46

MICHIGAN
STATE HIGHWAY DEPARTMENT
Charles M. Ziegler
State Highway Commissioner

REPORT #46

DESIGN RECOMMENDATION
Section 3
INDUSTRIAL EXPRESS HIGHWAY

RESEARCH LABORATORY
TESTING AND RESEARCH DIVISION
June 25, 1943

PAVEMENT DESIGN FOR SECTION 8
INDUSTRIAL EXPRESS HIGHWAY

The following recommendations for slab thickness on Section 8 of the Industrial Express Highway were arrived at by means of Westergaard's Analysis for concrete pavement design. Two types of subgrade conditions have been considered, a two foot sand subbase material on clay subgrade (K = 100 p.c.i.) and a two foot stone subbase on clay subgrade (K = 300 p.c.i.). The following design requirements and assumptions have been employed for each type of subgrade condition.

1. Pavement for Class I - II traffic conditions
2. No load transfer devices
3. No steel mesh
4. 12' width of slab
5. Dummy and contraction joint spacing as designated in calculations
6. Maximum allowable unit stress, 575 p.s.i. based on 80% of modulus of rupture. On this basis, pavement is designed for infinite life expectancy, independent of traffic. Life expectancy means crack expectancy.
7. Concrete 5,000,000 p.s.i. modulus of elasticity
8. 750 p.s.i. modulus of rupture of concrete
9. Combined temperature and load stress are considered in calculations.
10. Impact factor at transverse joint edge and free edge corner = 1.50
11. No impact factor considered for longitudinal free edge and at interior of slab.

CASE I. SAND SUBBASE

On a foundation, composed of 24 inches of sand over a soft clay subgrade with the foundation possessing an assumed modulus value "K" equal to 100 p.c.i., the pavement slab will require the thickness values shown in Table I in order that the stresses in the concrete will not exceed 375 lbs. per square inch. The modulus value of 100 p.c.i. is based on the results from actual field tests on sand material (Hillsdale) of infinite depth.

TABLE I

THICKNESS OF CONCRETE

SLAB POSITION	LENGTH OF SLAB		
	20'	15'	10'
Interior of Slab	11"	7 1/2"	5 3/4"
Transverse Joint Edge	9 3/4"	9 3/4"	9 3/4"
Longitudinal Free Edge	12 1/2"	8 3/4"	8 1/2"
Free Corner	10"	10"	10"

The calculated values for slab thickness given in Table I indicate two possibilities for slab thickness which could be considered, first for 20 foot slabs, the thickness should be 12 1/2 inches uniform, or 12 1/2" - 11" - 12 1/2" non-uniform; second, if the slab lengths were reduced to 15 feet, a 10" uniform slab thickness would suffice. A slab thickness of 10 inches will be required for a 10 foot slab length. It is to be noted that 9 3/4" and 10 inch slab thicknesses are required for the transverse joint edge and free corner respectively, irrespective of the slab length. These two thickness values may be reduced to approximately 9 inches in both instances by ignoring the 1.5 impact factor, or by providing some means of load transfer to reduce the stress in the concrete at the corner and at transverse joint edge. Since it would seem unwise to disregard the impact factor and because steel bars are outlawed for the present, it is logical then that a 10 inch thickness and 15 foot slab lengt h would be the most satisfactory section to use.

For a 10 inch uniform thickness and 20 foot slab lengths, the stresses at the interior and longitudinal free edge become 400 and 450 p.s.i. respectively. The stresses at the other points remaining the same, namely 375 p.s.i.

On the basis of what is known at present on the endurance limit of concrete under certain traffic conditions it may be expected that for a slab of 10 inch thickness, 20 foot slab length, cracks will form at the end of approximately three years.

CASE II. STONE SUBBASE

On a foundation composed of 24 inches of crushed limestone on a soft clay subgrade with the foundation possessing an assumed modulus value "K" = 300 p.c.i., the following pavement slab thicknesses given in Table II will be required. We believed that a subgrade modulus value of 300 p.c.i. is a conservative value to assume for a 2 foot stone subbase design. Considerable field work under actual conditions is necessary to establish the true modulus for such a design requirement.

TABLE II

THICKNESS OF CONCRETE

SLAB POSITION	LENGTH OF SLAB		
	20'	15'	10'
Interior of Slab	Stresses	10 1/2"	8 1/4"
Transverse Joint Edge	for all in	11 1/4"	11 1/4"
Longitudinal Free Edge	excess of	11 3/4"	7"
Free Corner	375#	9 3/4"	9 3/4"

For the stone subbase section, the figures indicate a uniform thickness of 11 3/4 inches would be required for 15 foot slabs. For a 20 foot slab length, the stresses in all four slab positions are greater than 375 p.s.i.

The analysis indicates that a thicker slab will be required for a stone subbase than for a sand subbase or in other words, a stiffer subbase will require a thicker slab. This phenomenon is due to the fact that the temperature stresses in a slab tend to rise with the increase in rigidity of the subbase as illustrated by the work of Westergaard and the Public Roads Administration. This may be explained by considering the change in the bending moment of a curled piece of material, first when it is placed on a rigid support which provides practically a point contact, and second when the same material is supported on a soft support where contact is made over a considerable area of the object. The stresses due to bending moment will be smaller in the latter case. This is true only in the case of short slabs such as 10 - 15 and 20 foot length. For longer slabs, the changes in stress values caused by differences in subgrade modulus decrease to such an extent that for 30 foot slabs this factor is insignificant. Analysis shows that the increase in stresses due to this phenomenon for a difference in subgrade modulus from 100 p.c.i. to 300 p.c.i. amounts in value to approximately 100 p.s.i. for the 10 foot to 20 foot slab lengths.

CASE III. PRESENT DESIGN

The present design requirements call for a 9 inch uniform slab with 20 foot joint spacing. Under the same assumptions as for Case I the computed stresses will be as follows:

Interior	425 p.s.i.
Transverse Joint Edge	655 p.s.i.
Longitudinal Free Edge	480 p.s.i.
Free Corner	440 p.s.i.

The above figures indicate that the present slab will be underdesigned under the assumed conditions. On the basis of the fatigue curve presented by Bradbury (Reinforced Concrete Pavements, P. 55) for the traffic volume expected on this particular highway and for 760# modulus of rupture of concrete, it can be expected, that cracks will form in one year after construction. If we can expect the modulus of rupture value for the concrete to be at least 900 p.s.i., or better, then the present design will be adequate under the assumption that all stresses will not exceed 50% of the modulus of rupture.

SUMMARY

It is apparent that under our present construction practice, a 9 inch uniform pavement with 20 foot slabs is inadequate for the job if infinite life expectancy is desired. Life expectancy is understood to mean crack expectancy. On the basis of the previous assumptions, a 10 inch uniform pavement with 15 foot slab lengths would be the proper design for the section requiring the sand subbase.

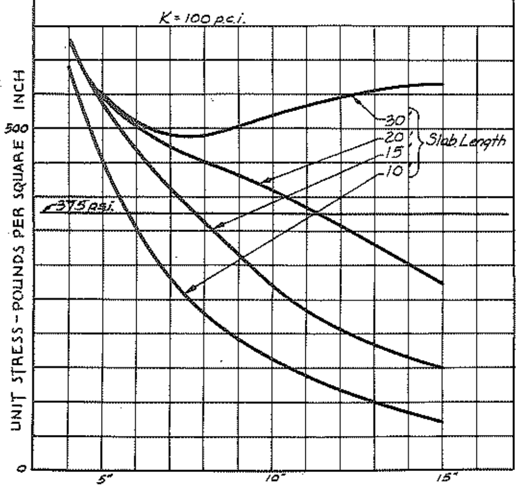
Adequate slab performance may be expected with the present design requirements (9" thickness - 20 foot slab lengths), provided load transfer devices are installed and cement content increased to produce higher strength concrete at early ages, and exclude heavy truck traffic from the pavement until the concrete has developed designated design strength.

We have no assurance that the stone subbase on soft clay will have a modulus value of 300 p.c.i., as used in calculating the stress values in this study. The correct value would have to be determined by actual tests on the existing subbase using a large concrete slab. It is only natural to assume that, because of the physical characteristics of the stone subbase material, the subgrade modulus value will be higher for the stone than that for the sand. For the stone section (with K = 300 p.c.i.) a 11 3/4" pavement with 15 foot joints is required.

The graphs illustrated in Figure I show the relationship between the several factors involved in determining the proper thickness of a concrete pavement under certain known conditions, and they may be used for further study in connection with this problem.

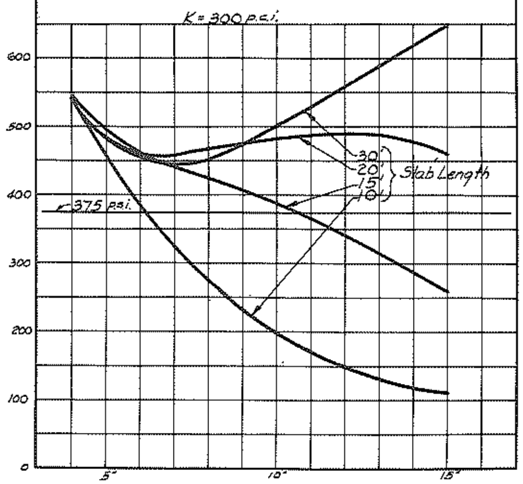
COMBINED INTERIOR STRESSES

P = 9000* Static Wheel Load in the Interior. Edge Warping Down. No Impact. a = 7", E = 5 x 10^6 p.s.i.; u = 0.15 for Load and = 0 for Temperature Stresses, e = 5 x 10^{-6}, t(°F) = 3h. k = 100 p.c.i.



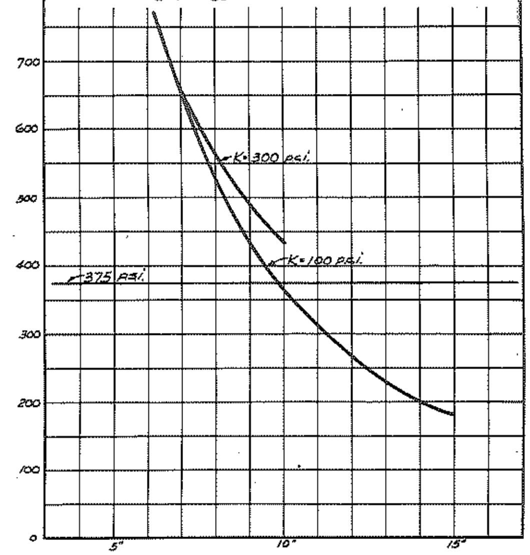
COMBINED INTERIOR STRESSES

P - 9000* Static Wheel Load in the Interior. Edge Warping Down. No Impact. a = 7", E = 5 x 10^6 p.s.i., u = 0.15 for Load and = 0 for Temperature Stress, e = 5 x 10^{-6}, t (°F) = 3h



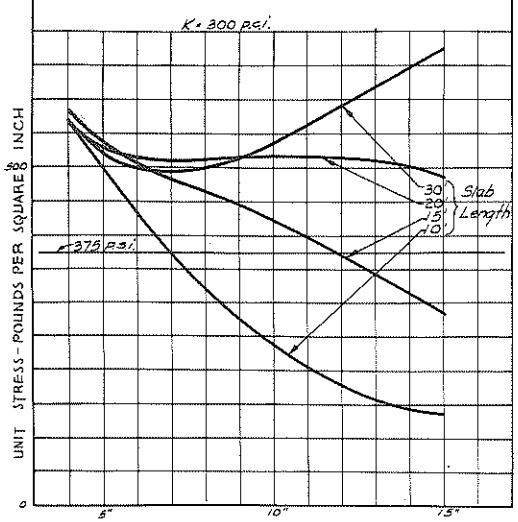
COMBINED FREE JOINT EDGE STRESSES

P = 9000* Static Wheel Load of Edge. Edge Warping Down. Impact Factor I = 1.50; E = 5 x 10^6; t(°F) = 3h. Width of Slab 12 Feet. e = 5 x 10^{-6}.



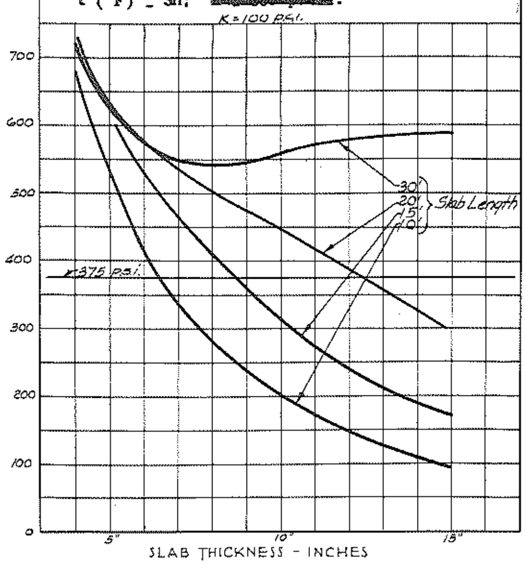
COMBINED FREE EDGE STRESSES

P = 9000* Static Wheel Load at Edge. Edge Warping Down. No Impact. a = 10", E = 5 x 10^6 p.s.i.; u = 0.15 for Load and = 0 for Temperature Stresses, e = 5 x 10^{-6}, t(°F) = 3h, [redacted].



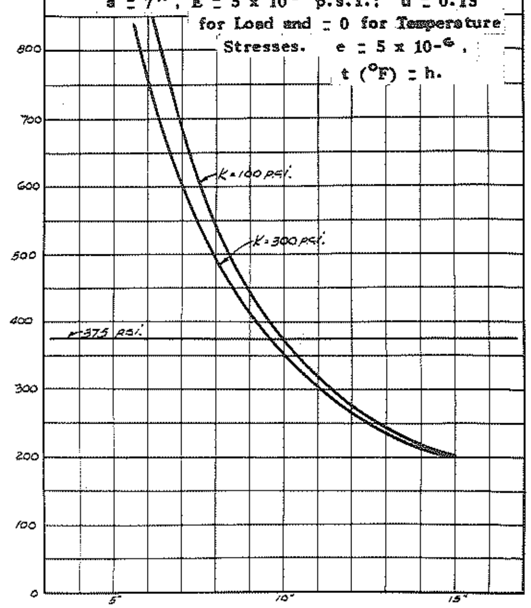
COMBINED FREE EDGE STRESSES

P = 9000* Static Wheel Load at Edge. Edge Warping Down. No Impact. a = 10", E = 5 x 10^6 p.s.i., u = 0.15 for Load and = 0 for Temperature stresses, e = 5 x 10^{-6}, t (°F) = 3h; [redacted].



COMBINED FREE CORNER STRESSES

P = 9000* Static Wheel Load at Corner. Edge Warping Up. Impact Factor I = 1.50; a = 7", E = 5 x 10^6 p.s.i.; u = 0.15 for Load and = 0 for Temperature Stresses. e = 5 x 10^{-6}, t (°F) = h.



PAVEMENT DESIGN CHARTS