INVESTIGATIONAL CONCRETE PAVEMENT IN MICHIGAN

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Conclusions obtained by theoretical formulae on concrete pavement design according to many contemporary authors are not completely substantiated by practical observations in certain localities or under varying conditions If it be true that there is a disparagement between these conclusions and practical observations of certain localities—then before any locality can accept such conclusions it is necessary to determine the causes for such differences and, where necessary, determine the proper conclusions for the given conditions This status and the desire to improve practices impelled the Michigan State Highway Department to construct an experimental concrete pavement which would embody certain modern theories of design and methods of construction The decision to build such a road was made prior to the submission by the Public Roads Administration of plans and procedure for construction of experimental roads. For this reason the set up is not entirely in agreement with the aforementioned plans. However, the plans of the Michigan Test Road coincided in a general way with the Public Roads Administration outlined procedure and necessitated only a few changes to correspond with other similar studies Table 1 contains a summary of all the sections included in this investigation

The road was constructed on M-115 in the north central part of Michigan's lower peninsula and entails a length of approximately 10 7 miles This is of sufficient length to reduce the variables of construction to a minimum for each feature investigated. With the exception of a few thousand feet of clay underlying a 1-ft sand cushion, the entire project was placed on a uniform sand subgrade constructed in 1937. This subgrade condition insured a uniformity in density and friction which will introduce few variables in the final analysis. The location of this project is ideal from the standpoint of grade, alignment and average weather conditions of Michigan. The maximum grade is 0 65 per cent, the maximum curvature 0 deg 45 min. with an approximate length of 3,500 ft. The experimental project was constructed as a 22-ft. width road under regular contract and construction procedure using the Michigan State Highway Department's 1940 plans and specifications with supplementals. The concrete aggregate was supplied from a local gravel pit of glacial origin common to Michigan.

JOINTS

Because of the nature of concrete, joints are a necessary evil and have been one of the most controversial subjects in the design of concrete pavements. Therefore, considerable attention was given to this subject in the Michigan Test Road.

Spacing. The primary end in the design of joint spacing should be the minimum use of joints particularly for expansion As each joint breaks the continuity of the concrete pavement and incorporates a new weakness, the maximum slab length should be used Because of the necessity of transverse joints the pavement requires a design to approach a continuous slab resistant to static and natural stresses.

Expansion Joints. Expansion joints were spaced to give sections of 120-ft., 360-ft, 480-ft, 600-ft, 900-ft, 1800-ft, and 2700-ft, lengths for various cross sections and various amounts of reinforcing steel In addition, 300-ft.

TABLE 1

COMPARISON OF MICHIGAN STATE HIGHWAY DEPARTMENT JOINT STUDY SCHEDULE WITH PUBLIC ROADS ADMINISTRATION SUGGESTED SCHEDULE

Section		Length	Expansion		Contraction		Weakened Plane Dummy	Reinf. lb. per hundred sq. ft.	Cross Section	Remarks
No	Sched		Spacing	Load Trans.	Spacing	Load Trans	Spacing			
		ft.	ft.		ft.				in.	
1	PRA	5280			15-20-25	None	None	None	9-7-9	Contraction spacing depends on type agg.
3F	MSHD	2700	2700		20	D.B.	None	None	9-7-9	See 3F & 4F adjacent 1 joint in 1 mile
4F	MSHD	2700	2700		10	D.B.	None	None	9-7-9	
3E	MSHD	1800	1800		20	None	None	None	9-7-9	
4E	MSHD	1800	1800		10	None	None	None	9-7-9	
2	PRA	2640	800	D.B *	15-20-25	None	None	None	9-7-9	*Approved load trans.
3-D-1	MSHD	900	900	D B *	20	D.B	None	None	9-7-9	
4-D-1	MSHD	900	900	D.B.	10	D.B.	None	None	9-7-9	
3-D-2	MSHD	900	900	D.B	20	D B	None	None	9-7-9	
4-D-2	MSHD	900	900	D B.	10	D B.	None	None	9-7-9	
3	PRA	2640	400	D B.	15-20-25	None	None	None	9-7-9	
3C	MSHD	1440	480	D B.	20	D.B.	None	None	9-7-9	
4C	MSHD	1440	480	D.B	10	D B	None	None	9-7-9	
4	PRA	1320	120-125	D B.	15-20-25	None	None	None	9-7-9	
10-B-1	MSHD	1080	120	D.B.	20	None	None	None	9-7-9	
10-B-2	MSHD	1080	120	D.B	15	None	None	None	9-7-9	
5	PRA	1320	120-125	D B.	15-20-25	D B.	None	None	9-7-9	
3A	MSHD	360	120	D.B	20	D.B	None	None	9-7-9	
4A	MSHD	360	120	D.B.	10	D B.	None	None	9-7-9	
10-A-1	MSHD	1080	120	D.B	20	D B	None	None	9-7-9	
10-A-2	MSHD	1080	120	D.B	15	D B.	None	None	9-7-9	
6	PRA	1320	120	D B	60	D B.	None	70	9-7-9	
S	MSHD	600	120	D.B	60	D B	30	60	9-7-9	
1A	MSHD	360	120	D.B.	60	D B	30	60	9-7-9	
2A	MSHD	360	120	D B	30	D B	15	37	9-7-9	
5A to G	MSHD	2520	120	D B	30	L T.	None	37	9-7-9	
7	PRA	1320	120	None	15-20-25	None	None	None	8 unif	

TABLE 1—*Concluded*

Section		Length	Expansion		Contraction		Weakened Plane Dummy	Reinf lb per hundred sq ft	Cross Section	Remarks
No	Sched		Spacing	Load Trans	Spacing	Load Trans	Spacing			
		ft	*ft*		*ft.*				*in*	
6A	MSHD	600	120	D B	30	None	None	None	8 unif	
6B	MSHD	600	120	None	20	None	None	None	8 unif	
6C	MSHD	600	300	None	15	None	None	None	8 unif	
6D	MSHD	600	300	None	10	None	None	None	8 unif	
8A	MSHD	600	120	D B	30	None	None	None	7 unif	
8B	MSHD	600	120	None	20	None	None	None	7 unif	
8C	MSHD	600	300	None	15	None	None	None	7 unif	
8D	MSHD	600	300	None	10	None	None	None	7 unif	
1B	MSHD	720	240	D B	60	D B	30	60	9–7–9	
1C	MSHD	1440	480	D B	60	D B	30	60	9–7–9	
1D	MSHD	1800	900	D B	60	D B	30	60	9–7–9	
1E	MSHD	1800	1800	D B	60	D B	30	60	9–7–9	
1F	MSHD	2700	2700	D B	60	D B	30	60	9–7–9	
2B	MSHD	720	240	D B	30	D B	15	37	9–7–9	
2C	MSHD	1440	480	D B	30	D B	15	37	9–7–9	
2D	MSHD	1800	900	D B	30	D B	15	37	9–7–9	
2E	MSHD	1800	1800	D B	30	D B	15	37	9–7–9	
2F	MSHD	2700	2700	D B	30	D B	15	37	9–7–9	
3B	MSHD	720	240	D B	20	D B	None	None	9–7–9	
4B	MSHD	720	240	D B	10	D B	None	None	9–7–9	
7A	MSHD	600	120	D B	60	D B	30	60	8–6–8	
7B	MSHD	600	120	D B	30	D B	15	60	8–6–8	
7C	MSHD	600	120	D B	20	D B	None	None	8–6–8	
7D	MSHD	600	120	D B	10	D B	None	None	8–6–8	
9A	MSHD	1800	100	L T	None	None	None	None	9–7–9	

sections were constructed on 7-in. and 8-in uniform pavement without reinforcement steel Since the project is built over a uniform subgrade, the findings should enable us to determine proper slab lengths for the various pavement designs.

Closely associated with expansion joint spacing is the requirement of expansion space. A 1-in joint width was maintained for the various lengths of slabs. Tests on joint width movement will be a primary factor in determining the necessary expansion opening

Contraction Joints· As in the case of expansion joints, contraction joints are essential in concrete pavement to relieve the slab of excessive stresses The spacing of the contraction joints is determined by the maximum length of slab that eliminates the possibility of transverse crack occurrence intermediately between contraction joints due to temperature, moisture and subgrade reactionary stresses.

Weakened plane "dummy" joints also are included in some of the sections and are placed at 15 and 30-ft. spacings for 8 – 6 – 8 in., and 9 – 7 – 9 in., cross section pavement using 37 and 60 lb. per 100 sq. ft. of reinforcing steel. This type of joint is used in Michigan as standard practice and an opportunity is afforded to evaluate weakened plane joints with contraction joints at close spacings.

The proper spacing of joints will be determined by permissible maximum stress intensities induced by linear frictional restraint and flexural weight restraint; whereas the detailed design features of the joint itself are determined by the desired structural interaction between jointed slab units.

Design: The design of joints necessitates consideration of structural features among which are freedom of movement for expansion or contraction, flexibility and load transfer where necessary. Together with these functions, consideration must be given in the joint design to adequate seal to prevent infiltration of water and foreign matter. Although these phases were not of major importance in this project, several units of various types of expansion and contraction joints were installed with the intent of determining their design weaknesses.

The efficiency of dowel bars and other load transfer devices will be compared with thickened edge joints for balanced design of pavement.

In conjunction with the contraction joint spacing investigation, various load transfer devices were installed together with dummy contraction joints having no feature for transference of load. Four major types will be studied, first, aggregate interlock with load transfer which involves the use of coated ¾-in. round bars 15-in. in length at 15-in. spacing transversely. Either a groove or ribbon type weakened plane 2½ in deep is used to control crack development. The aggregate interlock which results from the crack formed below the weakened plane aids in the transference of load when the joint is closed. With the joint open, the slip dowel bars function independently in the distribution of load stresses.

The second type of contraction joint is essentially the same as the first with the elimination of slip dowel bars. In this type, the transfer of load is dependent entirely upon aggregate interlock. Load transfer is obtained only when the joint is in a closed condition.

The third type of contraction joint makes use of the ¾-in. dowel bars without any assistance from aggregate interlock. This was accomplished by installing joints with a metal divider plate to insure a vertical division of the slabs with load transfer through slip dowel bars only.

The fourth type consists of a continuous plate dowel with a metal dividing strip. This type is intended to provide more uniform distribution of load transfer.

In some cases, both in expansion and contraction joints, corner bars 1-in. in diameter by 18-in. in length were used to maintain mutual elevation of the slabs.

These installations should enable us to evaluate load transfer and preservation of mutual elevation when using aggregate interlock, aggregate interlock plus load transfer devices and independent load transfer devices.

CROSS SECTION

In the design of a pavement slab on the basis of stress analysis many factors must be considered. The complex manner in which these factors are interrelated and the values of the factors have provided a very controversial field. It was believed, by the planners of the Michigan

Test Road, that on certain types of subgrades providing better than average support, reduced thickness of pavement might be used. Also, it has been argued that equivalent uniform thickness pavements are perhaps more satisfactory and economical than the balanced cross sections For example, a uniform thickness pavement designed to resist edge stresses requires no joint strengthening whereas the thickened edge type cross section demands strengthening for a balanced design It was hoped, in the planning of the test road, that some of these factors could be measured and some of the complex relations studied and simplified Therefore, four different types of cross sections were set up in the study of this project namely, 9–7–9 in, Michigan State Highway Department standard cross section; 8-in uniform, the approximate equivalent of 9–7–9 in; 8–6–8 in. a reduced cross section which might be used on subgrades of sufficient supporting value; and 7-in. uniform, the approximate equivalent of the preceding cross section

REINFORCEMENT

Elaborate surveys have been made to determine the value of steel reinforcing in concrete pavements. The results have again opened up a controversial field. Although the proponents of plain concrete pavements can present many plausible arguments, there are many unanswered questions. Among these are

(1) Relation of plain uniform cross section to reinforced "balanced" cross section

(2) Economics of reinforced cross sections of both types versus plain cross sections with adequate jointing.

(3) What is an adequate amount reinforcing steel?

It was felt in planning the Michigan Test Road that inasmuch as the length of the project allowed for comparatively long stretches of both types of pavements and observations could be made under identical conditions, perhaps some of the questions might be answered To this end, sections were constructed using 9–7–9 in; 8–6–8 in; 8-in and 7-in uniform cross section using plain concrete, and reinforced concrete with 60 lb per 100 sq ft and 37 lb per 100 sq ft. Joints were spaced as described under "Joint Spacings"

METHODS OF MEASUREMENT

For proper appraisal of the structural efficiency of the elements of design considered in this project, periodic visual examinations together with measurement of displacements and physical conditions must be made

DISPLACEMENTS

The displacements which occur in the various sections are affected by volume change of concrete, superimposed loads and subgrade differentials These displacements are determined by change in joint width and slab movement horizontally and vertically

Joint Width Change: Joint opening and closing is measured on reference points which are holes drilled in heads of galvanized roofing nails A Starrett micrometer caliper reading to 0 001 in. was adapted for taking measurements. The initial readings were taken the morning following the placing of the pavement and subsequent readings for daily, seasonal and permanent joint width determinations will be made insofar as possible in accordance with the Public Roads Administration outline. To insure accuracy of the readings and avoid any criticism of the results in the use of roofing nails as reference points, in one section consisting of a day's work, a series of brass plugs held in place with sulphur were installed. If variations develop that have been caused by corrosion of the nail heads, the entire project will be replaced with brass plugs set in sulphur.

Slab Movement: Practically all of the joints being studied for width movement have precise level reference points consisting of $\frac{5}{16}$-in. by $2\frac{1}{2}$-in. carriage bolts, set in the concrete at the time of construction to determine the vertical movement at the joints. Intermediate reference points were set in a number of slabs. The day following placing of the concrete, the initial elevations of all points were established by precise level measurements. During this coming winter, preferably a uniformly cold period, a complete set of levels will be run. This will be repeated during the summer of 1941, during a uniformly high temperature period. In this manner, the extremes in temperature variation and their effect on the concrete pavement will be established. Three years following the construction of the design project, a third set of levels will be run for observations on permanent vertical slab movement.

The relative horizontal movement of various concrete pavement slabs will be measured in conjunction with the vertical displacement and at such other times as may be necessary. To obtain accurate measurement of pavement movement, an 8-in. pipe casing was set in the subgrade to a depth of 6-ft., the interior of which is excavated. Centered in the casing is a 2-in. pipe to a depth of 12-ft. below the concrete pavement on top of which is placed a chrome plated pipe cap having reference cross hairs etched in the surface. In this manner the shifting of subgrade soil due to frost action or slab movement will not affect the original position of the reference pipe. A specially designed monument box, containing a machined brass bushing to hold a glass plate having etched cross hairs, set in a brass ring, is cast in the concrete immediately over the 8-in. casing. With a telescopic instrument constructed to permit adjustments both longitudinally and transversely in respect to the pavement, the increments between sight on reference pipe and reference plate can be measured to 0.1 mm. A line of sight is established at initial reading parallel to center line of pavement at location of monument box and the instrument attached on a tripod which can be repeatedly set up with a positive assurance of accuracy as to position and alignment. This feature of the design study incorporates observations on seventy-nine of the described installations.

PHYSICAL CONDITIONS

Physical conditions which must be measured are those which affect slab movements and those which are the result of slab movement. These conditions which are being measured in the Michigan Test Road are: temperature of concrete, moisture content of concrete and subgrade, strain in concrete, subgrade bearing capacity and meteorological conditions.

Temperature of Concrete: Temperatures are determined by the use of thermocouples embedded in the concrete and subgrade. For the pavement slab they are placed every inch throughout its depth beginning 1 in. from the surface. Subgrade temperatures are read at 1, 3, 7 and 13-in. below the pavement. Four such layouts were installed 5-ft. 6-in. from the edge of the pavement at critical points in the design project. At one of these locations two additional thermocouple assemblies were embedded as described except that the distance from the edge of pavement was 1-in. and 10-ft. 6-in. respectively in order to obtain temperatures at extreme edge and center of slab. All the thermocouple junctions were cast in lead after twisting and brazing and the point of entrance of wire leads into lead plugs taped and sealed with asphalt. This was done to insure true temperature readings without being affected by moisture leaks

Moisture Content: At the same locations as the thermocouples, moisture cell assemblies were also installed to measure moisture content. The moisture is determined, coincident with the temperature at similar adjacent positions in the slab and subgrade. The cells used for measuring moisture content consist of two exposed wires separated 1 in. and cast in chemically pure plaster of Paris to form blocks ½-in. by 1½-in. by 2½-in. approximately. The moisture bridge measures the resistance in ohms of potential from one pole to the other, the moisture content of the cell being inversely proportional to the resistance. The temperature and age of the concrete create variables in recording the moisture but a nomograph has been constructed for adjusting the resistance readings for such variations to obtain the true moisture content of the concrete pavement. In the subgrade a correction curve designed for temperature differentials only is necessary.

Strain in Concrete: Measurements of strain at the neutral axis and at the surface of the slab are being made at special locations to determine differences in tensile, compressive and warping stresses for various spacings of expansion and contraction joints.

The interior strains and temperatures of concrete are measured with the Carlson electric strain meter. This meter consists of very fine elastic music wire threaded on small porcelain spools which are rigidly secured to steel bars connected one to each end of the meter. One coil is immediately within the other but not touching it. The elastic wire is placed in position under tension and when the meter is under compression, the outer coil is released and the tension of the inner coil is increased, or vice versa for tension. The wire coils are at equal temperatures which is important as a $\frac{1}{10}$ deg. change introduces considerable error. Due to the linear relationship between resistance and tension, the resistance ratio is changed in direct proportion to the change in gage length. The coils are connected to a portable testing set, forming a Wheatstone bridge circuit. The strain meter is covered with a metal shield to protect it against moisture leaks and is embedded in the concrete in this manner. Twenty-six such meters have been placed.

Immediately over the Carlson strain meters and at a few additional locations surface strain measurements are being made with the Berry strain gage. In this manner, stress differentials between the surface and interior of concrete pavement can be analyzed for temperature and moisture changes in the concrete.

Subgrade Bearing Capacity: During construction, subgrade tests of density and moisture content were made. Subgrade bearing capacity tests were conducted prior to placing the pavement and check tests are contemplated through openings cored in the concrete pavement at the locations of the original tests. In these determinations, 10, 50 and 100 sq. in. area circular plates are used. The static load was applied through a hydraulic jack from a loaded truck. The resisting load was recorded by a dynamometer ring with a dial sensitive to 0.0001 in. deflection of the ring. The penetration of the plate was measured with three 0.001-in. dials equally spaced around the edge of the plate. Bearing values are established for each size plate with and without a superimposed load surrounding the plate equivalent to the weight of the concrete slab over an area affected by slab weight in respect to area of plate being loaded. It is hoped that the results of these tests will assist in the development of a simple method for determining subgrade modulus.

Meteorological Date. Throughout the construction of the project meteorological data were obtained including temperature, relative humidity, precipitation, evaporation, wind direction and velocity. The gathering of this information will be continued for the entire period of the design project investigation predetermined as approximately five years.

INCIDENTAL STUDIES

A few incidental studies were introduced into the Michigan Test Road which were of interest to the Michigan State Highway Department and pertinent to the improvement of concrete slab construction These sub-investigations comprised. stress curing of concrete, mechanical spreading of concrete and the use of various joint sealers.

Stress Curing: Eighteen hundred feet of concrete pavement were placed by the stress curing method of construction which eliminates steel reinforcement and transverse joints other than expansion. The slabs were laid in 100-ft. lengths and the pre-stressing of the concrete accomplished by use of canvas covered rubber hose pressure cells inserted in the joint openings. These were expanded to exert pressures based on results of tests on representative specimens 7 by 9 by 14-in. cast throughout the period of construction of the stress curing section. The pressures were increased at a rate controlled by determinations of strength increase of specimens up to a maximum of 200 lb. per sq. in. This pressure was maintained until the modulus of rupture reached the 7-day specification strength requirement of 550 lb. per sq. in. After this period, one slab was utilized to determine the subgrade friction factor by making use of the pressure cells to cause sliding. The pressures were applied in increments of 25 lb. per sq. in. at 10-min. intervals. In the first test no movement of slab occurred until the pressure reached 187 lb. per sq. in. and was then released with a resultant movement of 0 264 in. There was a small amount of residual movement after release of the pressure. In the second run, definite movement of the slab occurred at 50 lb. per sq. in. with a movement of 0.507 in. following application of 200 lb. per sq. in. load. A third test was run with very little change in values and the indicated subgrade value for sand was found to be about 1.75.

Mechanical Concrete Spreader: With the exception of 600 lin. ft the concrete for the design project was placed and consolidated by means of a mechanical concrete spreader Observations were made on the uniformity of distribution and placing of the concrete with and without the spreader. Flexural strength tests on beams cast on the subgrade with and without concrete spreader and beams vibrated with internal vibrator will be reported for 7 and 28 day tests to determine characteristics of strength for each type of concrete placement.

The study of the effectiveness of the concrete spreader was supplemented by the analysis of the fresh concrete by the Dunagan method Three samples immediately following the transverse finisher were taken at top, center and bottom of slab respectively and compared with analogous tests on standard construction.

Similar test samples were taken immediately before and after the mechanical longitudinal finisher to determine the effect of this method of finishing

Joint Sealers: The finishing and spreading operations in the construction of a concrete pavement are very important, yet there remains one other construction and design detail which may be of greater importance, namely, adequate and proper sealing of the joints. Probably many of our problems of pavement design would be simplified if more attention were given to this important item.

A seal of the asphalt oil latex type has been developed by the Michigan State Highway Department which shows promise of providing an adequate seal

In this project all of the expansion joints were sealed with this material except a few in which other types of fillers were use. These types included poured rubber, premolded rubber and tar A new type of expansion joint was also used which employs the poured filler of asphalt oil latex as a seal, completely sealing top, sides and bottom of joint. The contraction joints were sealed with premolded bituminous strip and asphalt oil latex seal Periodic observations will be made to determine the effectiveness of the various types of seals