AREAS PER FT. OF WIDTH

Wire Size Number		Nominal Diameter, Inches	Nominal Weight Lbs./Lin. Ft.	Cross Sectional Areas, Sq. In. Per Lin. Ft. — Center to Center Spacing						
Smooth	Deformed			2"	3"	4"	6"	8"	10"	12"
W31	D31	0.628	1.054	1.86	1.24	.93	.62	.465	.372	.31
W30	D30	0.618	1.020	1.80	1.20	.90	.60	.45	.36	.30
W28	D28	0.597	.952	1.68	1.12	.84	.56	.42	.336	.28
W26	D26	0.575	.934	1.56	1.04	.78	.52	.39	.312	.26
W24	D24	0.553	.816	1.44	.96	.72	.48	.36	.288	.24
W22	D22	0.529	.748	1.32	.88	.66	.44	.33	.264	.22
W20	D20	0.504	.680	1.20	.80	.60	.40	.30	.24	.20
W18	D18	0.478	.612	1.08	.72	.54	.36	.27	.216	.18
W16	D16	0.451	.544	.96	.64	.48	.32	.24	.192	.16
W14	D14	0.422	.476	.84	.56	.42	.28	.21	.168	.14
W12	D12	0.390	.408	.72	.48	.36	.24	.18	.144	.12
W11	D11	0.374	.374	.66	.44	.33	.22	.165	.132	.11
W10.5		0.366	.357	.63	.42	.315	.21	.157	.126	.105
W10	D10	0.356	.340	.60	.40	.30	.20	.15	.12	.10
W9.5		0.348	.323	.57	.38	.285	.19	.142	.114	.095
W9	D9	0.338	.306	.54	.36	.27	.18	.135	.108	.09
W8.5		0.329	.289	.51	.34	.255	.17	.127	.102	.085
W8	D8	0.319	.272	.48	.32	.24	.16	.12	.096	.08
W7.5		0.309	.255	.45	.30	.225	.15	.112	.09	.075
W7	D7	0.298	.238	.42	.28	.21	.14	.105	.084	.07
W6.5		0.288	.221	.39	.26	.195	.13	.097	.078	.065
W6	D6	0.276	.204	.36	.24	.18	.12	.09	.072	.06
W5.5		0.264	.187	.33	.22	.165	.11	.082	.066	.055
W5	D5	0.252	.170	.30	.20	.15	.10	.075	.06	.05
W4.5		0.240	.153	.27	.18	.135	.09	.067	.054	.045
W4	D4	0.225	.136	.24	.16	.12	.08	.06	.048	.04

NOTE: Wire sizes other than those listed above may be produced provided the quantity required is sufficient to justify manufacture.

requirements for both highways and airports. Tables 12 and 13 outline the use of welded smooth wire fabric following, in general, criteria of AASHTO. Tables 14 and 15 outline the use of welded deformed wire fabric also following, in general, criteria of AASHTO. Tables 16 and 17 outline the use of both smooth and deformed fabric following the criteria of FAA. Table 18 lists the wire sizes, diameter, cross-sectional area, unit weight per foot of wire, and estimated weight per square yard. Table 19 outlines the suggested lengths of sheets which may be used under the lap and clearance criteria listed above.

TABLE 12

SUGGESTED STYLES OF WELDED SMOOTH WIRE FABRIC FOR HIGHWAY PAVEMENTS

Coefficient of Friction F = 1.5, $f_s = 0.75\ f_y = 0.75 \times 65{,}000 = 48{,}750$ psi

Slab Thickness Inches	Slab Length in Feet				
	30	40	50	60	70
6″	6x12–W4xW4	6x12–W4xW4	6x12–W4xW4	6x12–W4xW4	6x12–W4xW4
7″	6x12–W4xW4	6x12–W4xW4	6x12–W4xW4	6x12–W4xW4	6x12–W5xW4
8″	6x12–W4xW4	6x12–W4xW4	6x12–W4xW4	6x12–W4.5xW4	6x12–W5.5xW4
9″	6x12–W4xW4	6x12–W4xW4	6x12–W4.5xW4	6x12–W5xW4	6x12–W6xW4
10″	6x12–W4xW4	6x12–W4xW4	6x12–W5xW4	6x12–W6xW4	6x12–W7xW4
11″	6x12–W4xW4	6x12–W4.5xW4	6x12–W5.5xW4	6x12–W6.5xW4	6x12–W7.5xW4
12″	6x12–W4xW4	6x12–W5xW4	6x12–W6xW4	6x12–W7xW4	6x12–W8xW4
13″	6x12–W4xW4	6x12–W5xW4	6x12–W6.5xW4	6x12–W7.5xW4	6x12–W9xW4
14″	6x12–W4xW4	6x12–W5.5xW4	6x12–W7xW4	6x12–W8xW4	6x12–W9.5xW4
15″	6x12–W4.5xW4	6x12–W6xW4	6x12–W7.5xW4	6x12–W8.5xW4	6x12–W10xW4

TABLE 13

SUGGESTED STYLES OF WELDED SMOOTH WIRE FABRIC FOR HIGHWAY PAVEMENTS

Coefficient of Friction F = 2.0, $f_s = 0.75\ f_y = 0.75 \times 65{,}000 = 48{,}750$ psi

Slab Thickness Inches	Slab Length in Feet				
	30	40	50	60	70
6″	6x12–W4xW4	6x12–W4xW4	6x12–W4xW4	6x12–W4.5xW4	6x12–W5.5xW4
7″	6x12–W4xW4	6x12–W4xW4	6x12–W4.5xW4	6x12–W5.5xW4	6x12–W6.5xW4
8″	6x12–W4xW4	6x12–W4xW4	6x12–W5xW4	6x12–W6xW4	6x12–W7xW4
9″	6x12–W4xW4	6x12–W4.5xW4	6x12–W6xW4	6x12–W7xW4	6x12–W8xW4
10″	6x12–W4xW4	6x12–W5xW4	6x12–W6.5xW4	6x12–W7.5xW4	6x12–W9xW4
11″	6x12–W4.5xW4	6x12–W5.5xW4	6x12–W7xW4	6x12–W8.5xW4	6x12–W10xW4
12″	6x12–W4.5xW4	6x12–W6xW4	6x12–W7.5xW4	6x12–W9.5xW4	6x12–W11xW4.5
13″	6x12–W5xW4	6x12–W6.5xW4	6x12–W8.5xW4	6x12–W10xW4	6x12–W11.5xW5
14″	6x12–W5.5xW4	6x12–W7xW4	6x12–W9xW4	6x12–W11xW4.5	6x12–W12.5xW5
15″	6x12–W6xW4	6x12–W7.5xW4	6x12–W9.5xW4	6x12–W11.5xW5	6x12–W13.5xW5.5

TABLE 14

STYLES OF WELDED DEFORMED WIRE FABRIC FOR HIGHWAY PAVEMENTS

Coefficient of Friction F = 1.5, $f_s = 0.75\ f_y = 0.75 \times 70{,}000 = 52{,}500$ psi

Slab Thickness Inches	Slab Length in Feet				
	30	40	50	60	70
6″	6x12–D4xD4	6x12–D4xD4	6x12–D4xD4	6x12–D4xD4	6x12–D4xD4
7″	6x12–D4xD4	6x12–D4xD4	6x12–D4xD4	6x12–D4xD4	6x12–D4.5xD4
8″	6x12–D4xD4	6x12–D4xD4	6x12–D4xD4	6x12–D4.5xD4	6x12–D5xD4
9″	6x12–D4xD4	6x12–D4xD4	6x12–D4xD4	6x12–D5xD4	6x12–D5.5xD4
10″	6x12–D4xD4	6x12–D4xD4	6x12–D4.5xD4	6x12–D5.5xD4	6x12–D6.5xD4
11″	6x12–D4xD4	6x12–D4xD4	6x12–D5xD4	6x12–D6xD4	6x12–D7xD4
12″	6x12–D4xD4	6x12–D4.5xD4	6x12–D5.5xD4	6x12–D6.5xD4	6x12–D7.5xD4
13″	6x12–D4xD4	6x12–D4.5xD4	6x12–D6xD4	6x12–D7xD4	6x12–D8xD4
14″	6x12–D4xD4	6x12–D5xD4	6x12–D6.5xD4	6x12–D7.5xD4	6x12–D8.5xD4
15″	6x12–D4xD4	6x12–D5.5xD4	6x12–D6.5xD4	6x12–D8xD4	6x12–D9.5xD4

TABLE 15

STYLES OF WELDED DEFORMED WIRE FABRIC FOR HIGHWAY PAVEMENTS

Coefficient of Friction F = 2.0, $f_s = 0.75 f_y = 0.75 \times 70{,}000 = 52{,}500$ psi

Slab Thickness Inches	Slab Length in Feet				
	30	40	50	60	70
6″	6x12–D4xD4	6x12–D4xD4	6x12–D4xD4	6x12–D4.5xD4	6x12–D5xD4
7″	6x12–D4xD4	6x12–D4xD4	6x12–D4xD4	6x12–D5xD4	6x12–D6xD4
8″	6x12–D4xD4	6x12–D4xD4	6x12–D4.5xD4	6x12–D5.5xD4	6x12–D6.5xD4
9″	6x12–D4xD4	6x12–D4.5xD4	6x12–D5.5xD4	6x12–D6.5xD4	6x12–D7.5xD4
10″	6x12–D4xD4	6x12–D5xD4	6x12–D6xD4	6x12–D7xD4	6x12–D8.5xD4
11″	6x12–D4xD4	6x12–D5.5xD4	6x12–D6.5xD4	6x12–D8xD4	6x12–D9xD4
12″	6x12–D4.5xD4	6x12–D5.5xD4	6x12–D7xD4	6x12–D8.5xD4	6x12–D10xD4
13″	6x12–D4.5xD4	6x12–D6xD4	6x12–D8xD4	6x12–D9.5xD4	6x12–D11xD4.5
14″	6x12–D5xD4	6x12–D6.5xD4	6x12–D8.5xD4	6x12–D10xD4	6x12–D11.5xD5
15″	6x12–D5.5xD4	6x12–D7xD4	6x12–D9xD4	6x12–D10.5xD4.5	6x12–D12xD5

TABLE 16

STYLES OF WELDED SMOOTH WIRE FABRIC FOR AIRPORT PAVEMENTS

Coefficient of Friction $F = 0.585\sqrt{\frac{L}{T}}$, $f_s = 0.67\ f_y = 0.67 \times 65{,}000 = 43{,}000$ psi

Slab Thickness Inches	Slab Length In Feet				
	40	50	60	70	75
6"	6x12–W5xW4	6x12–W5xW4	6x12–W5xW4	6x12–W6.5xW4	6x12–W7xW4
7"	6x12–W5xW4	6x12–W5xW4	6x12–W5.5xW4	6x12–W7xW4	6x12–W7.5xW4
8"	6x12–W5xW4	6x12–W5xW4	6x12–W6xW4	6x12–W7.5xW4	6x12–W8xW4
9"	6x12–W5xW4	6x12–W5xW4	6x12–W6xW4	6x12–W7.5xW4	6x12–W8.5xW4
10"	6x12–W5xW4	6x12–W5xW4	6x12–W6.5xW4	6x12–W8xW4	6x12–W9xW4
11"	6x12–W5xW4	6x12–W5xW4	6x12–W7xW4	6x12–W8.5xW4	6x12–W9.5xW4
12"	6x12–W5xW4	6x12–W5.5xW4	6x12–W7xW4	6x12–W9xW4	6x12–W10xW4
13"	6x12–W5xW4	6x12–W5.5xW4	6x12–W7.5xW4	6x12–W9.5xW4	6x12–W10.5xW4.5
14"	6x12–W5xW4	6x12–W6xW4	6x12–W7.5xW4	6x12–W9.5xW4	6x12–W10.5xW4.5
15"	6x12–W5xW4.5	6x12–W6xW4.5	6x12–W8xW4.5	6x12–W10xW4.5	6x12–W11xW4.5
16"	6x12–W5xW4.5	6x12–W6.5xW4.5	6x12–W8xW4.5	6x12–W10.5xW4.5	6x12–W11.5xW5
17"	6x12–W5.5xW4.5	6x12–W6.5xW4.5	6x12–W8.5xW4.5	6x12–W10.5xW4.5	6x12–W11.5xW5
18"	6x12–W5.5xW5	6x12–W6.5xW5	6x12–W8.5xW5	6x12–W11xW5	6x12–W12xW5
19"	6x12–W6xW5	6x12–W7xW5	6x12–W9xW5	6x12–W11xW5	6x12–W12.5xW5
20"	6x12–W6xW5	6x12–W7xW5	6x12–W9xW5	6x12–W11.5xW5	6x12–W12.5xW5
21"	6x12–W6.5xW5	6x12–W7xW5	6x12–W9.5xW5	6x12–W12xW5	6x12–W13xW5.5
22"	6x12–W7xW5	6x12–W7.5xW5	6x12–W9.5xW5	6x12–W12.5xW5	6x12–W13.5xW5.5

TABLE 17

STYLES OF WELDED DEFORMED WIRE FABRIC FOR AIRPORT PAVEMENTS

Coefficient of Friction $F = 0.585\sqrt{\frac{L}{T}}$, $f_s = 0.67\ f_y = 0.67 \times 70{,}000 = 47{,}000$ psi

Slab Thickness Inches	Slab Length in Feet				
	40	50	60	70	75
6″	6x12–D5XD4	6x12–D5xD4	6x12–D5xD4	6x12–D6xD4	6x12–D6.5xD4
7″	6x12–D5xD4	6x12–D5xD4	6x12–D5xD4	6x12–D6.5xD4	6x12–D7xD4
8″	6x12–D5xD4	6x12–D5xD4	6x12–D5.5xD4	6x12–D6.5xD4	6x12–D7.5xD4
9″	6x12–D5xD4	6x12–D5xD4	6x12–D5.5xD4	6x12–D7xD4	6x12–D8xD4
10″	6x12–D5xD4	6x12–D5xD4	6x12–D6xD4	6x12–D7.5xD4	6x12–D8.5xD4
11″	6x12–D5xD4	6x12–D5xD4	6x12–D6.5xD4	6x12–D8xD4	6x12–D8.5xD4
12″	6x12–D5xD4	6x12–D5xD4	6x12–D6.5xD4	6x12–D8xD4	6x12–D9xD4
13″	6x12–D5xD4	6x12–D5xD4	6x12–D7xD4	6x12–D8.5xD4	6x12–D9.5xD4
14″	6x12–D5xD4	6x12–D5.5xD4	6x12–D7xD4	6x12–D9xD4	6x12–D10xD4
15″	6x12–D5xD4	6x12–D5.5xD4	6x12–D7.5xD4	6x12–D9xD4	6x12–D10xD4
16″	6x12–D5xD4	6x12–D6xD4	6x12–D7.5xD4	6x12–D9.5xD4	6x12–D10.5xD4.5
17″	6x12–D5.5xD4.5	6x12–D6xD4.5	6x12–D8xD4.5	6x12–D9.5xD4.5	6x12–D11xD4.5
18″	6x12–D5.5xD4.5	6x12–D6xD4.5	6x12–D8xD4.5	6x12–D10xD4.5	6x12–D11xD4.5
19″	6x12–D6xD4.5	6x12–D6.5xD4.5	6x12–D8xD4.5	6x12–D10.5xD4.5	6x12–D11.5xD5
20″	6x12–D6xD4.5	6x12–D6.5xD4.5	6x12–D8.5xD4.5	6x12–D10.5xD4.5	6x12–D11.5xD5
21″	6x12–D6.5xD4.5	6x12–D6.5xD4.5	6x12–D8.5xD4.5	6x12–D11xD4.5	6x12–D12xD5
22″	6x12–D7xD5	6x12–D7xD5	6x12–D9xD5	6x12–D11xD5	6x12–D12xD5

TABLE FOR ESTIMATING WEIGHT OF WELDED WIRE FABRIC FOR ALL FABRIC HAVING UNIFORM SPACING OF WIRES APPROXIMATE WEIGHTS IN POUNDS PER SQUARE YARD OF WELDED WIRE FABRIC

Wire				Spacing and Weight of Longitudinal Wires			Spacing and Weight of Transverse Wires	
Size Number	Dia. In.	Area Sq. In.	Weight Lbs./Ft.	4"	6"	12"	6"	12"
W1* or D1*	0.113	0.01	0.034	0.9562	0.6502	0.3442	0.6247	0.3124
W2 or D2*	0.159	0.02	0.068	1.9124	1.3004	0.6884	1.2494	0.6248
W3 or D3*	0.195	0.03	0.102	2.8686	1.9506	1.0326	1.8741	0.9372
W4 or D4	0.225	0.04	0.136	3.8248	2.6008	1.3768	2.4988	1.2496
W5 or D5	0.252	0.05	0.170	4.7810	3.2510	1.7210	3.1235	1.5620
W6 or D6	0.276	0.06	0.204	5.7372	3.9012	2.0652	3.7482	1.8744
W7 or D7	0.298	0.07	0.238	6.6934	4.5514	2.4094	4.3729	2.1868
W8 or D8	0.319	0.08	0.272	7.6496	5.2016	2.7536	4.9976	2.4992
W9 or D9	0.338	0.09	0.306	8.6058	5.8518	3.0978	5.6223	2.8116
W10 or D10	0.356	0.10	0.340	9.5620	6.5020	3.4420	6.2470	3.1240
W11 or D11	0.374	0.11	0.374	10.5182	7.1522	3.7862	6.8717	3.4364
W12 or D12	0.390	0.12	0.408	11.4744	7.8024	4.1304	7.4960	3.7488
W13 or D13	0.406	0.13	0.442	12.4306	8.4526	4.4746	8.1211	4.0612
W14 or D14	0.422	0.14	0.476	13.3868	9.1028	4.8188	8.7458	4.3756
W15 or D15	0.437	0.15	0.510	14.3430	9.7530	5.1630	9.3705	4.6860

**Designations with asterisk rarely made. They are included in this table for calculation purposes only.*

EXAMPLE: Table 16–15" Slab joints at 60'– highway pavement welded deformed wire fabric style 6x6–D10.5xD4.5

D10.5 Longitudinal wires combine	D10 @ 6"	=	6.5020
To find Wt. of .5 use 1/10th of	D5 @ 6"	=	0.3251
D4.5 Transverse wires combine	D4 @ 12"	=	1.2496
To find Wt. of .5 use 1/10th of	D5 @ 12"	=	0.1562
All wires–pounds per square yard		=	8.2329

Based on 96" width c. to c. of outside longitudinal wires.
Based on 98" length of transverse wires, i.e., 96" width of fabric plus 1" overhang each side.

TABLE 19

ESTIMATING QUANTITY OF WELDED WIRE FABRIC

Assume: Standard End Lap = 12", Standard Edge Lap = 6", Standard Edge Clearance = 6"

Concrete Pavement Slab			Welded Wire Fabric Sheets				Ratio—Area of Fabric to Area of Concrete
Width Feet	Length Feet	Area Sq. Yd.	Number	Width Feet	Length Feet	Area Sq. Yd.	
24	30	80.00	3	8	29	77.33	0.967
			6	8	15	80.00	1.000
			2	11	29	70.89	0.886
			4	11	15	73.33	0.917
24	40	106.67	6	8	20	106.67	1.000
			9	8	14	112.00	1.050
			4	11	20	97.78	0.917
			6	11	14	102.67	0.962
24	50	133.33	6	8	25	133.33	1.000
			9	8	17	136.00	1.020
			6	11	17	124.67	0.935
			8	11	13	127.11	0.953
24	60	160.00	6	8	30	160.00	1.000
			9	8	21	168.00	1.050
			12	8	16	170.67	1.067
			6	11	21	154.00	0.963
			8	11	16	156.44	0.978
24	70	186.67	9	8	24	192.00	1.029
			12	8	18	192.00	1.029
			8	11	18	176.00	0.943
			10	11	15	183.33	0.982

6.5 FABRIC FOR PAVEMENTS WITH SKEWED JOINTS — Pavements with skewed joints have usually been limited to plain concrete until recently. Dowels for skewed joints in reinforced slabs are usually supported in a skewed wire basket that aligns the dowels parallel to the longitudinal axis of the pavement.

One Highway Department uses welded wire fabric in skewed slabs. Deformed wire fabric 6 x 12 — D4.9 x D4 with a sheet length of 18 ft. is placed midway between the ends of 27-ft. panels skewed 4 ft. in 24 ft. This leaves an unreinforced end section between the end of the fabric and the doweled joint.

6.6 TIE BARS — The steel in the longitudinal joint must prevent separation of the lanes and assure load transfer. These joints may be 1) plane-of-weakness joints in which a controlled crack occurs beneath a groove, 2) cold joints with concrete keys and keyways or 3) butt joints with smooth joint faces. The plane-of-weakness joint, type 1, transfers loads by aggregate interlock and sufficient steel is placed to prevent opening of joint. The keyed joint, type 2, opens slightly from drying shrinkage and the key, being about 1/4 the slab depth, can develop only limited shear; therefore it needs more steel than type 1. The butt joint, type 3, transfers load only by subgrade support and needs still more steel to produce the necessary shear resistance. Thus steel requirements for lane joints vary with joint type.

Deformed steel reinforcing bars meeting ASTM A 615 are usually specified for tie bars. Grades 40 and 60 with respective working strengths (f_y) of 27,000 and 40,000 are the types used. The maximum spacing between tie bars should be about 36 in.

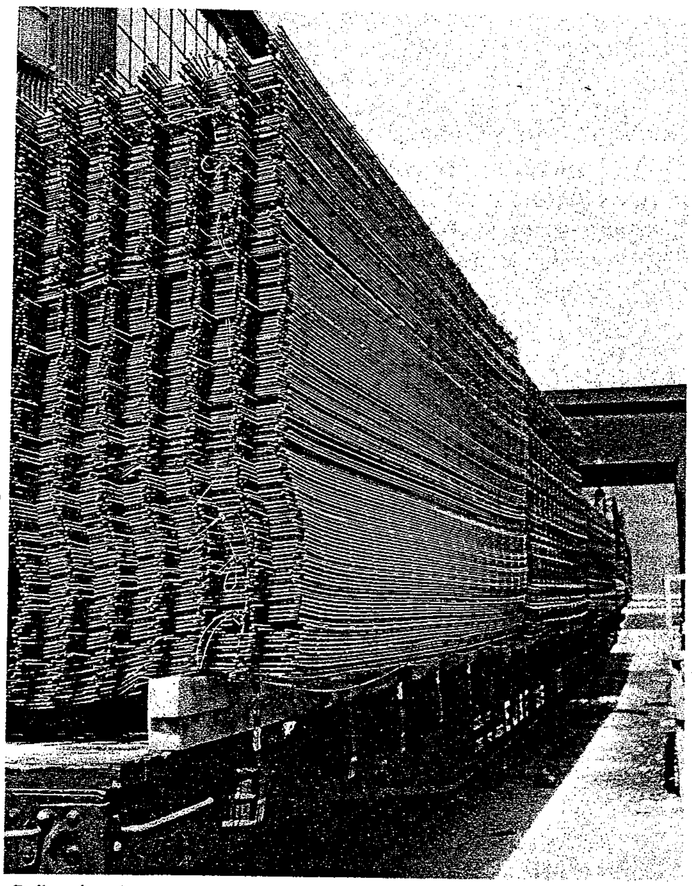
The subgrade drag theory formula can be used to provide the required steel at the lane joint.

$$A_s = \frac{FL6.25h}{f_s}$$

where L = pavement width, ft., then A_s is the steel area required to contain a plane-of-weakness-lane joint, and tie bars can be designed on this basis. For example in the 9 in. by 50 ft. slab with single lane steel fabric

$$A_s = \frac{2 \times 24 \times 6.25 \times 9}{27{,}000} = 0.10 \text{ sq. in.}$$

In most States, tie bar diameters are 1/2 to 5/8 in. (No. 4 and 5 size) with lengths of 24 to 36 in. In the preceding example 0.10 sq. in./ft. steel can be achieved by No. 5 bars at 36 in. centers.



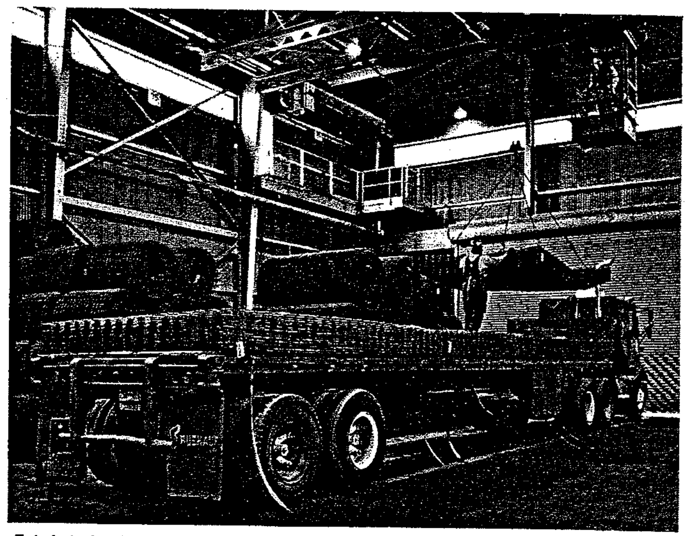
Railroad car loaded with fabric for a paving job. Fabric is shipped in bundles.

Keyed and butt joints need a safety factor as argued above. Laboratory tests[29] on beams, both static and dynamic, suggest a safety factor of 1.5 for keyed joints and 2 for butt joints. Therefore with keyed joints at A_s = 0.10 x 1.5 = 0.150 sq. in./ft. and butt joints A_s = 0.10 x 2 = 0.20 sq. in./ft. The tie bars would be No. 4 at 16-in. or No. 5 at 24 in. for keyed joints and No. 4 at 12 in. or No. 5 at 18 in. for butt joints.

6.7 HANDLING AND PLACING FABRIC

6.7.1 Production. The automatic welding equipment can produce fabric widths up to 156 in. (13 ft.) and fabric length up to 50 ft. for paving. Virtually all paving fabric is in sheet (or mat) form. Typical sheet sizes are 6 ft. to 11 ft. 6 in. wide and 20 ft. to 30 ft. in length.

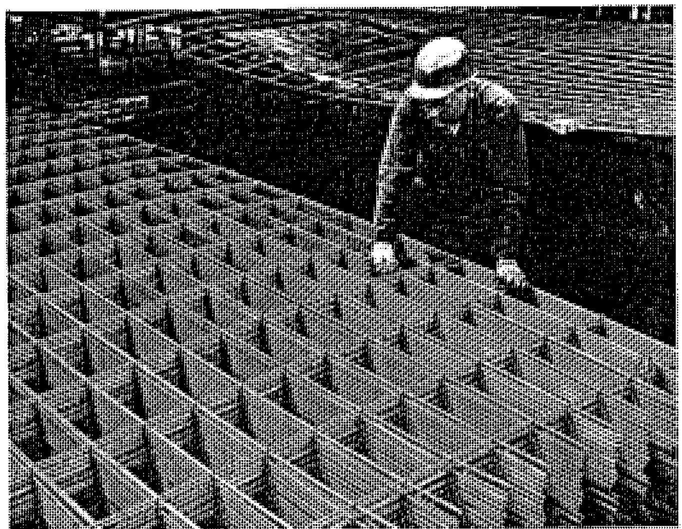
6.7.2 Shipments. Railroad shipments are generally restricted to about 138 in. wide or less, by 40 ft. long or less, subject to availability of rail cars and to direct routing of cars avoiding routes of restrictive clearances. The fabric must be loaded on cars to the Governing Rules of the Association of American Railroads which prescribe the specific banding, heights and widths of loads for safe movement. Truck shipments are generally restricted to fabric widths of about 96 in. to 106 in. or less, by 40 ft. long or less. The fabric must be loaded to informal rules but usually include numerous tie downs by chains or strapping to avoid load shifting.



Fabric being loaded on truck. Note that sheet length was such that the entire truck bed could be used.

6.7.3 Sheet dimensions. The selection of fabric sheet dimensions will of course be governed by the slab dimensions. Factors affecting sheet dimensions are overall slab dimensions, fabric edge and end laps, and clearance between edge and end of slab. Table 19 outlines typical combinations of sheet widths and lengths for various roadway slab dimensions. It is generally advantageous to use one sheet size only on a project to avoid errors and simplify logistics. One additional consideration is to check the use of fabric lengths over 18 feet to insure that full loads can be made via truck or rail. By using sheets 18 feet or less two stacks of fabric bundles can be loaded on the 40-feet long trailer or rail car with the lower freight costs sometimes offsetting any higher lapping costs.

6.7.4 Unloading. The unloading of fabric bundles is usually accomplished with common four-legged

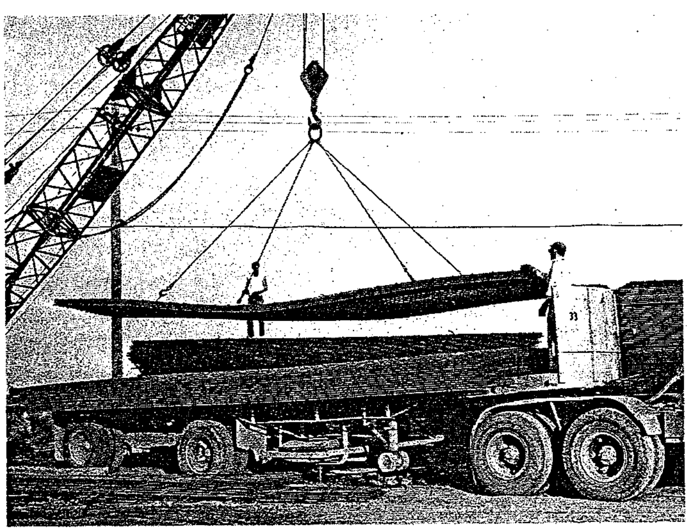


Important considerations in determining sheet size are amount of lapping, production capability, shipping method and finally ease of handling on job with least labor.

slings from a crane. The sling hooks should engage the bottom wires of the fabric bundle at approximately one-quarter points to evenly distribute the load. When the sheets are overly wide or long, a special lifting frame or equalizer may be constructed to lift the bundles. The importance of maintaining flatness in the sheets is extended to the importance of obtaining the proper elevation of the fabric in the concrete slab.

6.7.5 Placing. There are three general methods of placing welded wire fabric: 1) supporting fabric on chairs and placing concrete on chaired fabric; 2) placing concrete in two lifts (in this method the fabric is placed on the first lift and then the second lift is placed and finished); and 3) placing fabric on concrete placed to full depth and mechanically depressing fabric.

Fabric being unloaded at job site. These are long, heavy sheets and were distributed from mesh cart during paving operations.

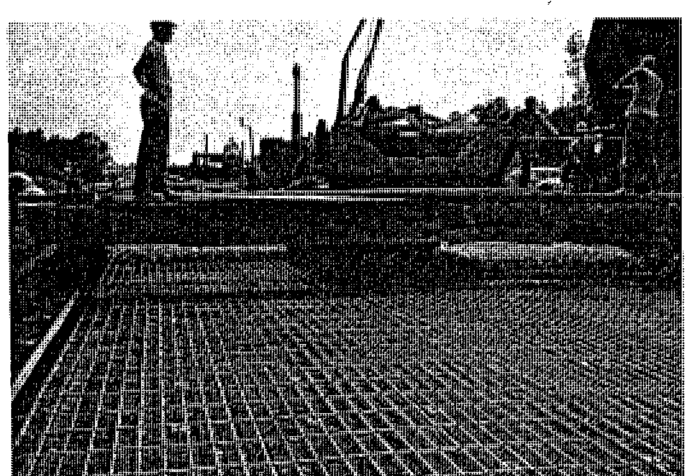


Fabric can be distributed in two ways. One method involves placing fabric on carts which are towed on shoulder. Fabric is generally hand-carried and placed. A second method involves use of a mesh cart which is placed directly in the paving train usually between the spreader and finishing machine.

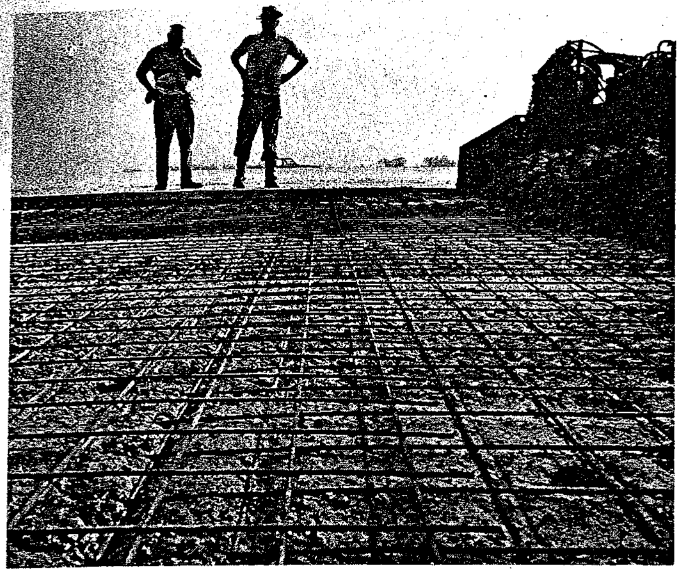
The selection of the method usually involves requirements of specifications, method of pavement and available equipment.

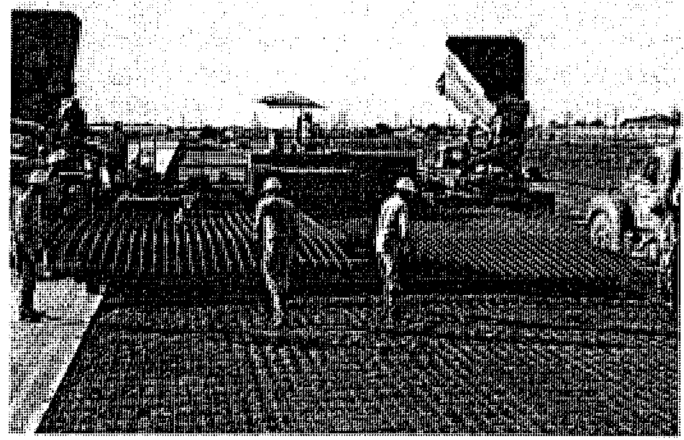
6.7.6 Wire Ties at Laps. The edge laps and end laps are generally wire tied to prevent separation of the fabric sheets during paving operations. Minimal typing at the four corners of the sheets is usually sufficient to maintain the overlapped position. The fabric depressing equipment sometimes shifts the fabric forward from its orginally placed location; this can be corrected by compensating for the creep when originally placing the sheets, or by installing restraining stakes driven into the subbase.

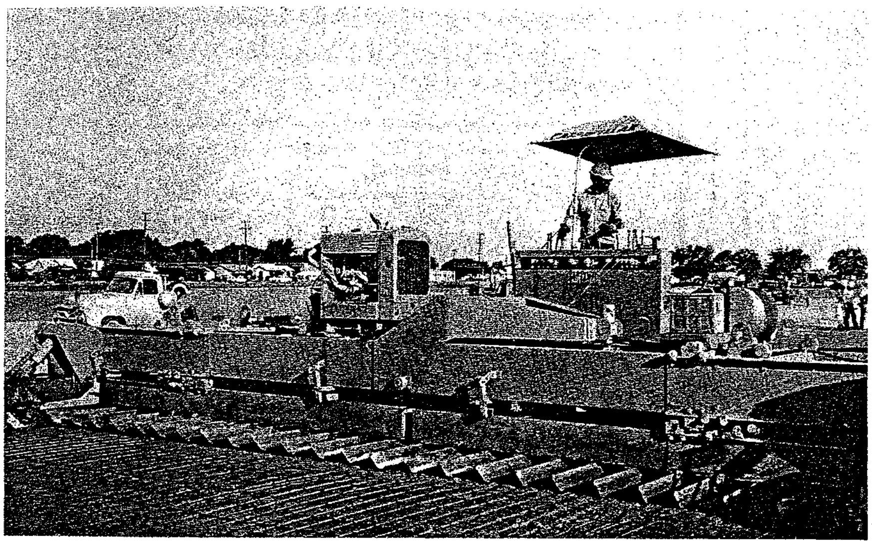
6.7.7 Tolerances. The design of reinforced concrete pavement slabs is not to a high degree of precision. Two-figure accuracy is typical in reinforced concrete design. The time and effort of the designer and inspector is best spent in recognizing and providing for stress concentration and not in striving to a high degree of precision. Fabric placed to the accuracy of $\pm 1/2$ inch in specified depth is extremely well placed. Fabric placed to the accuracy of ± 2 inches in specified horizontal location is extremely well placed. Physical properties of fabric are always based on nominal dimensions of the wire. Mill test reports for compliance with specifications will usually suffice.



Fabric supported on chairs before concreting. This is a one-pass operation. It can be used with either formed or slip-formed operations.





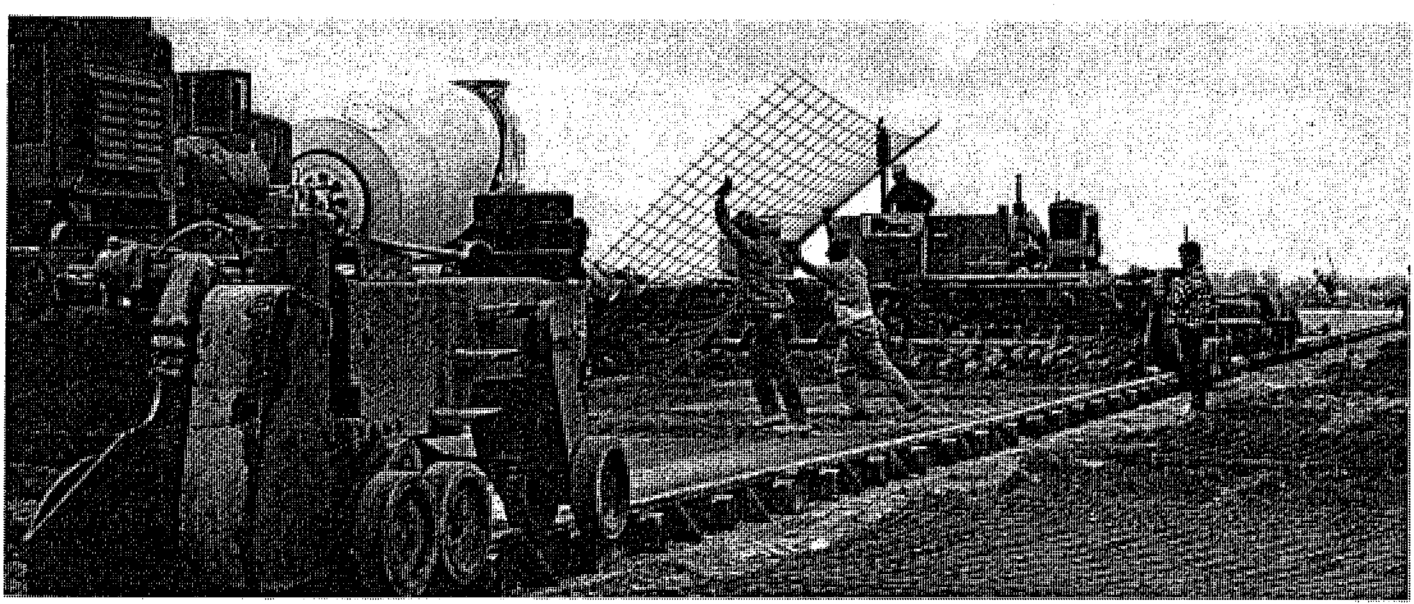


[Upper left] Concrete placed in two lifts. Fabric is placed on first lift. Finishing machine follows and places and finishes pavement.

[Upper right] Fabric being placed from mesh cart. This unit is placed in paving train and often towed by spreader. This equipment is used both in two course work and one course work where fabric is mechanically depressed.

[Left] Fabric being depressed mechanically in one-pass operation. Concrete is placed full-depth, fabric is depressed and pavement is then finished.

[Below] Fabric is sometimes placed at side and hand carried into place. A small crew can handle a lot of reinforcement in one day, because fabric comes in big pieces.



7. PAVEMENT JOINTS

Reference has been made in previous sections to the functions of joints in pavements, i.e., 1) to relieve curling or warping stresses by allowing vertical bending; 2) to reduce friction stresses by permitting slabs to shorten, and 3) to provide expansion space to permit "growth" or lengthening of a project when growth conditions of the concrete prevail. A more complete discussion of pavement joints is provided in an NCHRP synthesis[30] published in 1973. The particular function of each joint type and design to provide this function are best discussed by separating into two main classes: 1) longitudinal joints and 2) transverse joints.

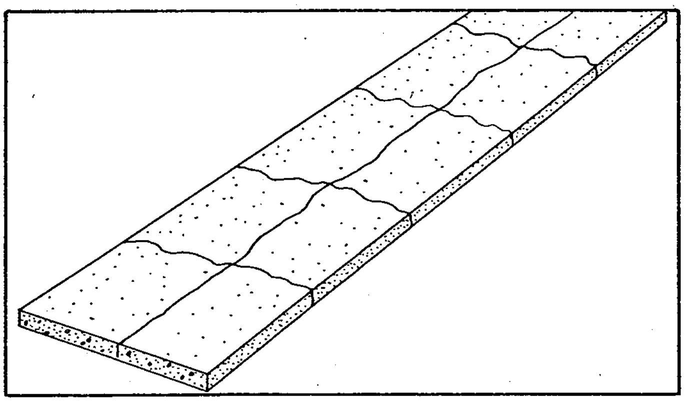


FIGURE 7
TYPICAL CRACKING PATTERN IN A PAVEMENT WITHOUT JOINTS

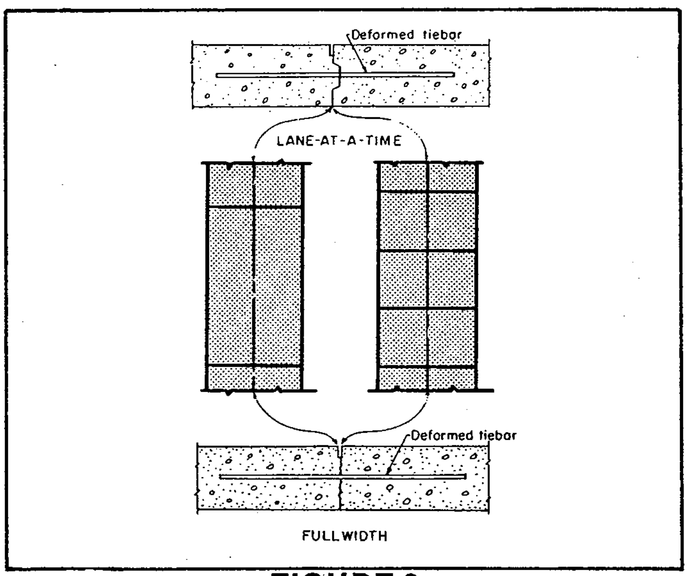


FIGURE 8
TWO TYPES OF LONGITUDINAL JOINTS. KEYED JOINT IS AT TOP AND OFTEN USED WHEN PAVING ONE LANE AT A TIME. BOTTOM JOINT IS WEAKENED PLANE JOINT AND IS USED WITH FULL-WIDTH PAVING.

7.1 **LONGITUDINAL JOINTS** — In highway pavements longitudinal joints are usually lane joints. They provide curling relief only and do not permit horizontal movement. They may be one of three classifications, i.e., 1) weakened plane, 2) keyed, and 3) butt joints.

The weakened plane joint is simply a vertical groove, formed in the fresh mix, or sawed in the hardened concrete to a depth 1/4 h and a width of 1/8 to 1/4 in. The groove is usually filled with a poured sealant such as rubber-asphalt because no need for extensibility is anticipated.

Keyed joints are constructed by forming a trapezoidal keyway in the vertical face of the slab. Typical dimensions are as shown in Figure 9. The tie bars are either in two sections (so that a threaded insert can be installed in the keyway slab and the male section installed before the adjacent slab is cast) or, bent rebars are placed into the keyway recess. These are then straightened for the adjoining slab after the keyway attains sufficient strength.

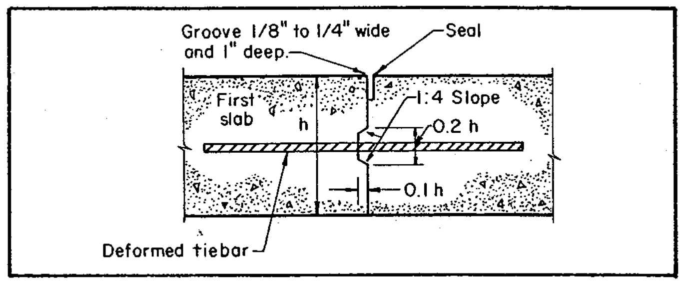


FIGURE 9
SUGGESTED DIMENSION GUIDE FOR KEYWAY

Butt joints are smooth-faced joints with no aggregate interlock. Tie bars are driven into the face at mid depth after the slip form paver has passed, or bent rebars are installed in place similar to the procedure for keyed joints.

Both keyed and butt lane joints should be grooved at the surface to accept sealant. Depth of groove should be sufficient usually 1 to 1-1/2 in. to contain the sealant. Width is again 1/8 to 1/4 in.

7.2 **TRANSVERSE JOINTS** — Joints placed to control transverse cracking are either at right angles to the lane joints or skewed at an angle approximately 2 ft. longitudinally to 12 ft. transversely. Contraction joints increase in width with initial concrete shrinkage and temperature contraction and hypothetically never close with later temperature expansion. In the past, however, sealants have not been sufficiently effective to prevent some particle infiltration and the joint space created by slab contraction gradually becomes filled and thus restricted.

Longitudinal keyed joint.

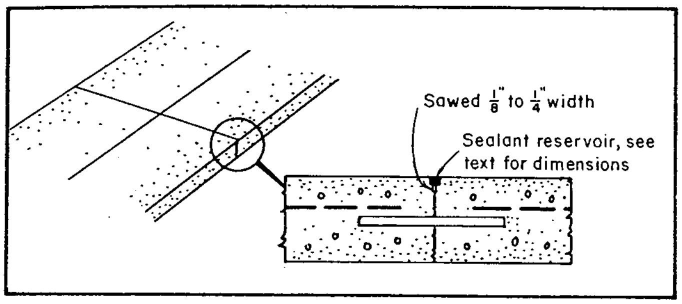


FIGURE 10
DETAIL FOR DOWELED CONTRACTION JOINT

Expansion joints are placed at structures and intersections to absorb the end movement of a pavement if temperatures become excessive, or if there is some "growth" of the concrete for some physical or chemical reason. Joints with more than normal provision to permit pavement expansion are often placed either side of bridges to assure the dissipation of thrust and prevent bridge damage by lateral displacement. These are often called "bridge joints".

Construction joints may be either transverse or longitudinal. Their purpose is to assure easy transition between slabs when they are cast at different times, such as two adjacent lanes in lane-at-a-time construction, or between successive paving operations when the delay has permitted the already cast concrete to set, or "night joints" at the end of a day's operations. They may be designed as contraction, expansion, or tied joints depending upon the locations in the plan.

All joints provide relief of warping stresses by hinge action. All joints provide some degree of load transfer, whether by aggregate interlock, keys, tie bars, dowels, or—in the case of some bridge joints—by a sub-slab sill. Contraction joints, in addition, reduce friction stresses by creating discrete slabs that can contract or shrink. Expansion joints perform all the functions of other joints plus the function of permitting some slab length increase.

7.2.1 Contraction joints —The simplest contraction joint is a weakened plane joint in plain pavements. A groove 1/4 the pavement depth is formed in the fresh mix or sawed in the "green" but hardened concrete before concrete contraction begins. A sealant reservoir must be provided by widening the top 1 in. of the groove. The width of this reservoir, R, is calculated for a sealant with cold temperature extensibility ratio q by the formula R = w/q, hence using the equation in Section 5.1 we find $R = \frac{12L}{q}(eT + d)$. For a hot-poured sealant with cold temperature extensibility q = 10 percent = 0.1, R = 0.04/0.1 = 0.4 in. If the reservoir is not molded in the fresh mix it may be sawed at any time before construction traffic is allowed, with the provision that rope or jute be forced into the joint groove to the base of the planned reservoir before sawing so that the crack beneath the groove will not be plugged with the residue.

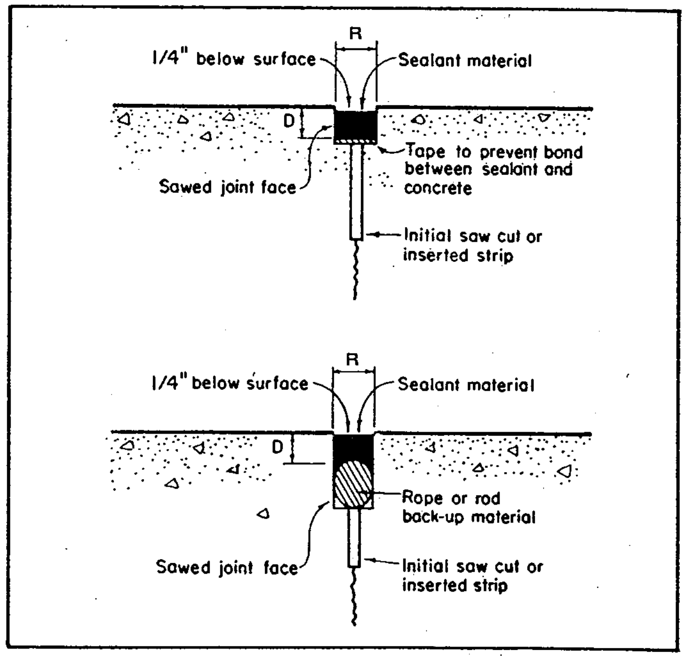
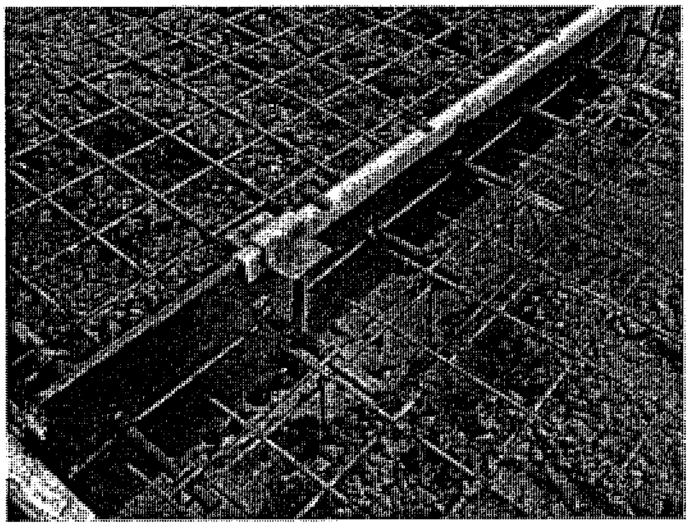


FIGURE 11
DETAILS FOR SAWED CONTRACTION JOINT WITH RESERVOIR FOR SEALANT

Contraction joints between slabs reinforced with welded wire fabric require load transfer dowels. Dowels are placed at mid-depth and aligned parallel to the center line and usually at 12 in. spacings.

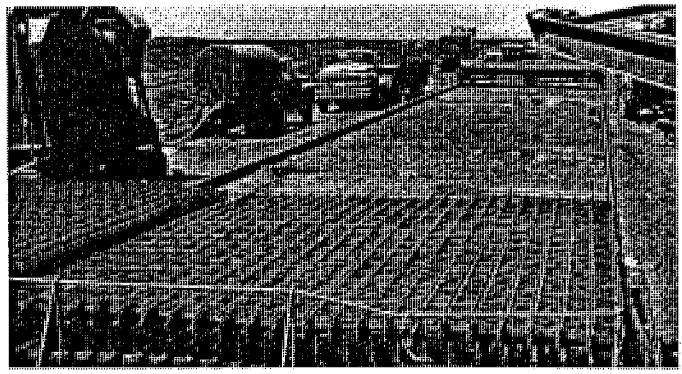
They are usually held in rigid wire baskets anchored to the base. Standard dowel length for highways is 18 in. and diameters in inches are h/8 where h is pavement depth. All burrs are removed and at least 1/2 of the dowel length is coated to prevent bond to the concrete around the dowel. The dowels are usually carbon steel bars produced to ASTM A 615, Grade 40. The dowels may also be structural tubing with plugged ends produced to ASTM A 501 or ASTM A 53.



Doweled pavement being placed. Properly aligned dowels are effective load transfer devices.

The crack-initiating groove above the dowels may be molded in the wet mix or sawed in the green concrete as soon as possible without causing raveling and before the first contraction phase. Its depth is usually h/4, but early formation of this crack is imperative and depths to h/3 are sometimes required. Sealant reservoir widths are calculated by equation in Section 7.2.1. As discussed in Section 5.2, sealants with good cold weather extensibility are required if wide reservoirs are to be avoided.

Premolded sealants require smooth-walled reservoirs best constructed by sawing. The material is installed precompressed into the recess that has been precoated with a solvent-lubricant. Machine installation is preferred to avoid elongation. Requirements on reservoir width R for a premolded sealant of nominal width N_o are such that the strip will always be compressed at least 20 percent but not more than 50 percent. For simplicity and a small margin of safety one may use $N_o = 4w$ and $R = 0.55N_o$ for reservoirs constructed in hot weather. For the 100 ft. slab discussed in Section 5.2 with $w = 0.35$ a premolded neoprene compartmented seal of nominal width $N_o = 4 \times 0.35 = 1.40$ in. would be placed in a reservoir of width $R = 0.55 \times 1.40 = 0.77$ in. or, in round numbers a 1-3/8 in. strip in a 3/4 in. reservoir. Standard specifications for preformed sealants are AASHTO M 220 and ASTM D 2628.



Welded wire fabric in paving train.

7.2.2 Expansion joints — Expansion joints differ from contraction joints in that a treated, compressible material 3/4 in. to 1 in. thick is placed across the full pavement width. Its depth is h - 1 and it is held vertically in the dowel supporting unit at dowel mid-length. Metal or plastic caps on the greased end of each dowel provide expansion spaces equal to the thickness of the compressible material. Dowel spacing and diameter are the same as for contraction joints.

The expansion joint material must be capped with a removable strip, its top flush with the finished pavement surface. This is removed after final finish to form a 1 in. deep sealant reservoir the width of the compressible filler board. Early in the pavement life, expansion joints behave like contraction joints. For this reason, sealants with good extensibility are required. Only at later ages, as the pavement lengthens because of contraction joint infiltrations or any other reason, does the joint begin to absorb the pavement movement.

As premolded strips require smooth-walled reservoirs, they are not well suited as sealants for expansion joints of the conventional type. Special premolded sealants for openings much greater than the joint described here are made with anchor pins that mold into the concrete.

At bridges, often several conventional expansion joints are separated by relatively short slabs to assure ample thrust protection. Other expansion devices are wide-flange beams resting on sleeper slabs and designed in such a manner than one slab slips beneath the top flange. These can provide several inches of expansion space. Also, compartmented neoprene or other material as mentioned previously may rest on a sub-slab and be anchored to adjoining slabs to provide more than ordinary expansion space.

8. AIRFIELD PAVEMENTS

Rigid concrete pavements for airfields are designed essentially by the same principles that apply to highway pavements. Soils are examined and subgrades prepared with the most suitable mateials in the upper layers. Subbases or bases are built as economy dictates and are usually of relatively high load bearing capacity in order that concrete thickness may be minimized. Drainage is particularly important to preserve soil load bearing capacity and to prevent frost damage in northern areas.

Joints control cracking as in highway pavements. Load transfer methods are similar to those for roads but joint sealants are generally materials resistant to jet fuel spillage.

The principal differences between highway and airport pavements are: 1) pavements are thicker due to larger gross loads; 2) pavements are wider, and slabs in aprons and warm-up areas are joined at all four edges; 3) pavements supporting standing and slowly moving planes are thicker than those between ends of runways; and 4) joints are spaced further apart in airports to reduce cost of maintenance and more important to minimize "down-time" on runways and subsequent traffic disruption. Tables 16 and 17 outline the use of both smooth and deformed wire fabric following the criteria of the Federal Aviation Administration (FAA). Recommended dowel sizes for airport paving, based on pavement design and evaluation by the FAA are shown in Table 20.

TABLE 20
DOWEL SIZES FOR AIRPORT PAVING

Slab Thickness In.	Diameter In.	Length In.	Spacing In.
6–7	3/4	18	12
8–12	1	18	12
13–16	1-1/4*	20	15
17–20	1-1/4*	20	18
21–24	2*	24	18

Reference 35

**Dowels noted may be a solid bar or high strength pipe. High strength pipe dowels must be plugged on each end with a tight fitting plastic cap or with bituminous or mortar mix.*

8.1 **SLAB DIMENSIONS** — As in highways, airfield pavements are usually built in lanes. Joints in reinforced pavements may be spaced 45 ft. to 75 ft.

The Corps of Engineers[33] has developed a nomograph to permit reduction of reinforced concrete from plain concrete slab thickness. It shows, for example, that 70 ft. slabs with $A = 0.18$ sq. in./lin. ft. and $f_y = 56{,}000$, then 10 in. may replace plain slabs of depth 12 in., etc.

Welded wire fabric is widely used in airfield paving.

8.2. **JOINTING** — Tiebar areas for airfield pavement joints are computed in the same manner as for highways. As airfields are multilaned, tiebars at the innermost lane joints are considerably larger than those in outer lanes. It is important that the peripheral slabs of aprons and warm-up areas be tied to the inner slabs to prevent permanent outer displacement of the peripheral slabs. This is true also of outer lanes of wide runways.

Keyed construction joints must always be tied. Even a slight opening of a joint with trapezoidal key permits impact between key and keyway and eventual destruction of the lip of concrete above the keyway.

Doweled joints in airfield paving are essentially the same as in highway pavements and similar conditions govern their use.

Sealants are of jet-fuel resistant plastics or preformed neoprene. Slab length and extensibility of sealant are the same as for highways. Highway restrictions apply also to the preformed strips.

9. RESIDENTIAL STREETS AND PARKING AREAS

Only light and slow moving traffic is anticipated on residential streets and smoothness tolerances are more liberal. A designer may have a choice of using a well-drained base course of high quality and plain concrete pavement, or simply grading the old street material for proper drainage and using steel reinforcement to preserve slab integrity should frost damage occur.

For passenger vehicles and the few trucks per week necessary for residential deliveries and sanitation, a 6-in. slab thickness is adequate. For incomplete suburban developments with streets subject to passages of concrete ready-mix and dump trucks, 8-in. thickness is required. A curb is usually preferred and this may be either integral or a separate curb and a gutter strip tied to the pavement. Integral curbs are usually more economical.

Parking areas are treated similar to residential pavements. It is most important that the subgrade be prepared with a network of underground drains in large parking lots to prevent water accumulation after rainstorms and from melting snow. Finished pavement slopes of 1 in. per 20 ft. are needed to minimize local shallow water pockets, or "bird baths". Flatter slopes are permitted only if base preparation precludes settlement and road-paving equipment is used to attain a precise grade.

Joints in parking lot pavements are usually plane of weakness using aggregate interlock, except that construction joints and those joining perimeter slabs are tied. The perimeter slabs must not be allowed to be moved outward successively and produce a wide joint space that grows progressively wider as it fills with solid particles. Joint restraint is readily provided by use of welded wire fabric reinforcement.

Concrete streets give a neighborhood a first class appearance. WWF can be used efficiently in street construction.

10. NOTES ON PAVEMENT MAINTENANCE

Weaknesses in design or construction, or in materials, become evident in pavements with age and use and the pavements require maintenance. Maintenance falls into two classes: preventive and palliative. Preventive maintenance usually is a costly one-time operation; palliative maintenance is a cheaper repetitive procedure that becomes costly because of the repetition. Some of the problems in pavements and maintenance treatments follows.

10.1 FOUNDATION PROBLEMS — There are several evidences of pavement failure directly attributable to the foundation, usually resulting in slab cracking and vertical displacement. Some common sources of trouble are pumping, frost heave, settlement, and swelling soils.

10.1.1 Pumping occurs when the foundation materials become suspended in free water beneath the slab and passing traffic forces the pavement to deflect abnormally and eject the water carrying the suspended material. It may occur at slab edges or at joints. Its cause is poor drainage in conjunction with a high proportion of fine soil in the foundation. Treatment is to improve the drainage, or eliminate the source of water and replace the ejected material—usually by slab jacking. Its prevention is to provide good lateral drainage, build the base at a sufficient height above the water table to forestall saturation, use an open graded or chemically stabilized subbase, design and seal joints as recommended, and, if necessary, use paved shoulders tied to the roadway slab and a longitudinal edge seal.

10.1.2 Frost heave in climates where frost penetrates beneath the slab is due to the freezing of contained moisture in a pocket of soil. It is recognized by excessively wide cracks and elevated or tilted slab areas. Although these distressed areas return approximately to grade at warm temperatures, a few winters with repeated action destroy aggregate interlock and reduce serviceability. Treatment is to clean and seal the cracks and to eliminate the source of moisture. A permanent cure is remove the broken concrete and the susceptible material in the pocket and replace them with good material. The new foundation material must be thoroughly compacted.

10.1.3 Settlement results from the use of unstable materials such as peat in the subgrade, or from improper compaction. Evidence is a broken depressed area. Treatment is slab jacking to grade. It is usually difficult to make a permanent correction by maintenance. Deep slurry jacking may be beneficial, but usually the settlement will progress and require jacking or filling the depression each year until cessation. Slab replacement can then be done.

10.1.4 Swelling soils occur primarily in arid regions where the moisture content beneath the slab exceeds that in exposed areas. Uniform swelling is not detrimental but differential swelling creates undulations. If it is known that soils are susceptible to swell before construction it is prudent to stabilize the top 2 feet of subgrade with lime or other agent to reduce sensitivity.

10.2 JOINT PROBLEMS — Joints are often a major souce of pavement distress. Although they are necessary because concrete slabs change length with temperature and moisture fluctuations, they are vulnerable areas of weakness because there is no transfer of moment at these discontinuities. Evidence of joint distress is spalling, corner breaks, broken seal, abnormal opening, buckling (blow-ups), and key-way cracks.

10.2.1 Spalling — The breaking of small areas of concrete at joints is usually due to high compressive stresses at hard inclusions between joint faces. These may have infiltrated from the top through a broken seal, or from the subgrade when pumping occurs. Prevention of further occurrence is accomplished by curing the pumping, cleaning the joint thoroughly, and resealing. If spalls are large, the joint face is restored by replacement of spalled sections with fresh concrete, usually with pretreatment of epoxy on the old surface.

Raveling is similar in appearance to light spalling, but this occurs when sawing concrete before it has attained sufficient strength to retain the aggregates. Raveled joint faces will not retain premolded strips.

10.2.2 Corner breaks can be the result of infiltrated stone, or misaligned dowels, or poor soil support. Breaks occur both at outside and inside corners. Treatment is determined by examination and elimination of the cause. Infiltrated materials are removed by joint cleaning and resealing. Misaligned dowels should be cut at both joint faces. Soil support is restored by jacking after drainage blockage is repaired.

10.2.3 Broken seals are not damaging in themselves but are sources of future damage by permitting water and particle infiltration. Restoration of a broken seal should follow the same procedures as original installation with the additional chore of thoroughly cleaning the joint area for its full depth. The past practice of cleaning only the top groove and filling with a sealant can trap particles between joint faces, reducing closure, causing stress concentrations and spalling, and eventual buckling.

10.2.4 Abnormal opening may be a wide opening or no opening at all. When no opening is observed, either the crack has not formed beneath the groove, or the dowels are so badly misaligned that the joint is "frozen". This causes abnormal wide openings to occur in adjacent joints. If these joints are designed for aggregate interlock load transfer, no interlock will remain because of the wide opening. If they are doweled, the sealant will be ineffective because of a lack of adequate extensibility to accommodate the large movement. Reinforcement in slabs with a frozen joint will be stressed above design values and transverse cracks occurring near the frozen joint may open. Treatment of a frozen joint will require an assessment of conditions. It may be more beneficial to cut new joints at either side of a frozen joint than to cut through the joint. Permanent treatment is to remove the joint and pavement for sufficient distance to build a new joint and to tie the new slab portions to the old slabs to force the joint to function. The old wide joints must be cleaned and resealed.

10.2.5 Buckling, or blow-ups, occur in some pavements after several years of use because of accumulated movement of long sections of pavement due to improper joint closure. Blow-ups occur when slabs expand, producing sufficient compressive force to cause the pavement to buckle or "blow-up". The accumulated infiltration of hard, relatively incompressible materials into joints over a period of years in effect shortens the joint opening and aggravates this condition.

There has been some recent indication that certain coarse aggregates have a significant bearing on joint performance[36]. Blow-ups occur after a sustained period of high temperature, and it is often simultaneous with high humidity. It is a serious deficiency because of the sudden occurrence and creation of a traffic hazard.

A buckled pavement is repaired by removal of the damaged concrete and replacement. A single new expansion joint may be constructed and the new concrete tied to the old, or sufficient old concrete may be removed to enable construction of a short slab and a pair of expansion joints. The pavement "growth" that caused the buckling is likely to continue and if no hot-weather joint closure is observed more expansion space must be provided. This is done by sawing and removing short sections of pavement during contraction cycling and replacing with new sections incorporating expansion space.

Prevention of buckling in susceptible pavements is accomplished by a thorough cleaning of all joints and resealing during cool periods when the joints are open and the "incompressibles" can be removed. In most cases this can be done each 4 or 5 years. An alternate to this expensive maintenance is the construction of new expansion space as described above.

10.3 CONSTRUCTION TRAFFIC — Construction traffic should be prohibited from using the new concrete pavement too early for two reasons: 1) the low strength concrete will crack under the heavy loads, and although these are hair-line cracks the damage is just as significant as overload cracks at later age; 2) the truck traffic fills the joint spaces with construction and road materials and abnormal effort is required to clean these joints prior to sealing.

If conditions are such that construction traffic must use the new pavement, rope or jute should be packed into the joint spaces before traffic is permitted and all loads should be weighed and reduced to assure stresses below 50 percent of concrete strength; also, ramps must be built to provide access and egress without endangering the edge concrete.

A COMMENT FROM WRI

This manual has been prepared to help understand the fundamentals of design of jointed reinforced concrete pavements. As mentioned in the foreword, thousands of miles of these pavements have been in service for many years—some of them for decades—and some have been grossly overworked, carrying far more and heavier traffic than ever contemplated when they were designed and built. Their overall performance record is excellent.

The decision-maker has three basic options open when designing concrete pavements: 1) plain, jointed pavements; 2) reinforced, jointed concrete, and 3) continuously reinforced concrete pavements. Each type has advantages. Many factors affect pavement design, construction and performance. Among these factors are types of soil, subbase, traffic, particularly truck traffic, temperature variations, amount of rainfall, topography, drainage conditions, equipment available, and—of course—economics.

Welded wire fabric is used extensively in reinforced, jointed pavements. A considerable tonnage of fabric is also used annually in continuously reinforced concrete pavement (CRCP) for highways. We feel that jointed reinforced pavement is still one of the best buys available from the standpoint of both cost and performance.

We would like to emphasize some of the points discussed in this manual:

Number of Joints. The primary purpose of pavement reinforcement is to hold the panel together to permit effective aggregate interlock performance. Thus, the length of the reinforced concrete panels can be increased, thereby decreasing the number of joints substantially. Joints, even relatively simple sawed and sealed joints, are expensive to install and maintain. Fewer joints also improve rideability.

Reinforced Concrete. The amount of reinforcement used in pavement as distributed steel is relatively low. However, the fact remains that reinforcement does add to the structural capacity of a concrete slab and jointed reinforced pavement offers this added benefit.

Doweled Joints. An integral part of a reinforced concrete design is the use of dowels as a load transfer mechanism. There have been great improvements in dowels—such as plastic coatings and heavier, more easily placed dowel baskets within the last few years. Experience in both warm and cold climates has shown that dowels are essential when the highway carries even a moderate amount of truck traffic.

If plain pavements are to be doweled, a cost analysis of plain, doweled pavement with close joints should be compared with reinforced doweled pavement containing far fewer joints. The added value of reinforcement per se and the reduction of the number of joints should also be considered in this analysis. Doweled joints are part of the mesh-dowel system and, thus, provided.

The proper joint spacing must be carefully selected with two primary considerations—performance and economics. A considerable portion of this book is devoted to joints, particularly their function and design. Joints are an integral part of jointed pavements, whether plain or reinforced. In reinforced pavements using the subgrade drag theory formula to determine steel areas, the steel cross-sectional areas will increase as the length increases. Conversely, joint costs including dowels will decrease as the length of the panel decreases. Thus, the designer must interrelate performance objectives and economic considerations and arrive at a solution that maximizes both.

In conclusion, we invite your study of reinforced jointed pavements. WRI feels that jointed reinforced concrete is a proven system. It offers a reinforced slab with doweled joints at a moderate cost. We challenge you to look at it.

SYMBOLS AND ABBREVIATIONS *

A_c	Area of concrete, sq. in., per foot of section width
ADT	Average daily traffic
ADTT	Average daily truck traffic
A_s	Area of steel reinforcement sq. in. per ft. of concrete section
c	Base condition coefficient
D	Percent traffic in heaviest traveled lane at peak
d	Concrete shrinkage coefficient, in./in.
e	Coefficient of temperature contraction, in./in./deg. F
E_c	Young's modulus for concrete
F	Coefficient of friction between slab and base
f_s	Working stress of steel, psi
f_t	Tensile strength of concrete, psi
f_y	Yield strength of steel reinforcement, psi
h	Thickness of concrete
h_c	Thickness, in., of concrete overlay
j	Number of cars equivalent to one truck
K	Design hour volume as percent of ADT
k	Foundation modulus
kip	1,000 pounds
L	Length of slab, ft.
LSF	Load safety factor
MR	Modulus of Rupture of concrete
N	Total number of traffic lanes in both directions
n	Ratio of elastic moduli; steel to concrete
N_o	Nominal width of premolded joint sealant, in.
P	Passenger cars per lane per hour
pci	Pounds per square inch per inch
pH	Hydrogen ion concentration (acidity or alkalinity index)
PI	Plasticity Index
P/S	Prestressed
psi	Pounds per square inch
q	Sealant extensibility ratio
R	Width of sealant reservoir in a joint, in.
r	Poisson's ratio for concrete
S	Concrete residual compressive stress at mid slab
s_f	Stress in concrete from frictional drag
T	Temperature change in degrees Fahrenheit
Tadt	ADTT as percent of ADT
Tph	Trucks per hour as percent of total traffic
vph	Vehicles per hour
w	Joint opening, inches

*Partial list.

ORGANIZATIONS

AASHTO	American Association of State Highway & Transportation Officials
ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
FAA	Federal Aviation Administration
PCA	Portland Cement Association
WRI	Wire Reinforcement Institute

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History and Purposes of Wire Reinforcement Institute, Inc.

The Wire Reinforcement Institute is a voluntary association of manufacturers of welded wire fabric. It was founded in Washington, D.C., in 1930, and was organized to disseminate technical information and to extend the use of welded wire fabric through scientific and market research. It provides technical service in the public interest and cooperates with Government agencies in any program considered essential to the national welfare.