

SP 51-1

Light-Traffic Roads Of Concrete

By
E. Guy Robbins

Synopsis: Knowledge gained from slipforming heavy-duty concrete airport and primary road pavements has been applied to slipforming thin-concrete pavements for secondary and county roads carrying low volumes and light weights of traffic. Studies show that at low volumes of traffic there are few heavy multi-axle trucks in the traffic stream. Several thickness-design procedures are compared, and the serviceability index design model is discussed. Jointing and construction practices are summarized, noting that transverse joint intervals in light-traffic pavements vary from 15 to 20 ft (4.57, 6.10 m) up to 40 ft (12.19 m). A major survey shows that performance of thin-concrete county and secondary road pavement is good.

Keywords: axle loads; concrete construction; concrete pavement; concrete; highways; joints (junctions); performance tests; research; serviceability; slip-form construction; structural design.

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INTRODUCTION

Progress through knowledge is slow but never ending. It took years of learning and development to provide today's highly efficient paving equipment and know-how for economically slipforming 18-in. to 24-in. -thick (45.7, 61.0 cm) heavy-duty concrete airport pavements. Many miles of 8-in. , 9-in. , and 10-in. -thick (20.3, 22.9, 25.4 cm) concrete pavements are built yearly to carry heavy (volume and weight) traffic on the Interstate and primary highway systems. Knowledge gained in these areas is being applied to build concrete pavements thinner-- 6 and 7 in. (15.2, 17.8 cm) thick--for the more lightly traveled secondary and county rural roads.

Presented here for engineers concerned with concrete design and performance are: background information on thin pavements carrying light traffic; a discussion of traffic patterns on these roads; some thickness-design comparisons, including comments on the serviceability index design model; brief summaries of jointing and construction practices; and the results of a major survey on thin-concrete pavement performance.

RESEARCH

There has been very little research on pavement for light-traffic rural roads. The emphasis on most highway research programs is on major highways carrying large volumes of heavy-weight traffic. However, two projects conducted in the United States have helped to establish design guidelines and document the excellent performance of concrete for light-traffic roads.

The first project, known as the AASHO Road Test, was conducted by the American Association of State Highway Officials* in 1958-1961 and reported by the Highway Research Board in 1962 (1). Concrete pavement thicknesses from 2-1/2 to 12-1/2 in. (6.4, 31.8 cm) were tested under axle loads from 2000 lb. (907 kg) on a single axle to

*Now the American Association of State Highway and Transportation Officials

48,000 lb. (21,773 kg) on a tandem axle. The 1.1 million axle loads of test vehicles probably subjected the test pavement to as many loads over a period of two years as a normal rural road will carry in 25 to 30 years.

The quality of performance of the various pavement designs at the AASHO Road Test was determined from serviceability measurements at various intervals throughout the test. Figs. 1, 2, and 3 present the performance histories of the 3-1/2-in., 5-in., and 6-1/2-in. (8.9, 12.7, 16.5 cm) concrete test sections, respectively, with the serviceability index plotted at various numbers of axle load applications. These results show the excellent performance of the 5-in. and 6-1/2-in. (12.7, 16.5 cm) pavements for the lighter axle loads under the conditions prevailing at the Road Test, i.e. the soil and climate of central Illinois. There was no significant difference in the performance of the pavements, whether plain or reinforced, with or without subbase (a granular subbase of 3, 6, or 9 in. -- 7.6, 15.2, 22.9 cm). These results are evidence that 8-in. or 9-in. (20.3, 22.9 cm) concrete pavement is not required on many miles of light-traffic roads.

The second project, of equal interest, was an experimental road built by Greene County, Iowa, in 1951. It consisted of 2 miles of 4-1/2 in., 5-in., and 5-1/2-in. (11.4, 12.7, 14.0 cm) concrete slabs. After 15 years the county reported: "There is strong evidence that thin concrete pavements, when based on realistic design loads and built with modern techniques, are both economical and desirable for secondary road systems." (2) The performance of all three designs was excellent. In fact, even after 21 years, there is no substantial difference in their performance. There is also no major performance difference between the plain and the reinforced pavements designed for this project.

THE IOWA STORY

The state of Iowa provides the most striking example of concrete for light-traffic rural roads. It was in Iowa that the first slipform paver was used. The Iowa State Highway Commission developed it for use on the state's secondary system (3).

Iowa has over 90,000 miles (144,810 km) of rural secondary roads --and soils that are excellent for farming but notoriously poor for highway foundations. Most Iowa counties had attempted to provide all-weather surfaces through the use of gravel. However, diminishing supplies of gravel; degradation of the surfacing from thawing of subgrades in the spring after deep frost penetration in the severe Iowa winters; the need for limiting loads in the spring; and the dust problem in the summer--all indicated the need for a more practical solution.

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Thus, the slipform paver was developed in the late 1940's. Slipform paving is a low-cost method of building concrete pavement, with a minimum of labor, on a narrow right-of-way with deep side ditches. It was used on two projects--a 1-mile (1.6 km) section and a 1/2-mile (0.8 km) section of 6-in. (15.2 cm) pavement--in 1949. The success of these projects, plus the experimental road in Greene County already mentioned, led to the acceptance of slipformed 6-in. (15.2 cm) plain concrete pavements by most Iowa counties.

With the development of commercial slipform paving equipment in 1955, use of concrete pavements spread rapidly in Iowa. There are more than 3000 miles (4827 km) of concrete pavements built by the slipform method on county roads in this state. Fig. 4 shows a breakdown of Iowa concrete paving mileage county by county by the end of 1973.

THE STORY IN OTHER STATES

Following Iowa's example, several states are now using plain concrete for light-traffic roads. In Nebraska in 1969 through 1973 over 325 miles (522.9 km) of 6-in. to 8-in. -thick (15.2, 20.3 cm) concrete were paved by counties and the state; most of this is 6-in. to 7-in. (15.2, 17.8 cm) pavement on the secondary road system of the Nebraska Department of Roads. In Minnesota over 40 miles (64.4 km) of 6-in. and 6-1/2-in. (15.2, 16.5 cm) concrete pavement have been constructed on the county road system. Illinois recently revised its design standards to permit 6-in. and 7-in. (15.2, 17.8 cm) plain concrete with no subbase; some 32 miles (51.5 km) were built on Illinois county roads in 1970 to 1973. Other concrete paving projects have been built on light-traffic roads in Michigan, Pennsylvania, North Dakota, and Wisconsin.

TRAFFIC STUDIES

Highway statistics show that local rural roads represent 71 percent of the rural road mileage (some 2.26 million miles--3.64 million km), and these roads carry 24 percent of the traffic. However, most of the published data regarding traffic volumes and weights are for major rural and urban highways. Such information is an essential ingredient in the proper design of highways.

Although traffic data for lightly traveled rural roads are meager, some data are available. Of the 90,000 miles (144,810 km) of rural secondary roads in Iowa, 16,000 miles (25,744 km) carry over 100 vehicles per day, including 5 to 15 percent trucks. Throughout the state, traffic ranges from about 100 to 1060 vehicles per day on the secondary system.

Several traffic studies for Portland Cement Association (PCA)--one by M. P. Brokaw* in 1965 and the other by this author** in 1968--show that at low traffic volumes the number of heavy trucks (tractor semitrailers and combinations) diminishes rapidly. In Brokaw's study of Wisconsin traffic, a consistent relationship was found between two-way dual-tired truck volume and tractor semitrailer and combination truck volume (Fig. 5). The basic equation is:

$$\text{Log (DT ADT)} = 0.7830 \text{ Log (TST ADT} + 4) + 0.8296$$

where DT ADT = two-way dual-tired trucks daily

TST ADT = two-way tractor semitrailer and combination trucks daily

My own study summarized the 1968 traffic count data for rural highways in seven states (Table 1). It related total two-way traffic volume to commercial traffic and to the type of trucks in the traffic stream. This study agreed with Brokaw's study that at low traffic volumes there are few multiaxle trucks present.

In order to properly evaluate the effects of heavy commercial vehicles on the pavement and the part they play in the structural design of the slab, PCA helped to develop a computer program that converts data from Federal Highway Administration (FHWA) standard loadometer tables (W-4) to probability constants for use in structural design. These probability constants approximate the number of axles of each load group per 1,000 trucks. However, loadometer data are not generally available for local rural roads and PCA developed general probability constants for them (4). Table 2 gives the results for county rural roads in axles per 1000 trucks--with the minimum, average, and maximum for each load group on single and tandem axles. These traffic data can be used for the thickness design of concrete pavements when more accurate information is not available.

THICKNESS DESIGN

Various thickness-design procedures are used by highway departments. One of them, the PCA method of design (5, 6), is based on influence charts developed from Dr. H. M. Westergaard's equation

*Unpublished data by M. P. Brokaw, Senior Paving Engineer, Portland Cement Association, Skokie, Illinois, 1965.

**Summary of 1968 traffic data by author in Table 1.

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for flexural stress due to a load at the slab edge. Another method, the AASHO interim design guide (7), is based on the results of the AASHO Road Test. Both methods provide a structural design analysis based on subgrade and concrete strengths, design life, and the weights and repetitions of axle loads of traffic.

Table 3 is a design comparison of these two methods (plus the serviceability index design model, discussed below) for various traffic volume levels for one subgrade condition. These values will vary some for different assumed truck traffic volume and weight patterns, subgrades, and concrete strengths.

The Illinois Department of Transportation uses a modified AASHO interim guide procedure with certain minimum requirements (Table 4). Also, the Minnesota Department of Highways has a simplified design table that provides suggested designs for different subgrades and anticipated traffic (Table 5).

A separate empirical design method based on the performance of plain concrete pavements has been developed by M. P. Brokaw of the Portland Cement Association. In 1971-1972 he made an extensive study and analysis (8) of the performance of plain concrete pavements (no mesh or dowels) in service in four Midwestern states. The study covered some 3500 miles (5,632 km) of pavement 6 to 10 in. (15.2, 25.4 cm) thick and with transverse joint spacing of 15 to 20 ft (4.56, 6.10 m). It involved the measurement and analysis of truck traffic, general subgrade conditions, faulting, and age, as well as use of the PCA Road Meter, a device installed in a passenger car to measure the Present Serviceability Index (PSI) of pavements while traveling at a speed of 50 miles (80.5 km) per hour (9). The results of this field investigation of plain concrete pavement performance produced the serviceability index design model.

The model equations are:

For A-1, 2, 3 subgrades,

$$\text{PSI} = 5.41 - 1.8 \log [1014/10^{0.56P_o + 1.94TA^2/D^{5.47}} + (A + 1)^{0.58} - 1] - 0.01A + 0.65 \log D - 0.62$$

For A-4, 5, 6, 7 subgrades,

$$\text{PSI} = 5.41 - 1.8 \log [1014/10^{0.56P_o + 1.11TA^2/D^{4.60}} + (A + 1)^{0.70} - 1] - 0.01A + 0.65 \log D - 0.62$$

where PSI = serviceability index following years of service (A) after construction

P_o = serviceability index constructed

T = two-way average daily traffic of tractor semitrailer and combination vehicles during years of service (A)

A = years of service after construction until reaching PSI

D = thickness of pavement in inches

Note that Table 3 includes thickness design values for a given set of conditions using the model.

The import of the serviceability index design model is two-fold:

1. The advantages of plain concrete pavement can be extended to major truck routes by increasing the pavement thickness without using dowels and distributed reinforcement.
2. Because plain thin-concrete pavements have a greater capacity for truck traffic than previously predicted, they are especially suited for use on the secondary and county highway systems.

JOINTING

Jointing details vary from state to state. The plain (unreinforced) pavements have transverse construction joints sawed at various intervals. For example, in Iowa the joints are sawed at 40-ft (12.19 m) intervals; in Illinois, at 20-ft (6.10 m) intervals. Nebraska uses joints skewed and sawed at 15-ft (4.57 m) intervals; Minnesota at 20-ft (6.10 m) intervals.

On most projects the only subbase provided under concrete pavements is the old or existing gravel surface bladed into shape for the proper cross section. These pavements usually are somewhat narrower than primary and Interstate pavements; i. e., they have a width of 20 or 22 ft (6.10, 6.71 m) rather than the 24-ft (7.32 m) width generally used on major roads.

The only steel used is in the 1/2-in. -diameter (1.3 cm) tiebars across the longitudinal centerline joint. Most projects have a 2-in. (5.1 cm) crown to facilitate drainage and use a slightly lower cement factor (470 to 517 lb. of cement per cubic yard - approx. 279,307 kg/m³) than used on primary highways. All use air-entrained concrete.

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CONSTRUCTION

In recent years concrete light-traffic roads have been built almost entirely by the slipform paver. Generally the slipform paver is preceded by some type of electronically controlled automatic fine grader that scarifies, levels, and cuts the subgrade to full width. Most such fine graders now take both horizontal and vertical guidance from a preset string line. In Iowa, where the right-of-way is narrow and the side ditches quite deep, a special belt conveyor is mounted on the fine grader to carry the central-mixed concrete over the fine grader and deposit it on the grade just ahead of the slipform paver.

The slipform paver performs all operations of spreading, consolidating, and finishing the concrete; only a minimum of hand-finishing is required. The final surface texture is obtained with a burlap drag and the pavement is cured with white-pigmented membrane.

PERFORMANCE

The performance of the relatively thin, plain concrete pavements on county roads in Iowa is well documented. In 1968 and 1969 a performance evaluation (10) was made of 2044 miles (3289 km) of concrete pavement on the Iowa secondary road system--95 percent of all mileage built since 1955. Of the roads surveyed, 90 percent were 6 in. (15.2 cm) thick; about 8.5 percent, 7 in. (17.8 cm); and 1.5 percent, 8 in. (20.3 cm). They had traffic counts from about 100 to as much as 2000 vehicles per day.

The survey was conducted by using the PCA Road Meter (9) to measure the Present Serviceability Index (PSI). The weighted average of current PSI value for each year's construction ranged from 3.26 in 1955 to 4.15 in 1969 (Fig. 6). The average PSI for the total 2044 miles (3289 km) in the study was 3.91.

Comparison of the PSI in Fig. 6 with the road roughness plot in Fig. 7, which is based on the Bureau of Public Roads* roughometer, shows that the lower PSI of the old projects is only partially accounted for by loss of PSI due to age. Much of the difference is due to improvements in both equipment and construction techniques during this period.

It is gratifying that the average PSI value for pavements up to 13 and 14 years old was 3.26 or better. In other words, the 2044 miles

*BPR, which is now the FHWA

(3289 km) of rural county concrete roads surveyed had a service-ability rating in the good category (PSI of 3.00 or better) after 2 to 14 years of service.

SUMMARY

Knowledge of the traffic characteristics, design, construction and performance of major highways has been modified and adapted for the design of thin-concrete pavements carrying light traffic. Traffic studies show that at low traffic volumes there are few heavy multi-axle trucks in the traffic stream. Although various thickness-design procedures are used, the performance of thin-concrete pavement on county and secondary roads is good.

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Table 1--Summary of Traffic Mix on Rural Highways*

ADT	CVpd	HCpd	TST		2A-6T		3A		4A		5A	
			No.	Percent of HCpd	No.	Percent of HCpd	No.	Percent of HCpd	No.	Percent of HCpd	No.	Percent of HCpd
220	35	0										
280	50	10			10	100						
460	100	38			36	95			2	5		
585	132	57	0	0	44	78	8	13	5	9		
840	200	97	25	26	73	76	13	13	11	11		
1110	273	140	52	37	104	74	19	14	17	12	0	0
1580	400	215	98	46	116	54	28	13	28	13	43	20
1940	500	272	132	49	121	45	36	13	36	13	79	29
4000	1000	570	381	67	162	28	72	13	76	13	260	46
6300	1500	900	610	68	202	22	115	13	121	13	462	52
11400	2500	1650	1350	82	278	17	211	13	222	13	939	57

*1968 W-1 traffic count data for rural highways. Average values for Minnesota, Arizona, Missouri, Louisiana, Nebraska, Wisconsin, and Illinois.

Nomenclature:

ADT = average daily traffic

CVpd= all commercial vehicles
per day

HCpd= heavy commercial vehicles
(all larger than 2-axle, 4-
tired vehicles) per day

TST = tractor semitrailers and
combinations per day

2A-6T = 2-axle, 6-tired vehicles per day

3A = 3-axle vehicles per day

4A = 4-axle vehicles per day

5A = 5-axle vehicles per day

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Table 2--Axles per 1000 Trucks* on County Highways

Axle load kips**	Axles per 1000 trucks		
	Min.	Avg.	Max.
<u>Tandem</u>			
50			.27
48			.27
46			.44
44			6.85
42			16.25
40		4.58	23.51
38		10.49	30.19
36	4.85	18.49	34.85
34	2.44	27.67	33.26
32	2.41	28.11	27.26
30	2.22	27.37	22.30
28	2.22	23.73	22.30
26	2.22	28.74	22.30
24	3.34	21.89	21.18
22	3.34	14.44	21.18
20	3.34	14.49	21.18
<u>Single</u>			
26			1.56
24			16.71
22		13.84	33.15
20	4.85	24.30	40.44
18	18.25	56.29	50.41
16	99.95	55.40	57.92
14	99.95	65.32	57.92
12	152.08	207.70	244.14
10	152.08	217.01	244.14

*All vehicles larger than 2 axles, 4 tires. Calculated from generalized probability constants.

**Axle load in thousands of pounds (1 kip = 453.6 kg).

Table 3--Thickness Design Comparisons for Relatively Low Traffic Volume and One Axle-Load Distribution

Two-way commercial vehicles per day (CVpd)	Two-way average daily truck traffic (ADTT)*	Two-way multiple-unit trucks per day (MU ADT)*	E18 traffic per day in design lane**	Design thickness, in. (cm), for 35-year analysis period		
				PCA method [†]	AASHTO method ^{††}	Serviceability index design model [‡]
123	49	8	18	6.0 (15.2)	5.1 (13.0)	
260	130	40	56		6.2 (15.7)	6.0 (15.2)
312	165	55	75	6.5 (16.5)	6.6 (16.8)	
320	170	57	75			6.5 (16.5)
398	215	80	100		6.75 (17.1)	7.0 (17.8)
508	275	110	133		6.8 (17.3)	7.5 (19.1)
1210	705	375	400	7.0 (17.8)		

*Percent varies with traffic volume.

**Equivalent 18-kip single-axle load calculation based on 1.695 E18/MU ADT and 0.201 E18/(remaining CVpd).

[†]Design based on modulus of subgrade reaction (k), load safety factor (LSF), and modulus of rupture (MR), with $k = 150 \text{ pci}$ (40.7 N/cm^3), $\text{LSF} = 1.0$, and $\text{MR} = 650 \text{ psi}$ (4482 KN/m^2).

^{††}Design based on $k = 150 \text{ pci}$, $\text{MR} = 650 \times 3/4 = 489 \text{ psi}$ (3372 KN/m^2), and a terminal serviceability index of 2.0.

[‡]Design based on A-4, 5, 6, 7 subgrade.

Table 4--Minimum Structural Design Requirements from Illinois Division of Highways Manual on Structural Design, 1970

Road and street classification	Portland cement concrete pavements*		Subbase**	
	Type	Min. thickness, in. (cm)	Type	Min. thickness, in. (cm)
Class I	Continuously reinforced	8 (20.3)	Stabilized granular material	4 (10.2)
Class II	Standard reinforced	8 (20.3)	Stabilized granular material	4 (10.2)
Class III	Standard reinforced	7 (17.8)	Granular material ⁺	4 (10.2)
Class IV	Standard reinforced	6 (15.2)	Granular material ⁺	4 (10.2)

*For municipal streets having curbs and gutters and storm sewer systems, and for which the responsibility for maintenance is to be borne entirely by the municipality, the minimum required pavement thickness shall be 6 in. (15.2 cm). Where the design thickness is 6 in. or 7 in. (15.2, 17.8 cm) standard reinforcement may be omitted at the option of the designer provided sawed transverse contraction joints are spaced no greater than 20 ft (6.10 m) apart. A standard reinforced 10-in. (25.4 cm) pavement may be used in lieu of continuously reinforced pavement on urban sections.

**Subbase will not be required for urban sections having curbs and gutters and storm sewer systems.

⁺Pavement for Class III and Class IV roads and streets may be designed with or without a subbase, at the designer's option.

Table 5-- Rigid Pavement Thickness Based on One-Way, 20-Year Projected Average Daily Traffic*
(from Minnesota Department of Highways Road Design Manual, 1971)

Pavement thickness, in. (cm)	Soils Class A-4, 5, 6, 7 (Subgrade k-150)		Soils Class A-1, 2, 3 (Subgrade k-300)	
	HCADT**	TST HCADT ⁺	HCADT	TST HCADT
6 (15.2)--non-reinforced	25	5	100	20
6-1/2 (16.5)--non-reinforced	100	15	250	50
7 (17.8)--nonreinforced	200	25	500	100
7-1/2 (19.1)--non reinforced	300	40	750	150
8 (20.3)--non-reinforced	750	100	-	-
8 (20.3)--reinforced	1000	200	7500	1250
9 (22.9)--reinforced	Unlimited	750	Unlimited	Unlimited
10 (25.4)--reinforced	Unlimited	Unlimited	Unlimited	Unlimited

*Pavement thickness determined on the basis of traffic analysis studies for each project.

Passenger car and 4-tired truck volumes do not affect the design thickness of pavement.

**Heavy commercial average daily traffic consisting of single-unit, 2-axle, 6-tired trucks and 3-axle trucks.

⁺Heavy commercial average daily traffic consisting of 3-axle to 5-axle tractor semitrailer trucks.

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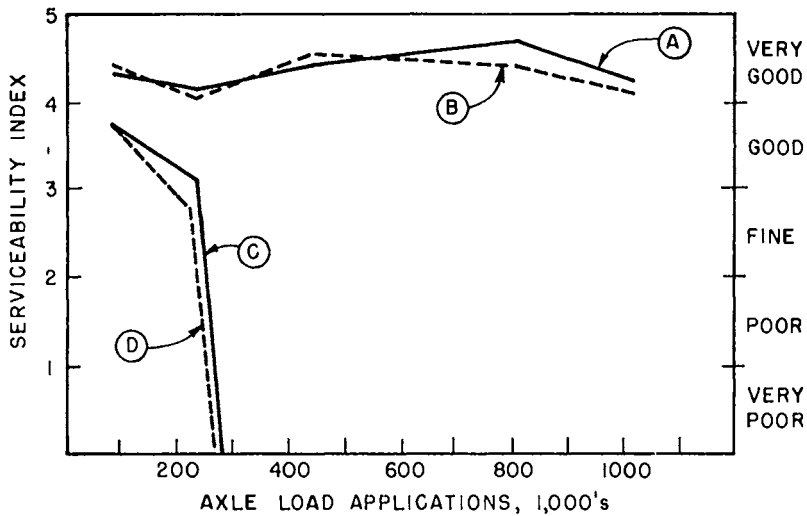


Fig. 1--AASHO Road Test performance of 3-1/2-in. (8.9 cm) concrete (1000 lb. or 1 kip = 453.6 kgf)

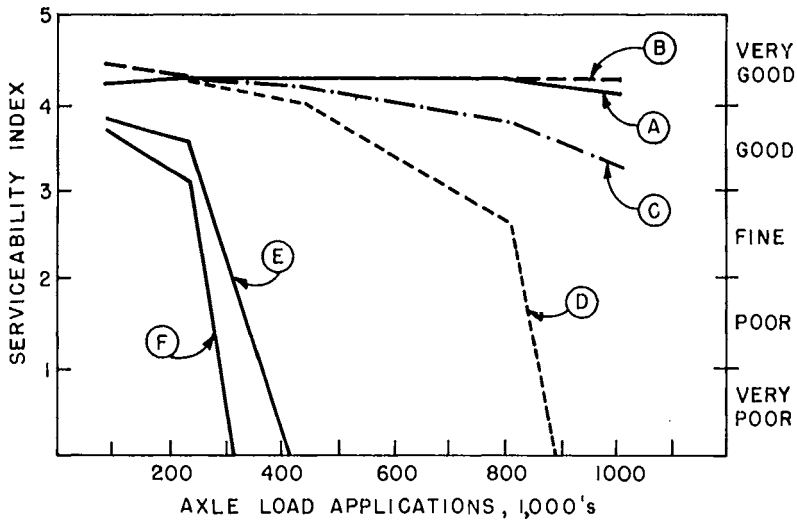


Fig. 2--AASHO Road Test performance of 5-in. (12.7 cm) concrete (1000 lb. or 1 kip = 453.6 kgf)

- | | |
|--------------------------------|----------------------------------|
| (A) 2,000 LB. AXLE (7 SECT.) | (D) 24,000 LB. TANDEM (8 SECT.) |
| (B) 6,000 LB. AXLE (7 SECT.) | (E) 18,000 LB. AXLE (8 SECT.) |
| (C) 12,000 LB. AXLE (8 SECT.) | (F) 32,000 LB. TANDEM (8 SECT.) |

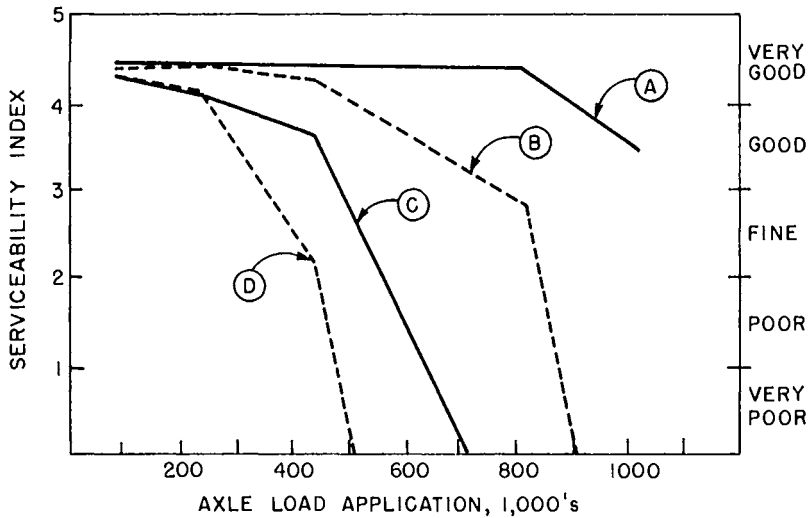


Fig. 3--AASHTO Road Test performance of 6-1/2 in. (16.5 cm) concrete (1000 lb. or 1 kip = 453.6 kgf)

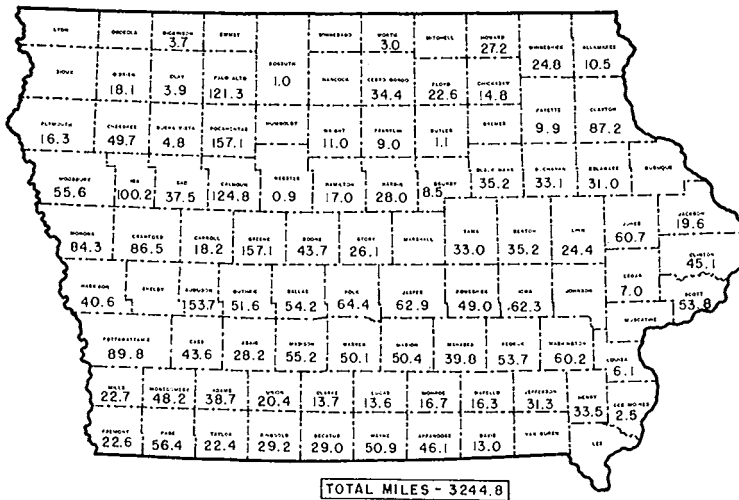


Fig. 4--Miles of concrete paving in Iowa counties at end of 1973
(1 mile = 1.6 km)

- (A) 18,000 LB. AXLE (8 SECT.) (C) 22,400 LB. AXLE (6 SECT.)
(B) 32,000 LB. TANDEM (8 SECT.) (D) 40,000 LB. TANDEM (6 SECT.)

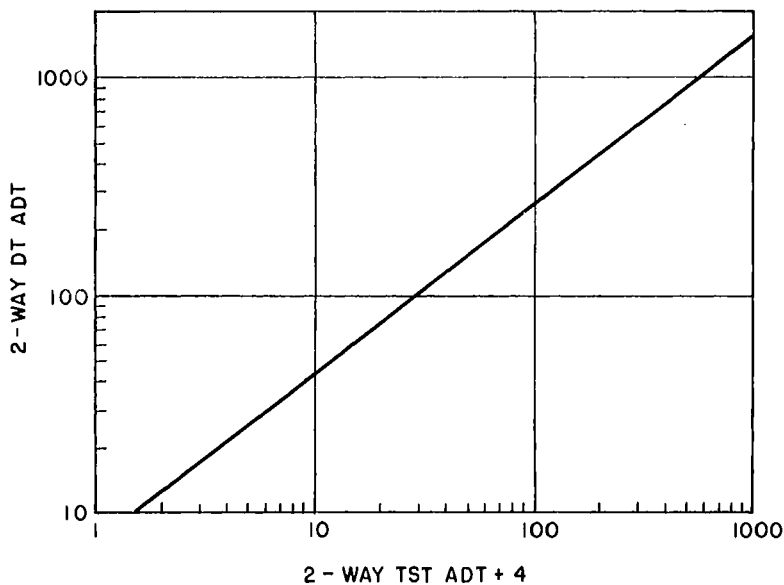


Fig. 5--Traffic relationship of two-way tractor semitrailer and combination trucks to all dual-tired trucks

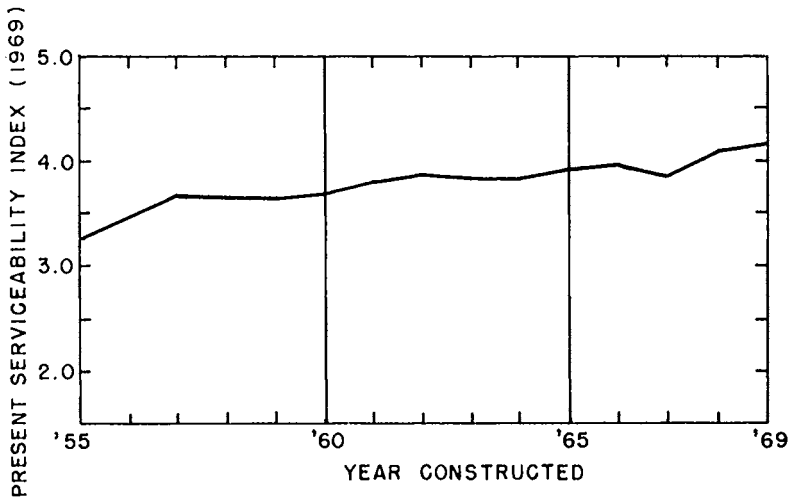


Fig. 6--Average PSI of concrete county pavements in Iowa

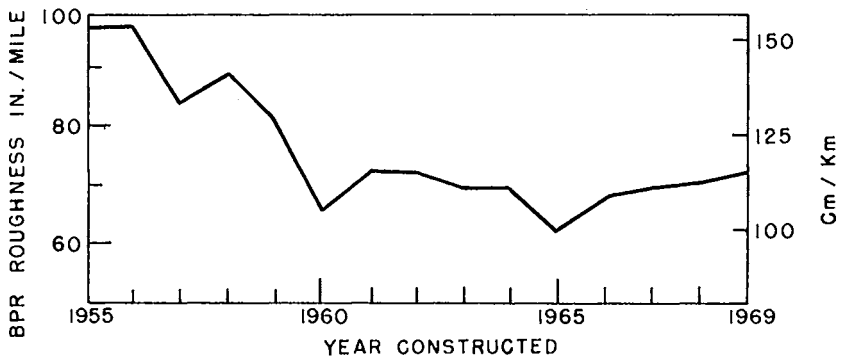


Fig. 7--Average as-constructed BPR roughness of concrete pavements in Iowa

SP 51-2

Looking To Stretch That Dollar

By
Robert E. Menard

Synopsis: With increases in revenues not keeping pace with the demand for more and safer roads Engineers at the Macomb County Road Commission sharpened their pencils and tailored their concrete pavements to meet individual project needs. Weighing maintenance problems and evaluating performance on existing pavements in the area, current pavement design practices were modified to reflect local experience and a bold and economical design was evolved.

Keywords: concrete construction; concrete pavements; construction costs; economics; deterioration; loads (forces); maintenance; performance tests; slip-form construction; subbases; structural design.

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Robert S. Menard received a bachelor of science degree from Michigan Technological University and is a registered professional engineer in the State of Michigan. Previously employed in the Construction Division of the Michigan Department of State Highways, and as Director of Engineering with the Macomb County Road Commission, the author is now employed as Engineer with the Marquette County Road Commission.

Just how does a County Road Commission provide a burgeoning population with an adequate road system? . . . Macomb County, the third most populace of the 83 Counties in Michigan is currently wrestling with that problem.

The purpose of this presentation is to demonstrate the evolution of a concrete pavement design intended to provide for more efficient use of construction funds. Some local history along with a chronological review of recent construction programs is provided so that the design changes that were initiated can be more fully appreciated in the light of the contributing problems.

For all practical purposes, Macomb County, in 1950, was basically rural having a total population of 185,000 and a typical rural road system. With the building boom of the late 1950's, brought on by industrial development and the swing to suburban living, the County was suddenly faced with the problems of urbanization. In the past 23 years, the population has more than tripled and currently numbers approximately 650,000.

The distribution pictures according to the 1970 census shows the southern 1/3 of the County to be highly urbanized and to contain 87% of the population. The upper 2/3 is basically rural-agricultural, embracing several small communities. It is projected that by 1990, the current population will double and the middle 1/3 of the County will yield to urban sprawl.

The Road Commission has responsibility for approximately 1200 miles of primary and local roads, 222 bridges and 749 major drainage structures. The bulk of the bridges and drain structures date back to the turn of the century and were designed to handle farm to market loads. Suddenly called upon to stand up to the rigors of rampant industrial, commercial and residential development many were severely damaged and failed.

Closures due to failure or advanced deterioration occur frequently resulting in discontinuities in the highway network. Many of the bridges, though able to carry the loads, are too narrow and lack the various features necessary to safely handle today's traffic volumes.

The problem is a double barreled one; that is, to develop the primary roads in the areas of most rapid growth to provide higher

capacities and safety features while attempting at the same time to complete and upgrade the primary road grid system in the outlying areas to provide for efficient cross county travel.

The ability of the Road Commission to provide an adequate modern highway system was and is continuously losing ground to the rapidly expanding needs. This inability to keep pace, in the final analysis, reduces to a lack of DCIARS.

The current complications presented by the energy crisis compounded by the soaring costs of labor, material and right-of-way have seriously reduced the mileage that can be squeezed out of the construction dollar.

Looking to stretch that dollar, the Road Commission turned to those economies in total pavement design available with portland cement concrete.

In the 60's, the pavement design for primary roads in Macomb County was substantially patterned after the traditional Michigan Department of State Highways design which:

1. Consisted of 9" uniform pavement with mesh reinforcement,
2. Allowed for hand finished joints on 71'-2" centers,
3. Required load transfer devices in both contraction and expansion joints and allowed the use of hot poured rubber joint sealant,
4. Generally specified standard curb and gutter sections.

The revenue pinch, while it always existed to some degree, had a special impact in the Fall of 1969 when the following year's program commitments far exceeded available funds. It was here that the conservative, traditional pavement design first came under fire.

The major project for 1970 was for three miles of five-lane pavement with curb and gutter. The first change was to eliminate the pavement reinforcement and shorten the spacing of contraction joints to 18'. All joints were specified to be sawed and filled with hot poured rubber-asphalt type sealer. The load transfer devices in the contraction joints were also eliminated, relying on aggregate interlock in the shorter slabs to prevent faulting. A further deviation from tradition was to specify integral curb and gutter.

The specification called for a monolithic section with the curb to be extruded on the struck off and consolidated pavement.

Based on average unit prices at that time, elimination of the pavement mesh and doweled construction joints saved \$155,000.00. The industry further responded to this design by bidding the pavement, including the integral curb, at \$0.61/Syd. less than the previous year.

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The following year - - 1971 - the major project was only slightly smaller . . . around 75,000 Syds. The only variation in design from the previous year was to saw the contraction joints on a skew of one foot in six feet. Although prices were a little higher, the increase didn't reflect much more than the prevailing inflationary trend.

The two major jobs for the year 1972 consisted of widening existing pavement from two to five lanes and totalled approximately 45,000 Syds. The jobs were packaged and let to one contractor. It was hoped to reduce overall inspection costs by combining the two jobs and also result in lower unit costs because of the total volumes.

Innovations for the year included integrally slipping a curb and gutter section with eight inches concrete base course and the experimental use of a treated subbase - - pozzolanic concrete.

The "pozzo base" was introduced experimentally on sections of the first of the two jobs to start because of its availability, promising features and competitive cost. Five inches of the material was substituted for the traditional ten inch granular subbase structure and attendant underdrain system. The characteristics of the material appeared so favorable that it was substituted entirely on the second job at a savings of approximately \$15,000.00.

The 1973 program totalled 166,000 Syds, incorporated all the changes in design mentioned so far and included another project designed and bid with the pozzolanic concrete base.

The shortage of critical construction materials, anticipated wage settlement problems with the various construction trades and fuel shortages combined to indicate 1974 construction costs would be out of sight. Early bidding reflected the uncertainty of the situation in costs running from 20 to 40% over last year. This presented a grim setting for Macomb County's program this year, the biggest ever, consisting of approximately 200,000 Syds, on four major projects.

The search for savings was directed at the only area not exploited so far in the total pavement design, that being the thickness of the slab. It is here that the major modifications were made this year.

Using the design procedure outlined in the County Road Association Road Design Manual and employing a 6 inch cement treated subbase or equivalent, the pavement thickness was analyzed for the 20-year projected traffic of 40,000 vehicles per day with a standard 10% truck split. Assuming CBR's as low as three and even doubling the truck traffic, it was found that a seven inch pavement would do the job.

Both the Federal Highway Administration and the Michigan Department of State Highways approved the design. Some of the factors contributing to the acceptance of the design were:

1. A reduction in pavement materials by 22%.
2. A reduction in fuel consumption by elimination the need for 1 out of every 5 batch trucks and 3 out of every 10 earth haulers.
3. Reducing the total section from 19 inches (9-4-6) to 13 inches minimizes the conflict with existing utilities such as gas service leads.
4. Conservation of quality granular materials.
5. An overall reduction in complete project time.
6. A reduction in the number of project personnel necessary to effectively administer a project.

The major jobs were set up to include a 6 inch plant processed cement or lime pozzolin treated aggregate. A seven inch plain concrete pavement was specified with undoweled skewed joints on 15 - 18' centers. The option to pave the curb and gutter separate or integrally was offered.

The projects were bid in June, unfortunately prices do not reflect the savings for the thinner section. This can be attributed to many factors, two of the most significant being the hard cold reality of inflation and a very difficult and restrictive construction schedule. It has been suggested that the cost of the tight construction schedule was buried in the most reliable and relatively large contract quantity, that being the concrete pavement.

One can only speculate on what savings might have been realized had the economic climate been more favorable and the construction schedule less demanding but on one point there appears to be general agreement . . . savings can and will result from less conservative designs tailored to satisfy the specific traffic requirements of individual projects.

In summary, what does this all add up to? . . . For the construction years 1970 thru 1973 considering only the elimination of the pavement reinforcement and doweled contraction joints, it has meant a savings of approximately \$580,000.00. Using 1973 costs, this translates into 5.3 lane miles of urban type primary roads.

Toss in the savings from the use of stabilized base and from the reduction in pavement thickness and Macomb County will have - "Stretched that Dollar" - into additional miles of concrete pavement.

SP 51-3

Road Design Manual: The Beginning

By
William C. Balfour

Synopsis: A presentation explaining the problem of Michigan county engineers in road construction. This problem was caused by a combination of vastly increased demands for road construction and the difficulties incurred by the interstate highway system documentation and tight specification requirements. This presentation explains the procedure followed by a subcommittee of the Michigan County Road Association in attempting to provide a design procedure that would correlate concrete and asphalt designs, utilize local materials, all with reasonable controls and costs. The results - the first printing of the "Road Design Manual" and the start of a common design language.

Keywords: concrete construction; concrete pavements; construction costs; construction materials; highways; roads; specifications; structural design.

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INTRODUCTION

In Michigan, in the late 1960's, our state highway system was undergoing a period of major growth and expansion. Not only was construction rapidly proceeding on the interstate system of limited access highways, but the counties and cities were undergoing a great increase in construction of roads and subdivision street mileages.

This increase of road construction was creating a growing shortage of specification materials used in the then prevalent designs resulting in a growing search for new methods of construction. Engineers were, consequently, looking for means of treating sub-standard materials, and, in addition, were looking for means of using different types of materials and designs. The Engineers were being assisted in their search by the many contractor and supplier organizations that were encouraging the use of the procedure or product which they were representing.

Discussion

The concrete paving proponents were advocating many variations in the method of constructing concrete pavements, such as: paving for city and county use without reinforcement, pavement placed directly on a compacted, existing subgrade, utilizing integral curb when curb was desired, and generally, using the very minimum of "added" items. In essence, they were strongly advocating just "plain" concrete pavement. This was also the beginning of the use of the so-called "Black Base" procedure advocated by the asphalt paving proponents. The asphalt proponents matched or exceeded the variations advocated by the concrete people.

Due to this great expansion in the interstate system, especially in the metropolitan areas, the cost of all paving materials, and the ability of the contractors to provide the trained manpower and necessary equipment, had significantly increased the overall cost of any paving program. The demand for an improved all weather roadway system was being felt, but the engineer was faced with an almost impossible task. How was he to determine the proper width, thickness and other details necessary for a roadway section that would provide the maximum all weather roadway with the longest life for the least money? The engineer was frequently challenged about his judgement on cost and durability by the individual contractors, suppliers, associations, his superiors and the taxpayers. How was he to provide a reasonable comparison between a concrete pavement, an asphaltic pavement or any other alternate section?

The need for some method of comparing materials became more and more evident as cities and counties made their individual decisions about what type of roadway to build, and frequently, were later faced with either a poor or failing section or an exorbitantly priced road. As these difficulties increased and became more readily apparent, the County Road Association of the State of Michigan decided to formulate some basic methods of comparison.

To this end, a subcommittee was appointed. This subcommittee was charged with attempting to formulate some equivalent road base designs, and then some uniform standards for the use in the agreed upon road base designs. The individual county engineer, upon having the basic sections established, could then apply his own local cost evaluation and decide on the method most suitable for his use.

The subcommittee attempted to meet with all of the related paving and supplier organizations, including: Portland Cement Association, Michigan Concrete Paving Association, National Asphalt Paving Association, Michigan Asphalt Paving Association, Chicago Testing Laboratory, Inc., California Highway Department, Illinois Highway Department, Minnesota Department of Highways, and Michigan Department of State Highways. We would like to thank all of these organizations for their interest, help and cooperation.

To further explain the problem facing this subcommittee, I should give a brief outline of some of the additional problems engineers in Michigan were encountering. In Michigan, in addition to each city having some form of independent street department, we have 83 separate counties, each with its individual road commissions and procedures. While all of these road commissions and road departments tend to be governed by the basic specifications published by our Michigan Department of State Highways, each organization has its own special problems of material supply, contractor availability, financing - and a certain desire to do things their own way. Thus, all of these organizations have a tendency to utilize local materials, local contractors and, generally, build a roadway at considerably less than so-called "Interstate" standards - which was where the highway department was putting most of its emphasis.

To aggravate this already difficult problem, the Michigan Department of State Highways, with its great emphasis on the interstate system, has tended to become very "documentation conscious". This policy tended to preclude the use of anything but the highest type of materials and procedures, thus, leaving almost no room for any new, experimental procedure or material.

After many meetings, reviewing volumes of literature and a mass of opinions and information, the subcommittee decided that the California method of design, adjusted to Michigan Department of State Highway basic material specifications, was the procedure that seemed to be most supportable.

Using the "Hveem" method of equating traffic conditions, existing soil conditions and other related information, as prescribed in

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the California Highway Departments "Road Base Design Method," cross referenced to utilize procedures of the Michigan Department of State Highway specifications for materials, the subcommittee felt we would have a valid, workable comparison theory.

The subcommittee felt that while this theory was valid, it remained to be tested. Consequently, the subcommittee decided to make a series of test computations and samplings to see if the results would be in line with current experience.

The respective paving associations were also asked to make a set of check calculations using any method for comparison with the subcommittee theory they desired. All of the respective paving associations had been working closely with our subcommittee and were thoroughly familiar with our procedure.

These calculations were made and compared. While differences did exist, the results were of such basic agreement that approval of the subcommittee procedure was received from all of the respective paving associations.

The sampling was then elaborated so that we could prepare a series of graphs utilizing these values for concrete pavement, bituminous aggregate pavement, and bituminous concrete pavement. The design chart for concrete pavement is shown in Fig. 1.

These graphs can be used to solve a great number of problems. The county engineer, having certain basic information as soil characteristics and proposed traffic estimates, will be able to establish specific details of depth for either portland cement concrete or bituminous pavement. The dollar value to the section application can now be made using current local cost analysis.

(Note: If the engineer desires an in-depth, individual computation, the information and procedures were included in the manual.)*

While this has been a quick review of a procedure we have undertaken in Michigan, I wish to repeat:

- (1) We had a problem.
- (2) We recognized this problem.
- (3) We found an acceptable solution.
- (4) We attempted to sell our solution.

With this "theory" now in print in the form of a "County Road Base Design Manual", we then set out to inform all our county engineers and contractors of our work and attempt to get them to both accept our results and to utilize our manual as a tool for road design.

* The County Road Association of Michigan, Road Design Manual (P.O. Box 487, Lansing, Michigan 48902, January, 1973.) Cost: \$5.00 per copy.

The method of approach was to introduce our manual as a part of a working session at the annual Michigan County Engineers Workshop.

This procedure was followed and a most spirited discussion was involved. The general feeling of those involved was that the presentation was successful.

An additional method of introducing our manual to the Michigan concrete paving contractors, their supervision, and other engineers of our cities, counties and state was by an informational presentation made at the annual Michigan Concrete Paving Association Annual Workshop.

This program was an attempt to inform the respective contractors and engineers that a standard guide was available and was a source document that was being utilized so they could make their own individual decisions on appropriateness of any design they are requested to construct. The general comment at that meeting was of concurrence with the design manual and a hope that all parties could benefit from this guide.

Conclusion

In conclusion, our respective paving associations have concurred with our findings which are an initial part of our Michigan County Engineers Design Manual. We wish to emphasize that, as we state in the design manual " the subcommittee wants it to be clearly understood that as a committee, they do not want to take credit for any data, documentation or procedure, all of which were first proposed, tested and researched by national trade associations, universities, and state highway departments, and in particular, the California Division of Highways. In summary, it can be said that the main function of the subcommittee was to serve as a catalyst in bringing various elements of the highway industry in Michigan together to seek a common design language.

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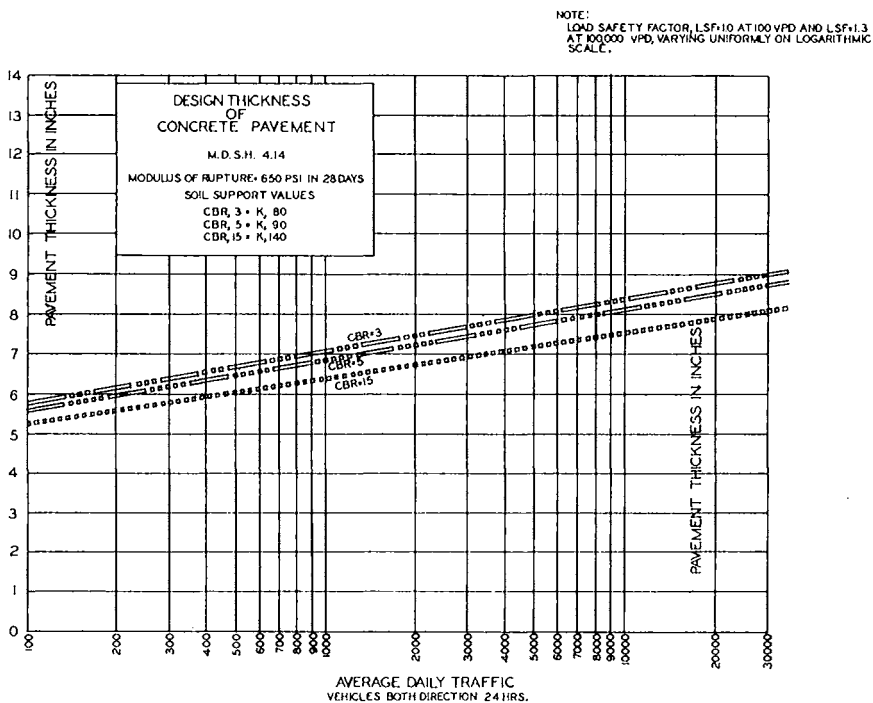


Fig. 1--Design chart

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Rigid Pavement Design Charts Based On A Finite Element Analysis

By
Michel Sargious and Sue K. Wang

Synopsis: The finite element method is used to determine the stresses and deflections in rigid pavement slabs of finite size, for both central and edge loading conditions. The main variables considered are the thickness of the slab, the modulus of elasticity of the subgrade, and the values of the load and tire pressure.

For the central loading case, the subgrade is treated as an elastic continuum. However, for the edge loading case, a Winkler's type model is assumed.

The results are presented in the form of simple design charts which relate thickness to stresses. These charts are for the case of single loads with different values of tire pressure and for different subgrade moduli. If the equivalent single wheel load concept is applied, the use of the charts can be extended to the cases of dual and dual tandem wheel assemblies.

For the case of edge loads, new charts are developed in this research program for converting dual or dual tandem wheel loads to equivalent single wheel edge loads. Similar charts are available in the literature for the case of central loads only.

Keywords: airports; axle loads; concrete pavements; concrete slabs; deflection; finite element method; foundations; loads (forces); modulus of elasticity; Poisson ratio; research; stresses; structural analysis; subgrades.

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Sue K. Wang is a Research Assistant of Civil Engineering. She obtained her B.Sc. degree in 1967 from the Department of Civil Engineering, Chu Hai College, Hong Kong, and her M.Sc. degree in 1967 from the Civil Engineering Department of the University of Calgary. She is author and co-author of five papers in the field of pavements.

INTRODUCTION

Until now, the most widely known and generally used design charts for rigid pavements have been based on Westergaard's formulae(1) which consider a Winkler type model for the foundation. However, when a vertical load acts at the centre of a pavement, it produces deflections at the surrounding points, and the deflected surface takes the shape of a basin. For this reason the subgrade or pavement foundation is treated as an elastic continuum in this analysis, for the case of a central load. The stiffness of each subgrade element is represented by a stiffness matrix rather than by one constant stiffness coefficient, as is the case when a Winkler's type foundation is assumed. For this central loading case two charts are developed for the design of rigid pavements. A computer program, based on a method described in a previous paper(2), by the authors, is used in obtaining the values of the stresses necessary for plotting the charts. For the case of edge loads, the extent of significant deflections produced at the surrounding points by a vertical load acting at or near the edge, is rather limited. For this reason a Winkler's type model is assumed for the foundation in this case and a new chart is developed for the design of rigid pavements under edge loads.

To allow the application of the equivalent single wheel load concept to the case of edge loads, three charts are developed for this purpose. The three charts will give the magnitude of the single wheel load which, when placed at the edge of a rigid pavement, will produce the same maximum stress as that produced by two or four closely spaced edge loads representing dual or dual-tandem wheel loading systems.

METHOD OF ANALYSIS

The finite element method(3) is used to determine the maximum deflections and stresses under central or edge loads. The tire imprint area on which the load acts is approximated to an ellipse having its major axis parallel to the direction of traffic and is of length equal

to 1.6 times the length of the minor axis.

The slab is divided into rectangular elements and the foundation is considered as consisting of a series of rectangular pressure areas whose centers coincide with and remain in contact with the nodal points of the slab. To limit the size of the slab, longitudinal and transverse cuts are imposed at sufficient distance from the load (figures 1 and 2). The location of the cuts is selected after several trials which produced converging results. The rotation θ_x is taken as zero along the longitudinal cuts, while θ_y is assumed as zero along the transverse cuts.

Since longitudinal joints are capable of transferring loads only, the moment M_y is considered as zero at any longitudinal joint.

The stiffness matrix of the whole pavement system is obtained by adding the slab stiffness and the foundation stiffness(2). The stiffness matrix of the subgrade, $[K_s]$, can be obtained by inverting the flexibility matrix of the subgrade. The terms for this flexibility matrix can be calculated from the Boussinesq equation which relates vertical displacements to applied vertical force (2). For the subgrade:

$$\{P\} = [K_s'] \{w\} \quad (1)$$

where

$\{P\}$ is a column matrix of contact pressure between the slab and subgrade.

$[K_s']$ is the stiffness matrix for the subgrade multiplied by a factor which depends on the elastic modulus and Poisson's ratio of the subgrade material, and $\{w\}$ is the downward displacement of the subgrade (or slab, since both are equal).

For the edge loading case $[K_s']$ is a diagonal stiffness matrix with constant diagonal terms K_s , where K_s is the modulus of subgrade reaction. For the slab:

$$\{F\} - \{P\} = [K_c] \{w\} \quad (2)$$

where

$\{F\}$ is a column matrix of the external forces as obtained from the distribution of the wheel load, and K_c is the stiffness matrix of the concrete pavement slab.

From equations (1) and (2):

$$\{F\} = \{P\} + [K_c] \{w\} = [[K_s'] + [K_c]] \{w\} \quad (3)$$

In order to obtain the load vector $\{F\}$, the pressure underneath the tire is assumed to be uniformly distributed over the tire imprint area. This pressure is then converted to nodal point loads, by

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multiplying by the area surrounding each node. Where the tire imprint is not covering a full rectangular element, proportioning is used to determine the nodal loads.

RESULTS FOR THE CASE OF A CENTRAL LOAD

The pavement segment shown in figure 1 is used to determine the stresses and deflections in a rigid pavement for the central loading case. Constant values of 4,000,000 psi and 0.16 are assumed for the modulus of elasticity E_c , and Poisson's ratio, ν_c of the concrete. The design charts shown in figures 3 and 4 are plotted for the maximum values of the stresses f_x and f_y . These charts are prepared to cover a wide range of practical cases. The variables considered are: the slab thickness, modulus of elasticity of the subgrade soil, magnitude of the load, and tire pressure. A suitable range of values is chosen for each variable. For example, values in the range between 1,800 and 11,000 psi are used for the modulus of elasticity of the subgrade and these correspond to moduli of subgrade reaction between 100 and 500 pci approximately.

The design chart given in figure 3 is for the maximum tensile stress, f_x , in the direction of traffic, while that in figure 4 is for the maximum tensile stress, f_y , in the transverse direction. The higher stress f_x is the one which governs the design of dowelled plain concrete and continuously reinforced concrete pavements. However, in the design of prestressed concrete pavements, high frictional stresses occur in the longitudinal direction and the longitudinal stress f_x becomes the governing stress due to load in the design.

The method of using the charts in figures 3 and 4 is indicated by the arrowed lines in both figures. The charts can either provide the pavement thickness, if the allowable concrete stress is known, or give the stress in a concrete pavement of known thickness.

RESULTS FOR THE CASE OF EDGE LOADS

The section of pavement shown in figure 2 is used to determine the stresses and deflections in a concrete pavement having $E_c = 4 \times 10^6$ psi and $\nu_c = 0.16$, under edge loads. The chart shown in figure 5 is plotted for the maximum stress, which occurs along the free edge at the point of tangency with the elliptical tire imprint.

In the analysis a suitable range of values is chosen for the slab thickness, modulus of subgrade reaction, magnitude of the load and tire pressure.

The arrowed lines in figure 5 illustrate the use of the chart in determining the pavement thickness if the allowable concrete tensile stress is known, or in checking the stress in a pavement of known thickness.

THE EQUIVALENT SINGLE-WHEEL EDGE LOAD

To the authors' knowledge, there are no charts available in the literature for determining the magnitude of a single-wheel load which, when placed at the edge of a rigid pavement, will produce the same maximum stress as that produced by two or four closely spaced edge loads. These edge loads can represent dual and dual-tandem wheel assemblies. The use of the existing charts for the central loading case, in determining the equivalent single-wheel load for an edge loading condition, can produce intolerable errors. For this reason three new charts are developed in this study to overcome this problem.

Figure 6 shows the pavement segment, the finite element mesh, the boundary conditions and the wheel locations which are considered in determining the equivalent single-wheel edge load. The chart shown in figure 7 is then plotted to determine the equivalent single-wheel edge load for dual wheel assemblies while the charts of figures 8 and 9 are for dual-tandem wheel assemblies. For the case of dual-tandem wheel assemblies, the two axles may produce stresses of opposite sign at the location of maximum stress, if the spacing between the axles is large and/or the radius of relative stiffness is small. In all cases covered by this study it has been found that the maximum stress occurs at the point of tangency of an outer wheel with the free edge.

Two examples are given hereafter to illustrate the use of figures 7, 8 and 9, and to show the errors that can be expected if the charts for the central load are used to determine the equivalent single-wheel edge load.

Example 1: Dual Wheel Loads

<u>Given:</u>	Truck axle load	= 18 kips
	Load on the dual wheels on each side	= 9 kips
	Tire pressure	= 60 psi
	Spacing between dual wheels on each side s (center to center)	= 14 in.
	Slab thickness h	= 7.0 in.
	Modulus of subgrade reaction k	= 200 pci
	Modulus of elasticity of the concrete E	= 4,000,000 psi
	Poisson's ratio of the concrete ν	= 0.15

Required: Value of the equivalent single-wheel load.

Solution: $\ell = 27.65$

$$\frac{s}{\ell} = \frac{14}{27.65} = 0.506$$

$$A = \frac{9000}{60} = 150 \text{ sq. in.}$$

$$\frac{A}{\ell^2} = \frac{150}{27.65^2} = 0.196$$

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From the chart in figure 7:

$$\frac{\text{Dual Wheel Load}}{\text{Equivalent Single Wheel Load}} = 1.27$$

$$\text{Equivalent Single Wheel Load} = \frac{9000}{1.27} = \underline{7090 \text{ lbs.}}$$

If the chart for the central loading case is used, then:

$$\frac{\text{Dual Wheel Load}}{\text{Equivalent Single Wheel Load}} = 1.19$$

$$\text{Equivalent Single Wheel Load} = \frac{9000}{1.19} = \underline{7560 \text{ lbs.}}$$

Example 2: Dual-Tandem Wheel Loads

<u>Given:</u>	Load on one main undercarriage assembly of a large aircraft	=	161,000 lbs.
	Tire Pressure	=	195 psi
	Spacing between dual wheels S	=	31.25 in.
	Spacing between axles S_T	=	61.25 in.
	Slab thickness h	=	12.0 in.
	Modulus of Subgrade reaction k	=	300 pci
	Modulus of elasticity of the concrete E	=	4,000,000 psi
	Poisson's ratio of the concrete ν_c	=	0.15

Required: Value of the equivalent single wheel load

Solution:

$$\frac{S}{\ell} = \frac{31.25}{37.44} = 0.83$$
$$\frac{S_T}{\ell} = \frac{61.25}{37.44} = 1.63$$
$$A = \frac{161000}{195} = 825 \text{ sq. in.}$$
$$\frac{A}{\ell^2} = \frac{825}{37.44^2} = 0.59$$

From the chart in figure 9, by interpolation:

$$\frac{\text{Dual Tandem Wheel Load}}{\text{Equivalent Single Wheel Load}} = 3.87$$

$$\text{Equivalent Single Wheel Load} = \frac{161,000}{3.87} = \underline{41,600 \text{ lbs.}}$$

If the chart for the central loading case is used, then:

$$\begin{aligned} \frac{\text{Dual Tandem Wheel Load}}{\text{Equivalent Single Wheel load}} &= 2.87 \\ \text{Equivalent Single Wheel load} &= \frac{161,000}{2.87} = \underline{56,000 \text{ lbs.}} \end{aligned}$$

CONCLUSION

The charts developed in this study provide the designer with a simple and fast tool to determine the thickness of a highway or airfield rigid pavement required to carry a certain central or edge wheel load. If the load is applied on dual or dual-tandem wheels, then the equivalent single-wheel load can be obtained from the appropriate charts in the literature, for the central loading case, or in this paper, for the edge loading case.

The same charts can also be used to check the maximum stress in an existing pavement under central or edge loads.

ACKNOWLEDGEMENT

The writers wish to express their sincere appreciation to the National Research Council of Canada for their financial support.

NOTATION

x,y	horizontal rectangular coordinates
S	center to center spacing of a pair of dual wheels
S _T	spacing of axles; center to center
A	total contact area of the tires of a wheel assembly
ℓ	radius of relative stiffness and equals
	$\left(\frac{E_c h^3}{12(1-\nu_c^2) k} \right)^{\frac{1}{4}}$
E _c	modulus of elasticity of concrete
E _s	subgrade modulus of elasticity
h	thickness of concrete pavement
ν _c	Poisson's ratio of concrete
ν _s	Poisson's ratio of subgrade soil
k	modulus of subgrade reaction
f _x	maximum tensile stress in a concrete pavement in the x-direction
f _y	maximum tensile stress in a concrete pavement in the y-direction
P	wheel load
p	tire pressure

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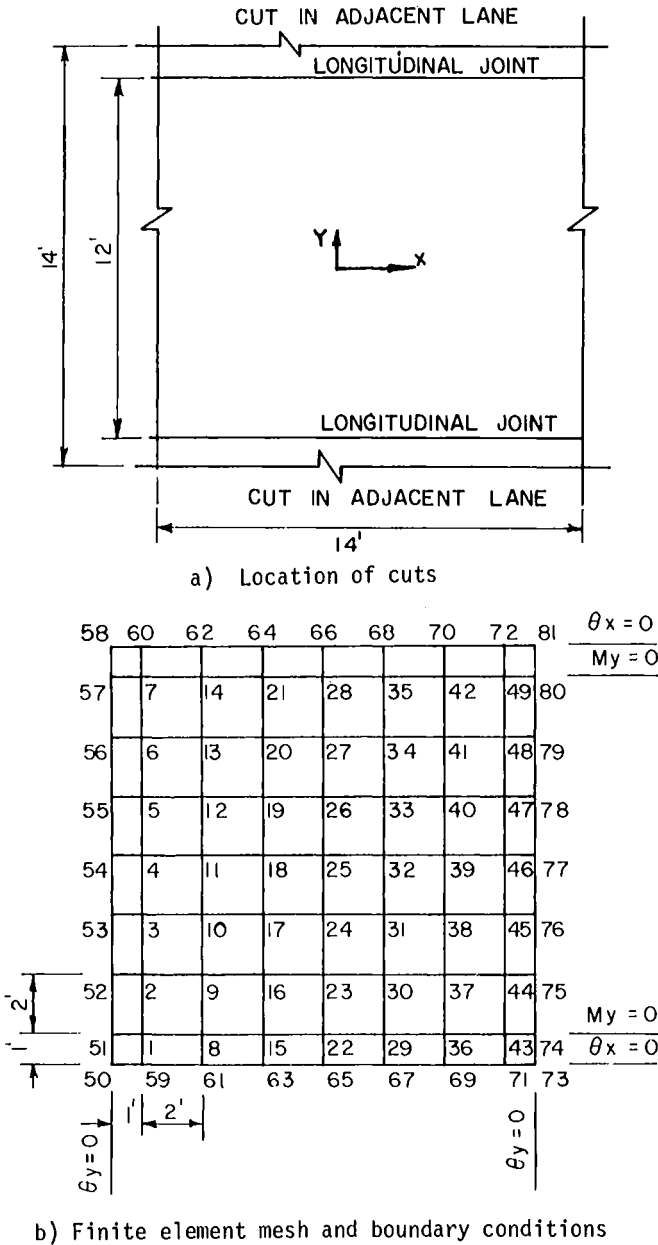


Fig. 1--Boundary conditions, location of cuts and finite element mesh for the pavement slab under central loads

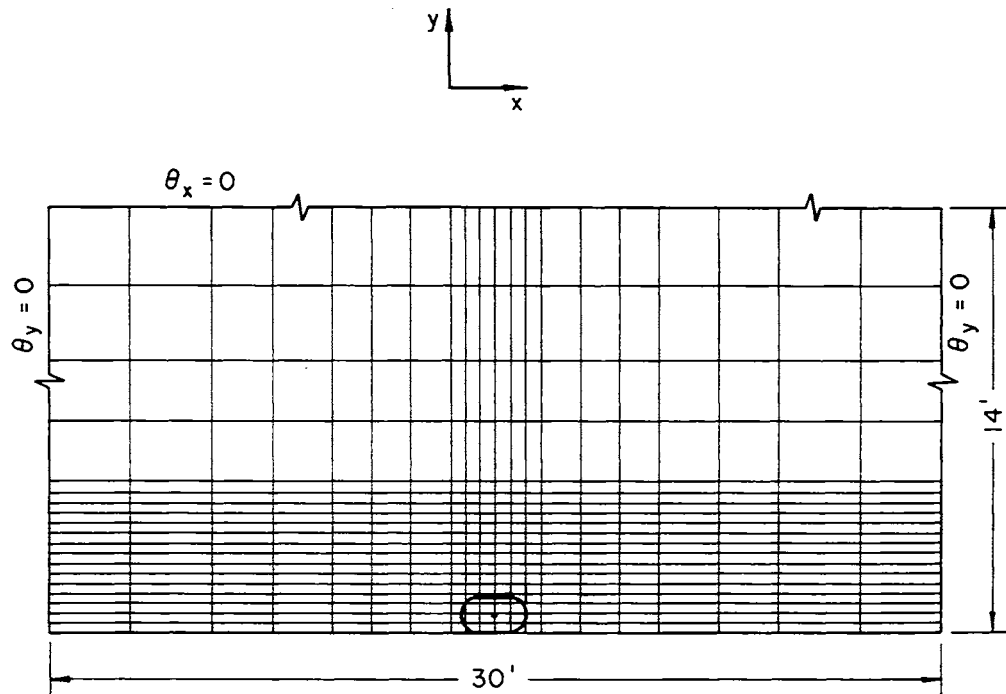


Fig. 2--Finite element mesh, boundary conditions and wheel location on the pavement slab for the case of edge load

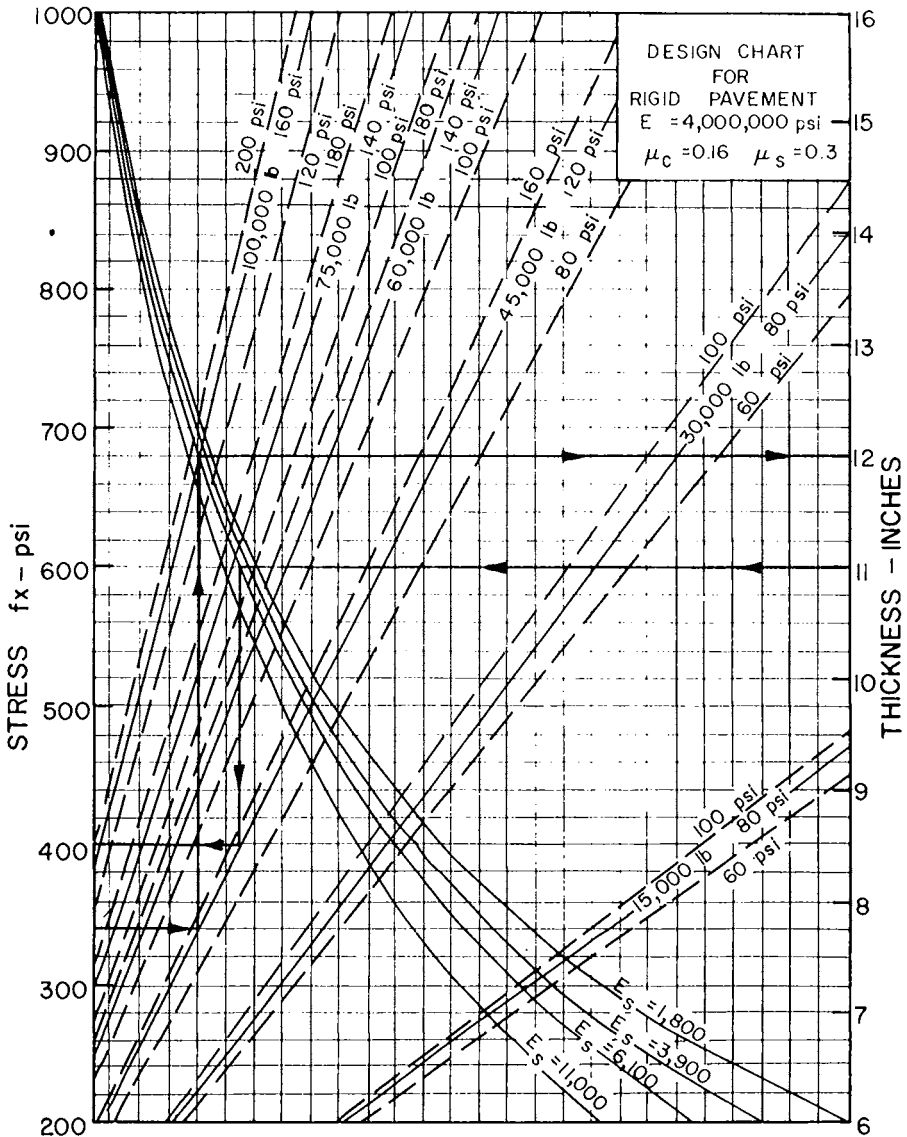


Fig. 3--Chart for determining the longitudinal Stress, f_x , due to load, for prestressed pavements design

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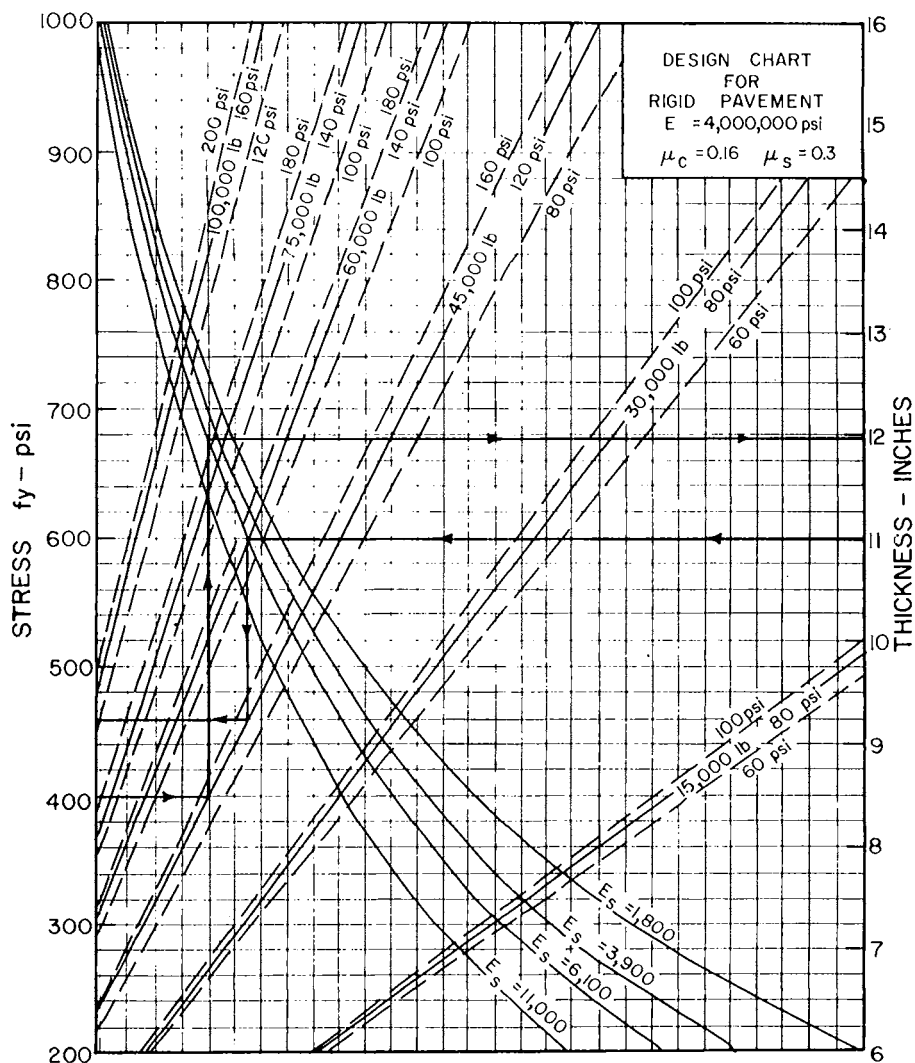


Fig. 4--Design chart for rigid pavements-case of central load

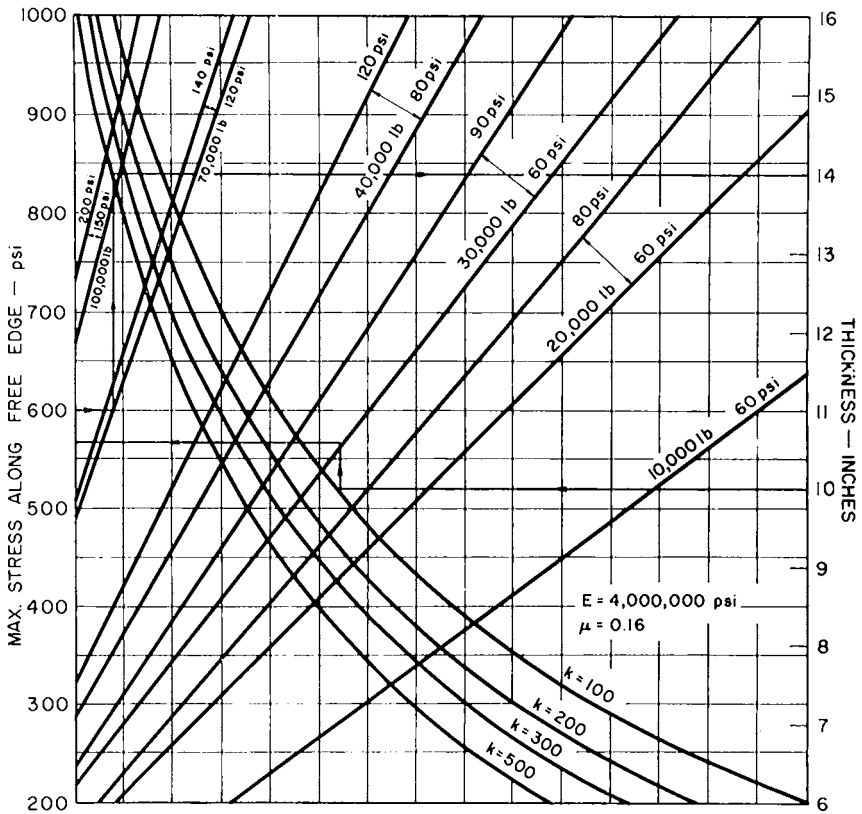
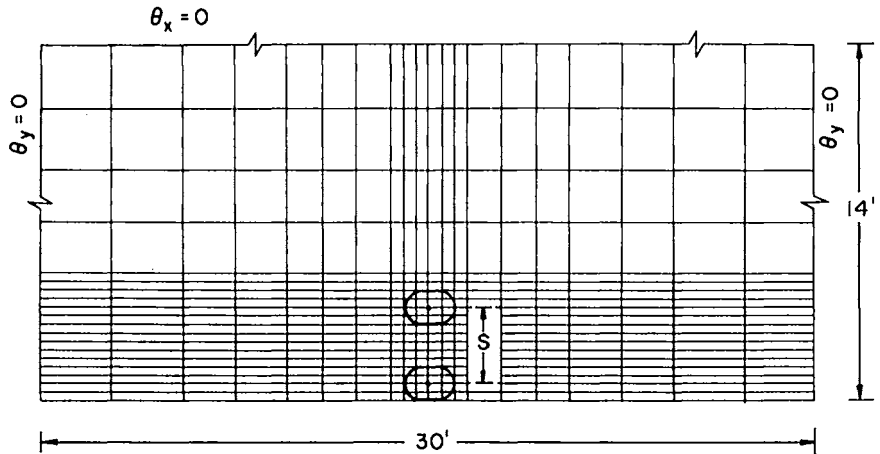
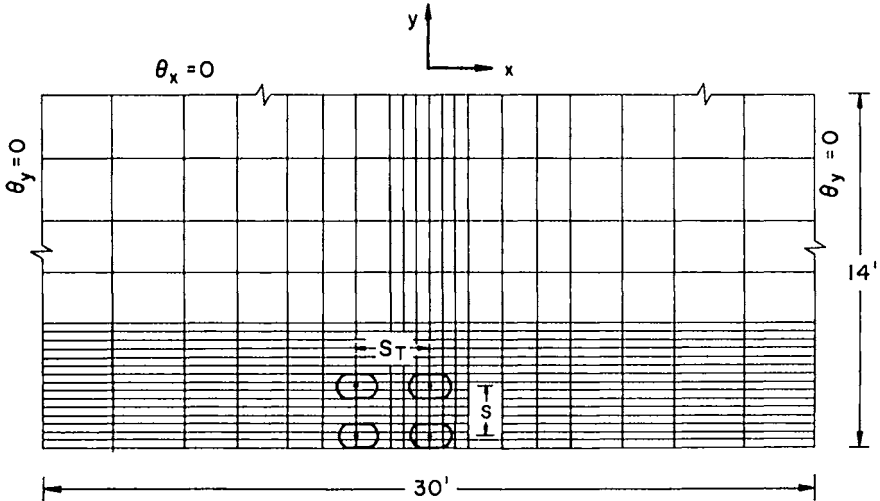


Fig. 5--Design chart for rigid pavements-case of edge load



a- DUAL-WHEEL EDGE LOADING



b- DUAL-TANDEM WHEEL EDGE LOADING

Fig. 6--Finite element mesh and boundary conditions for determining the equivalent single-wheel edge load for rigid pavements

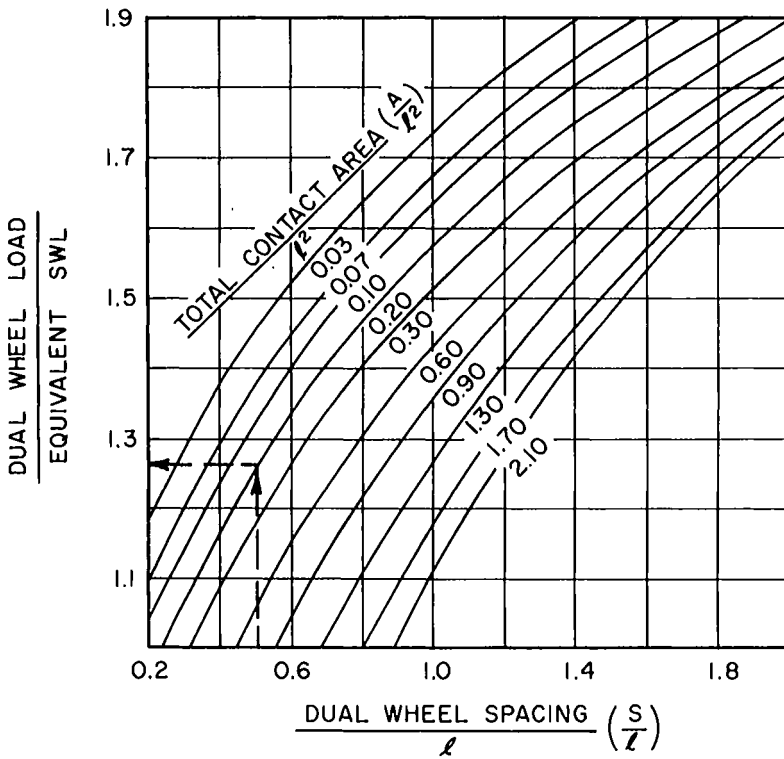


Fig. 7--Chart for determining the single-wheel edge load equivalent to dual wheel assemblies

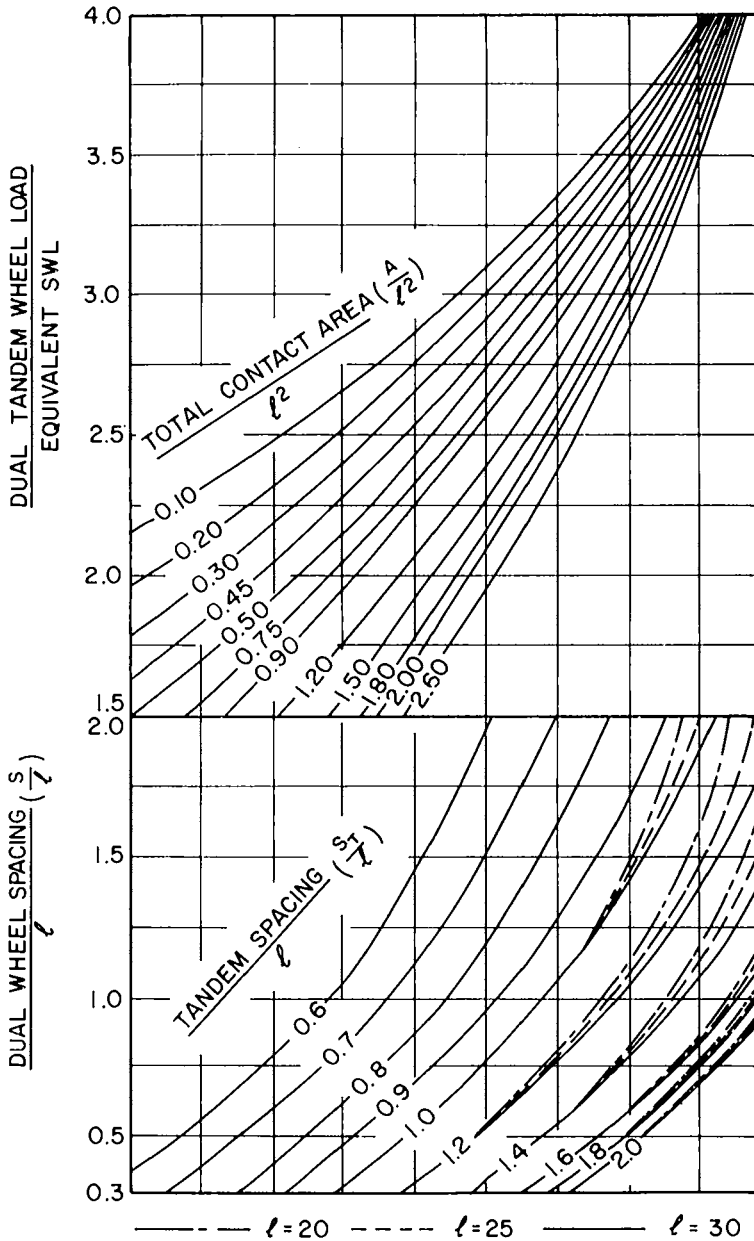


Fig. 8--Chart for determining the single-wheel edge load equivalent to dual-tandem wheel assemblies ($l=20$ to 30)

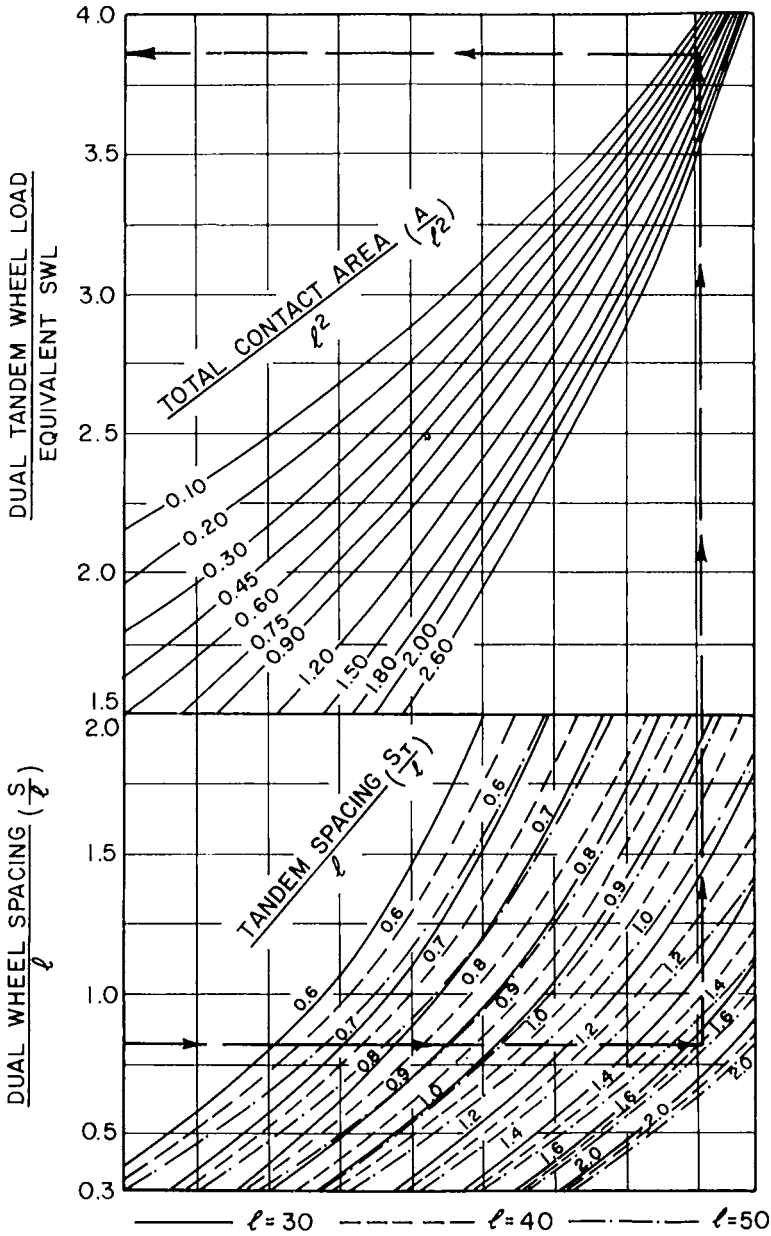


Fig. 9--Chart for determining the single-wheel edge load equivalent to dual-tandem wheel assemblies ($l = 30$ to 50)

SP 51-5

Airfield Pavement Construction: Slip Form Paving Method

By
Frazier Parker, Jr.

Synopsis: This paper presents the results of a study to evaluate the use of slip-form paving equipment for the construction of airfield pavements. Nine construction projects were observed and surface smoothness measurements were made on eight of the projects. The elimination of fixed side forms is the most appealing feature of the slip-form method, but it is also the one feature which causes the most complications. It is more difficult to form keys and keyways and to install tie bars and dowels in longitudinal construction joints without the aid of fixed forms. The free standing edges will slump to varying degrees. The smoothness measurements indicate that the deviations of the surface from a straightedge are greater along paving lane edges than they are in the interior of paving lanes. The depressions that result along longitudinal construction joints apparently do not significantly effect the functional performance of the pavement.

Keywords: airports; concrete construction; concrete pavements; construction equipment; construction materials; cracking (fracturing); deflection; dowels; joints (junctions); keys and keyways; mix proportioning; modulus of elasticity; paving equipment; performance tests; reinforcing steels; slip-form construction; taxiways; tensile strength; vibration.

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INTRODUCTION

Use of slip-form pavers for constructing concrete highway pavements began in 1949. However, the use of slip-form paving for airfield pavement construction did not begin until about 1960. During the 1960's slip-form paving was used sparingly in the United States and Europe for the construction of airfield pavements. The pavements constructed were mainly apron and taxiway pavements (1,2). In 1969, the use of slip-form paving at commercial airports began in earnest with approval being granted for its use on a number of major construction projects (3). In 1971 the Federal Aviation Administration (FAA) issued a change to their specifications for construction of rigid pavement (4) which permitted and provided guidance for the use of slip-form paving equipment.

In 1970, Corps of Engineers interest in slip-form paving was brought about by the identification of a major airfield pavement construction program and the recognition of potential savings which could be realized if slip-form pavers were used. This paper contains the results of a study to evaluate the construction of airfield pavements with slip-form paving equipment. The study consisted of a literature review and the observation of a number of paving jobs while under construction. During the field observations, current construction practices were observed and surface smoothness measurements made to access the ability of slip-form pavers to produce pavement meeting present construction criteria.

DESCRIPTION OF SLIP-FORM METHOD

Characteristics of Method

The term "slip-form paving" undoubtedly originated because the short side forms on the paver do not remain in place but move with the paver and slip along the edges of the pavement as it is formed. Initially the equipment had relatively long trailing forms as compared with todays machines. The term "slip-form" can also be thought of as applying to the top surface of the pavement as well as the edges (5), since the mechanism or form for shaping the pavement surface also moves with the paver.

In addition to these features, Gillis and Spickelmire (2) list and discuss a number of other characteristics which distinguish the method from fixed side form construction. Gillis and Spickelmire

also list six types of pavers; each of which had some distinguishing features. It is apparent that one could discuss semantics and the various processes that are used and those that have been used at great lengths. However, if the term is accepted as somewhat of a misnomer and a discussion of the characteristics of different machines delayed the general features of the method may be considered.

The term "slip-form method" may be applied to the process whereby pavement is constructed without the use of stationary side forms. In addition, modern slip-form pavers have the following characteristics:

- (a) They are self-propelled and crawler mounted.
- (b) Horizontal and vertical alignment may be automatically controlled.
- (c) The machines are capable of spreading, consolidating, and shaping the concrete to the desired cross section in one pass.
- (d) The pavement, as formed, will require only a minimum amount of hand finishing and only minor corrections in order for the surface and edges to meet required specifications.

The above listed characteristics generally apply to all currently used slip-form pavers. The two most important features are the elimination of the use of side forms and the fact that the slip-form paver forms the pavement cross section in one pass of one machine.

Types of Equipment

Presently, slip-form pavers are manufactured and marketed primarily by three companies. These are Guntert and Zimmerman Construction Division, Inc., CMI Corporation, and Rexnord, Inc. An example of the type pavers in use today is shown in Figure 1. The process whereby the concrete is shaped to the desired pavement cross section is different for each machine in some respects but similar in others.

Guntert and Zimmerman pavers form the concrete to the desired cross section by vibrating the concrete until it becomes fluid and confining it while in a maximum state of fluidity and density with a relatively large screed and side forms until it reverts back to a nonfluid state. Final surface finish is applied with pan floats. Figure 2 is a schematic illustrating the basic process in forming the pavement cross section. Since the process depends on the flow of the fluid concrete, it is important that the proper height of concrete be maintained in front of the conforming plate. If the head is too small the flow of the fluid concrete will not be adequate to fill the confined space, but if it is too large it may cause surging behind the forming plate which will result in high spots in the pavement.