DESIGN CONSIDERATIONS FOR CONTINUOUSLY REINFORCED CONCRETE PAVEMENT

Seaway Freeway, Detroit (Projects 82191 and 82194)

Research Laboratory Division
Office of Testing and Research
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At the request of C. H. Cash, Chairman of the Specifications Committee for the Seaway Freeway, this brief explanatory report has been prepared regarding design considerations influencing selection of a 9-in. pavement thickness and a 0.75 steel reinforcement percentage for the Seaway Freeway portion of I 75 in Detroit.

Selection of Pavement Thickness

Steps in determining the minimum acceptable thickness for the Seaway Freeway pavement included the following:

1. Estimation of probable traffic volume and characteristics.

2. Conversion of probable traffic loadings to equivalent 18-kip single axles, using methods developed during the AASHO Road Test.

3. Determination of the minimum pavement thickness required to carry probable traffic, also using AASHO Road Test methods.

The Department's Traffic Division estimates that maximum daily traffic traveling in one direction over the Seaway Freeway will be 40,000 vehicles, 18 percent of which will be commercial. It is assumed that approximately 90 percent of the commercial vehicles will be traveling in the highway's outer lane.

Next, using data from the 1961 Loadometer Study ("State of Michigan Annual Truck Weight Study: 1961"), for a location where traffic characteristics were similar to those anticipated for the Seaway Freeway, it was estimated that 3,170 equivalent 18-kip single axles will travel daily over one lane of the Freeway (the Appendix gives details for this computation). This estimate may be expanded to indicate an annual traffic loading of 1,160,000 equivalent 18-kip single-axle repetitions. By contrast, the traffic lane of the Department's experimental continuously reinforced 8-in. pavement, constructed as a segment of I 96 near Portland, carries an average daily loading of 378 equivalent 18-kip single axles, or 138,000 annually (since I 96 near Portland is in a rural area, it may be assumed that 95 percent of the commercial traffic travels in the outer lane).

Finally, AASHO Road Test methods were used to estimate the thickness required to carry Seaway Freeway traffic. Because the AASHO Road Test spanned a period of only two years, it has been shown that its results must be modified by a "time factor," when used to predict the performance of conventional highways with significantly longer life spans. In most cases, a conventional pavement slab deteriorates considerably faster than predicted by AASHO Road Test results. For example, Fig. 1 shows that as a function of traffic loading, conventional 10-in. thick rigid pavement slabs located in Illinois deteriorate at the approximate rate predicted by AASHO methods for pavements 6 to 7 in. thick [1]. However experimental results in Illinois (Figs. 2 and 3) indicate that continuously reinforced pavement performs better than conventional pavement of equal thickness, and therefore should perform more nearly as predicted by AASHO Road Test results.

Table 1 compares AASHO-estimated performance of the Seaway Freeway portion of I 75 with I 96 near Portland. Duplication of the 8-in. thickness used on I 96 is inadvisable since such a pavement would serve only 4 years in satisfactory condition on I 75. A 9-in. pavement would last nearly three times as long, however, and a 10-in. pavement would survive 22 years. Fig. 4 indicates the relationships between Serviceability Index, pavement thickness, and repetitions of 18-kip axle loads. Since studies have indicated that normally a Michigan pavement is resurfaced when its Serviceability Index is reduced to 2.5, this terminal value was used in these computations.

Selection of Reinforcing Steel

The selection of the proper percentage of steel was based on the "AASHO Interim Guide for the Design of Rigid Pavement Structures" (Appendix F, AASHO Committee on Design, April 1962), which states in

(1) Chastain, W. E., Sr. "Concept for Application of the Road Test Formulas in the Structural Design of Pavements." HRB Special Report 73 (1962), pp. 299-313.

part: "...for continuously reinforced concrete pavements the percentage of longitudinal steel (P_s) is determined by the formula:

$$P_s = (1.3 - 0.2 F) \frac{S_t}{f_s - N S_t} \times 100$$

where:

P_s = Ratio of area of longitudinal steel to area of concrete, in percent.

F = Coefficient of friction between pavement and subbase.

S_t = Tensile strength of concrete, psi (about 0.4 S_c, the modulus of rupture).

f_s = Allowable working stress in steel, psi.

N = E_s/E_c.

E_c = Modulus of elasticity of concrete, psi.

E_s = Modulus of elasticity of steel, psi.

"The formula is based on the following assumptions:

1. That sufficient bond area is provided to develop the full working stress of the steel.

2. That adequate load transfer is provided at transverse construction joints.

"The frictional factor (F) depends upon the surface smoothness of the subbase immediately beneath the rigid pavement. The value of F may range between 1 and 2, with 1.5 being commonly used."

The modulus of rupture for beams tested from the I 96 continuously reinforced pavement averaged 760 psi. The modulus of elasticity of concrete is generally about 5 million psi. A reasonable value for allowable working stress in steel, f_s, is 70 percent of the yield strength (60,000 psi for deformed steel bar); thus $f_s = (0.7)\ 60{,}000 = 42{,}000$ psi. Therefore,

$$P_s = (1.3 - 0.3)\ \frac{304}{42{,}000 - 1824} \times 100$$

$$P_s = 1.0 \times \frac{304}{40{,}176} \times 100$$

$$P_s = 1.0 \times 0.755 \times 100$$

$$P_s = 0.755 \text{ percent}$$

Hence, 0.75-percent steel has been selected for the Seaway Freeway pavement.

Additional Considerations

In addition to the design considerations already discussed, certain other significant practical considerations appear to justify a conservative design. From experience in repair of local areas on I 96 continuously reinforced pavement, it has been found that this type of pavement is difficult and relatively expensive to repair, in comparison with pavement of conventional construction. A further consideration in such work is the problem of traffic control during repair operations. Since high-speed traffic flow must be maintained on the Interstate System, both hazardous conditions and greater expense are involved when a lane must be closed temporarily.

APPENDIX

Computation of Number of Equivalent 18-Kip Single Axles Traveling Over Seaway Freeway

1. Information from the AASHO Road Test and 1961 Michigan Annual Truck Weight Study, was used to derive Table 2 and then Table 3.

2. The urban curve plotted in Fig. 5 (graph of 18-kip equivalent axles versus percentage of commercial vehicles) was derived from Table 3.

3. Since the Seaway Freeway has a predicted average daily traffic of 40,000 vehicles, with 18 percent of this traffic commercial, the maximum average number of equivalent 18-kip single axles is estimated as follows:

a. Using the percent commercial traffic for the Seaway Freeway (18 percent), enter Fig. 5 and obtain the number of equivalent 18-kip single axles per 1000 total vehicles (88 percent), using the urban traffic curve.

b. Assuming 90 percent of commercial traffic to be in the outermost lane, the daily number of equivalent 18-kip axles in this lane would be

$$88 \times 40 \times .90 = 3170$$

Annually, the quantity would be

$$365 \times 3170 = 1,160,000$$

The rural portions of Tables 2 and 3 and the rural curve plotted in Fig. 5 were used to estimate the number of equivalent 18-kip axles traveling over a traffic lane of I 96 near Portland. Computations would be similar to those given above.

TABLE 1
PERFORMANCE COMPARISON OF I 96 (PORTLAND) AND I 75 (SEAWAY FREEWAY)

Traffic, Load, and Performance Factors	I 96 (Portland)	I 75 (Seaway Freeway)		
Average daily traffic	3000	40,000		
Percent commercial	20	18		
Total annual equivalent 18-kip axle loads	138,000	1,160,000		
		Trial Thicknesses, in.		
Thickness, in.	8	8	9	10
Equivalent AASHO Road Test rigid pavement thickness, in. *	7 to 8	7 to 8	9	10
Total equivalent 18-kip axle loads before resurfacing required (based on AASHO Road Test data)**	5×10^6	5×10^6	13×10^6	26×10^6
Predicted life, years (based on AASHO Road Test data)	36	4	11	22

* Value based on Chastain, W. E., Sr. "Concept for Application of the Road Test Formulas in the Structural Design of Pavements." HRB Special Report 73 (1962), pp. 299-313.

** Based on Bartelsmeyer, R. R., and Finney, E. A. "Use of AASHO Road Test Findings by the AASHO Committee on Highway Transport." HRB Special Report 73 (1963), pp. 415-38.

TABLE 2
CONVERSION OF MICHIGAN INTERSTATE HIGHWAY LOADS
TO EQUIVALENT 18-KIP SINGLE AXLES

		Axle Load, lb	AASHO Equivalent 18-kip Factor for 10-in. Rigid Pavement*	Axles per 1000 Trucks & Combinations**	Equivalent 18-kip Single Axles per 1000 Truck & Combinations (to PSI = 2.5)
Rural	Single Axles	Under 3,000	0.0002	217.3	0.04
		3,000- 6,999	0.002	914.6	1.83
		7,000- 7,999	0.02	264.2	5.28
		8,000-11,000	0.08	444.0	35.59
		12,000-15,999	0.34	282.3	96.00
		16,000-17,999	0.80	199.2	159.70
		18,000-19,999	1.29	98.2	126.70
		20,000-21,999	1.98	4.3	8.52
	Tandem Axles	Under 6,000	0.001	9.0	.01
		6,000-11,999	0.01	145.6	1.46
		12,000-17,999	0.07	121.0	8.47
		18,000-23,999	0.26	101.5	26.39
		24,000-29,999	0.74	117.2	86.80
		30,000-31,999	1.32	38.0	50.20
		32,000-33,999	1.73	8.1	14.02
		34,000-35,999	2.22		
		36,000-37,999	2.80		
		38,000-39,999	3.45	1.9	6.55
				TOTAL	627.56
Urban	Single Axles	Under 3,000	0.0002	317.5	0.06
		3,000- 6,999	0.002	992.2	1.98
		7,000- 7,999	0.02	207.7	4.15
		8,000-11,999	0.08	320.9	25.67
		12,000-15,999	0.34	223.4	75.80
		16,000-17,999	0.80	132.0	105.60
		18,000-19,999	1.29	58.4	75.30
		20,000-21,999	1.98	14.1	27.90
		22,000-23,999	2.92		
		24,000-25,999	4.15		
		26,000-29,999	6.61	2.7	17.85
	Tandem Axles	Under 6,000	0.001	13.4	.01
		6,000-11,999	0.01	207.0	2.07
		12,000-17,999	0.07	43.1	3.01
		18,000-23,999	0.26	87.8	22.81
		24,000-29,999	0.74	85.5	63.30
		30,000-31,999	1.32	23.7	31.22
		32,000-33,999	1.73	13.9	24.10
		34,000-34,999	2.22	2.3	5.10
				TOTAL	485.93

* Finney, E. A., and Bartelsmeyer, R. R., "Use of AASHO Road Test Findings By the AASHO Committee on Highway Transport" HRB Special Report 73 (1962), pp. 415-38.

** "State of Michigan Annual Truck Weight Study, 1961."

TABLE 3
COMPUTATION OF EQUIVALENT 18-KIP SINGLE AXLES
PER 1000 TOTAL VEHICLES ON MICHIGAN INTERSTATE HIGHWAYS

	Commerical Vehicles			Automobiles			Total Equivalent 18-kip Single Axles per 1000 Vehicles
	Percent of Total Traffic	Per 1000 Vehicles	Total Equivalent 18-kip Single Axles per 1000 Vehicles	Percent of Total Traffic	Per 1000 Vehicles	Total Equivalent 18-kip Single Axles per 1000 Vehicles	
Rural	10	100	62.8	90	900	0.4	63.2
	20	200	125.6	80	800	0.3	125.9
	30	300	188.4	70	700	0.3	188.7
Urban	10	100	48.6	90	900	0.4	49.0
	20	200	97.2	80	800	0.3	97.5
	30	300	145.8	70	700	0.3	146.1

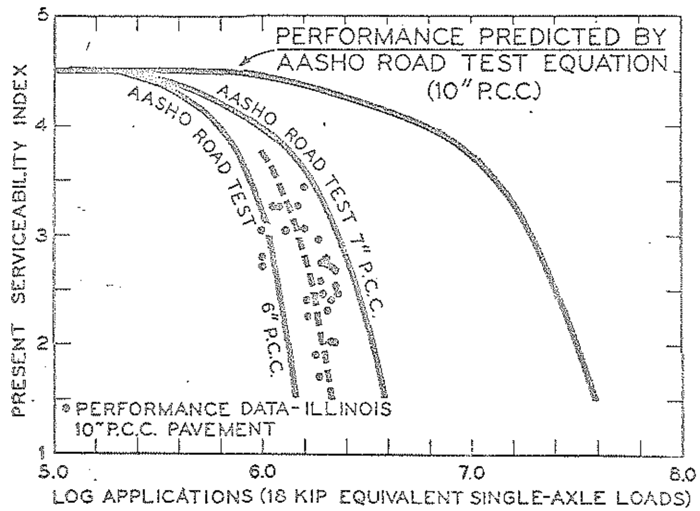

Figure 1. Performance of Illinois 10-in. PCC pavement vs predicted performance by AASHO Road Test equations (from Highway Research Board Special Report 73).

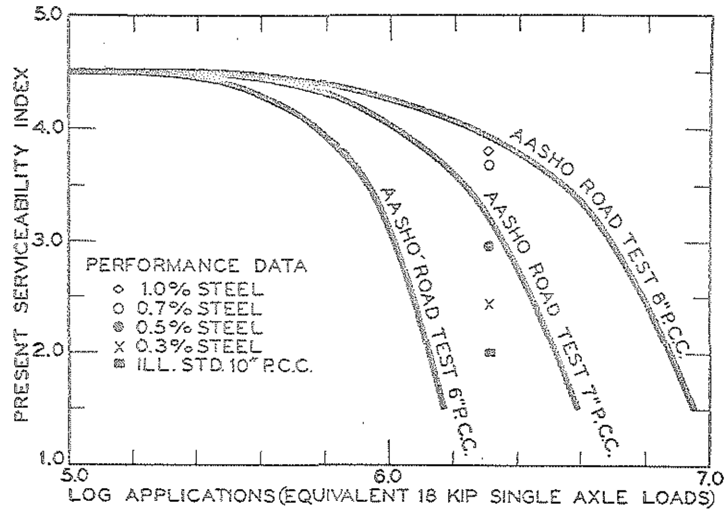

Figure 2. Performance of Illinois 7-in. continuously-reinforced PCC pavement vs Road Test equations (from Highway Research Board Special Report 73).

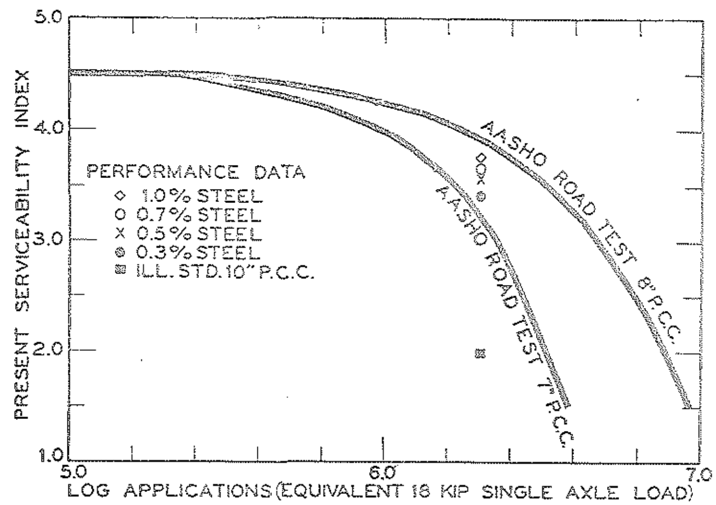

Figure 3. Performance of Illinois 8-in. continuously-reinforced PCC pavement vs Road Test equations (from Highway Research Board Special Report 73).

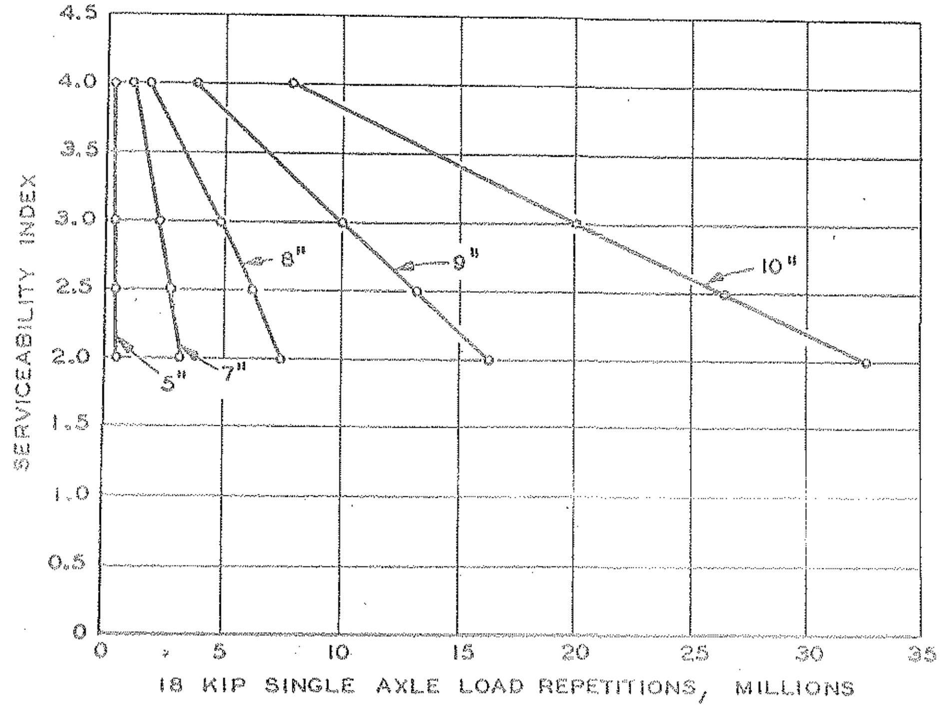

Figure 4. Relation between Serviceability Index, pavement thickness, and repetitions of 18-kip axle loads (prepared from AASHO Road Test Equations).

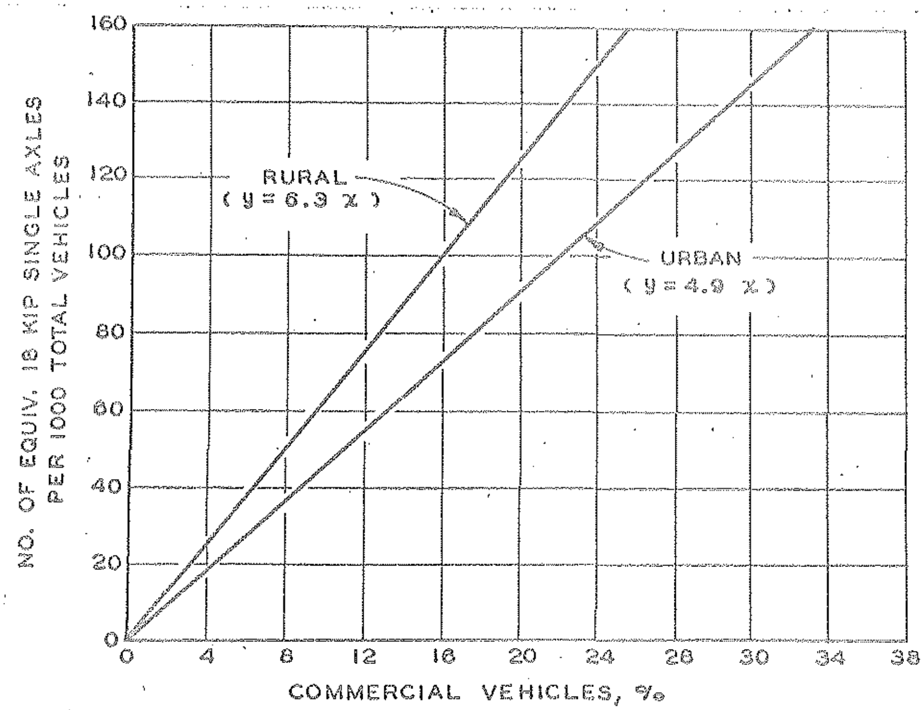

Figure 5. Relationship between percentage of commercial vehicles and total equivalent 18-kip single axle loads per 1,000 vehicles (based on 1961 Michigan Loadometer Survey).