LONGITUDINAL CRACKING OF CONCRETE PAVEMENTS ON STATE HIGHWAY 13 IN CLARK AND TAYLOR COUNTIES, WISCONSIN

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SYNOPSIS

A study has been made of the longitudinal cracking of concrete pavement on State Trunk Highway 13 in the vicinity of Abbotsford, Wisconsin The cracking is excessive and has continued to develop for several years, both transversely and longitudinally The longitudinal cracks often extend for hundreds of feet, sometimes on only one side of the center parting strip and sometimes on both sides The cracks follow a regular course from 2½ to 4½ ft from the centerline of the pavement The pavements are 9–6½–9 in section, 20 ft wide, with tie bar across the center joint at 2 ft or 4 ft centers

The study showed that the excessive cracking is confined to an area of Colby silt loam soil This soil is an exceedingly fine-grained soil, dense, plastic and subject to excessive frost heaving The amount of cracking is much reduced where the roadbed is elevated above the surrounding land on fill material taken from wide ditches Cracking is also less in the reinforced section than it is in plain concrete sections The theory is advanced that the tie bars stiffened the center section of the pavement and that the uneven heaving by frost then caused the slabs to crack longitudinally at a short distance from the ends of the bars

It has been noticed, for several years, hat longitudinal cracking of the concrete avement on State Trunk Highway 13 in he vicinity of Abbotsford, Wisconsin has een excessive and has been continuing to evelop each year These portions of avement are not only cracked longitudinally but also are badly cracked in a ransverse direction

The longitudinal cracks are not transient ones, but often extend for hundreds f feet, sometimes on one side of the cener parting strip, then on the other, and n some stretches are located on both sides f the centerline Their width varies rom thin widths to as much as 4 in These wide cracks, however, appear to be the result of spalling as the edge of the pavement is well in line It is quite important to note that these longitudinal cracks are regular in their position in the slab, for they are located from 2½ to 4½ ft from the centerline of the pavement

A complete study of this area was made during the summer of 1935, and the results of that study are herewith submitted.

GENERAL CONDITIONS OF THE NORTHERN AREA

An observational survey of the area surrounding Abbotsford disclosed the fact that the excessive longitudinal cracking of the modern concrete road-slab, having

Figure 1. A typical case of longitudinal cracking

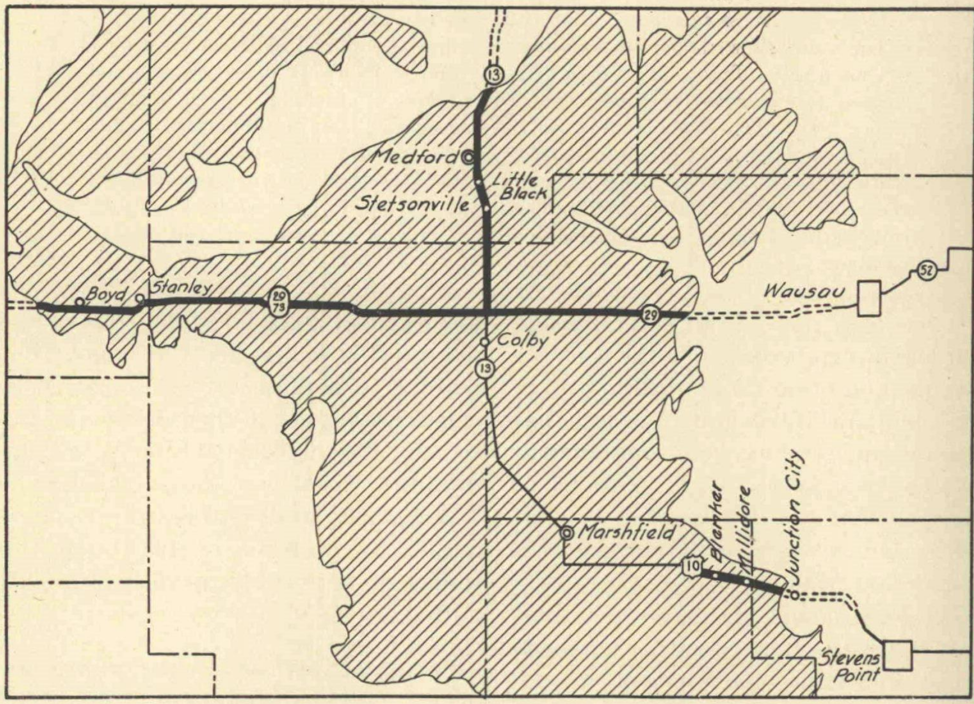

Figure 2. Sketch map showing locations of roads with extensive longitudinal cracking in relation to soil condition. The shaded area is that covered by the Colby silt-loam. The heavy solid lines show the excessively cracked roads. The sections free from excessive longitudinal cracking are indicated by the double dotted lines. Clark and Taylor Counties, Wisconsin.

a 9–6½–9 section with a longitudinal center parting strip and tie-bars, was confined to a definite area As one drives east on State Trunk Highway 29 from Chippewa Falls, there are few, if any, longitudinal cracks until a point four miles east of Cadott is reached From this point near Cadott to a point approximately 20 to 24 miles east of Abbotsford the longitudinal cracking is prevalent, and then as one continues eastward on State Trunk Highway 29, these cracks cease to appear. As one drives north on State Trunk Highway 13 from Abbotsford, the longitudinal cracking is present until a point two miles south of County Trunk Highway "M" (at Whittlesey) is reached To the north of this point, the longitudinal cracks are absent On the southeastern edge of the area where longitudinal cracks are excessive, the limit of such cracking, on State Trunk Highway 10, is between Junction City and Milladore

The above points are shown in Figure 2, and the roads in heavy lines show those concrete road slabs which exhibit excessive longitudinal cracking.

Upon plotting these roads upon a soil map of the area the significant fact became apparent that the roads experiencing trouble were all located upon the Colby silt-loam soil. The cracking ceased abruptly when the road passed from this soil to some other

COLBY SILT-LOAM SOILS

The Colby silt-loam soil is an exceedingly fine-grained soil, dense and plastic Figure 3 shows a vertical section of this type of soil The top few inches is a grayish brown, friable silt-loam, to a depth of approximately 36 inches the soil is a mottled gray and brown plastic silt-loam, and the bottom layer is a dense clay-loam containing sand and small pebbles

The thickness of these layers varies; on the top of the hills the dense clay-loam may be near the surface, while in the valleys this layer is deep below the surface Where the road-slab rests on the dense clay-loam, few, if any, longitudinal cracks exist These places of little longitudinal cracking occur usually on the tops of the hills This point, however, is not of practical value for roads must be constructed in the valleys as well as on ridges.

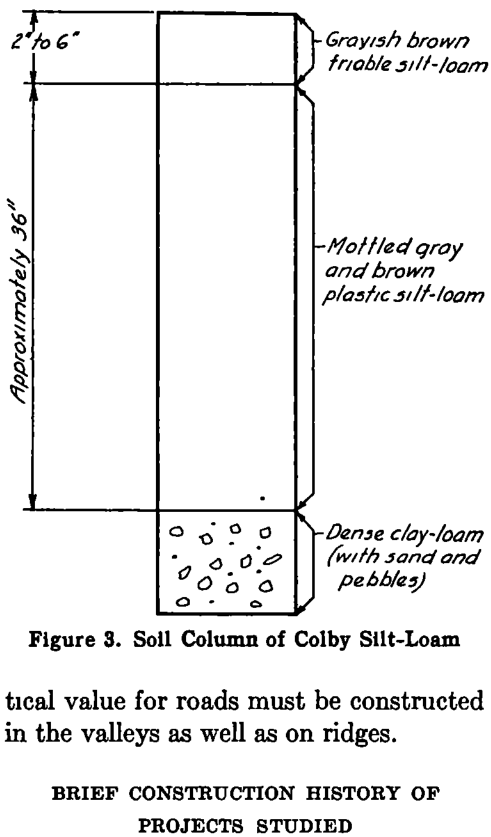

Figure 3. Soil Column of Colby Silt-Loam

BRIEF CONSTRUCTION HISTORY OF PROJECTS STUDIED

Only a portion of the concrete pavements built in the Colby silt-loam area could be studied in detail, but it is believed that the projects selected are typical examples of the behavior of a 20-foot thickened edge slab (9–6½–9) having a longitudinal center joint when placed on this type of soil and in a region subject to extreme weather conditions

The road selected for study was a portion of State Trunk Highway 13 from Abbotsford northward to Little Black

Table I gives the project numbers, dates of construction, etc , on this stretch of paving

It is important to note that on all four on these projects the centerline of the pavement practically coincided with the center line of the old gravelled surface. Thus, there was no over-hanging of the slab to cause longitudinal cracking

The amount of grading on all these projects was small (in project 147-Re the grading amounted to 5000 cu yds per mile), and that done was for shouldering and ditching In many places, the concrete slab was placed directly on the old surfacing, while in others the cut or fill at the centerline was small, the maximum being approximately 1 ft

On projects 147-S and 332-B, soil borings showed that the slab was resting, in many places on the old gravel surfacing It is doubtful, however, if this fact fully accounts for the lessened longitudinal cracking of these sections, for in both projects, 147-Re and 31, there are also many places where the slab rests on the old gravel surfacing

Project 147 RE

This project began at Abbotsford and extended northward to Dorchester

The aggregate for the concrete was obtained from the Eau Claire Sand & Gravel Company and consisted of rounded granitic particles

The tie-bars were 4 feet in length and spaced 2 feet on centers Deformed steel center parting strip was used

Projects 147-S and 332-B

These projects total 5 61 miles in length and were constructed from July 6 to October 31, 1928

Universal cement from the Steelton mills was used from Stations 110+30 to 216+00, and from 258+55 to 295+65 The remainder of the job was constructed of cement from the Duluth Mill

TABLE I

Project No	From	To	Date of Const	Spacing of Tie-bars (in feet)
147 Re	Abbotsford	Dorchester	1930	2
147-S	Dorchester	Taylor Co Li	1928	4
332-B	Taylor Co Li	Stetsonville	1928	4
31	Stetsonville	Whittlesey	1930	2

From Station 0 to 110, hard artesian water was used, and from 110 to 295 lake water was used in the manufacture of the concrete

Both the coarse and fine aggregate was from the Chippewa plant of the Eau Claire Sand and Gravel Company The materials were proportioned by volume and the pavement cured with calcium chloride at the rate of from 2 to 2½ lb per sq yd At the age of 4 months, the average core strength of this concrete was 4,688 lb per sq in

The reinforcing used in portions of the pavement was one-half inch square deformed bars, so placed as to form 3-ft squares and located 2 in from the top of the pavement.

The condition of the subgrade was as follows.

Sta	0– 2	Good
Sta	2– 14	Soft
Sta	14– 40	Fair
Sta	40– 60	Soft to Fair
Sta	60–140	Good
Sta	140–150	Soft
Sta	150–167	Good
Sta	167–186	Soft to Fair
Sta	186–210	Good
Sta	210–237	Fair to Good
Sta	237–259	Soft
Sta	259–264	Good
Sta	264–265	Soft
Sta	265–282	Good
Sta	282–235	Soft
Sta	285–296	Good

Steel reinforcing was placed in the following locations·

Sta	2+18	to	13+50
Sta	17+92	to	20+64
Sta	33+78	to	36+95
Sta	48+92	to	58+81
Sta	139+82	to	149+85
Sta	167+03	to	180+80
Sta	182+78	to	185+67
Sta	236+91	to	244+66
Sta	248+17	to	258+55
Sta	264+11	to	264+94
Sta	282+52	to	284+87

Tie-bars, 4 ft in length and spaced approximately on 4-ft centers, were used on these projects Deformed steel center parting strip was used Four dowel bars $\frac{5}{8}$-in round, 4 ft long, were placed across the expansion joints These were placed half-way between the top and bottom of the slab and were located at points 6 in. from the outside edge and 1 ft from the center parting strip It was noticed that this method of design permitted the adjacent ends of the slab (at expansion joints) to rise and thus produce a bump at the joint

Project 31

This project began at a point about one-half mile north of Stetsonville and extended northward to Whittlesey No information is available on the aggregate or the concrete strengths Deformed steel center parting strip was used, and the tie-bars were spaced two feet apart

DETAILED STUDY OF PAVEMENT CRACKING

A detailed study of the pavement cracking was made on State Trunk Highway 13 from Abbotsford to Little Black, for in this section, while most of the pavement was badly disfigured with wide longitudinal cracks, some portions were not cracked A soil survey and pavement cross-sections were taken together with the crack, or condition, survey

Project 147 RE

Parts of this project are reinforced with mesh reinforcement weighing 49 lb per sq in and placed 2 in from the top of the pavement The tie-bar spacing is 2 ft A summary of the cracking of this project from Station 39 to Station 210 is given in Table II

The longitudinal cracks were located from $2\frac{1}{2}$ to 4 ft from the centerline and in most cases were approximately 3 ft from the center of the slab In many places, these cracks appeared on both sides of the centerline

The maximum conditions of longitudinal cracking in the non-reinforced portion were two stretches each 500 ft long where the cracking was on both sides of the centerline In the non-reinforced section, the greatest continuous length of pavement where there were no longitudinal cracks was 300 ft

The maximum condition of transverse cracking in the non-reinforced section shows 160 ft of transverse cracks per station, while the maximum condition for the transverse cracking for the reinforced section was 135 ft for one station

Projects 147-S and 332-B

Portions of these projects are reinforced with ½-in bar steel placed 3 ft on centers in both directions and located 2 in below the top of the pavement The tie-bar spacing is 4 ft Table III shows summary of the cracking on sections of these projects

The longitudinal cracks in these sections varied from 3 to 5½ ft from the centerline, the average distance being approximately 4 ft

The maximum conditions of longitudinal cracking, in the non-reinforced sections, were not as severe as those in Project 147 Re However, there were two stretches that had 250 ft of longitudinal cracks all on one side of the center joint The longitudinal cracking here was in spots rather than continuous There appears to be little correlation between the longitudinal cracking and the condition of the subgrade prior to construction The entire length of these projects was not surveyed, as the time was limited and also due to the fact that those portions surveyed may be considered as average for the entire job

TABLE II

PROJECT 147 RE

	Length of Pavement (in feet)	Total Length of Long Cracks (in feet)	Total Length of Trans Cracks (in feet)	Ave Length of Long Cracks per 100 ft of Pavement (in feet)	Ave Length of Trans Cracks per 100 ft of Pavement (in feet)	Remarks
Non-reinforced	14,509	12,770	13,230	88	91	Open Cracks
Reinforced (49 lb Mesh)	2,615	110	1,345	4 2	51 4	Tight Cracks

TABLE III

PROJECTS 147-S AND 332-B

	Length of Pavement (in feet)	Total Length of Long Cracks (in feet)	Total Length of Trans Cracks (in feet)	Ave Length of Long Cracks per 100 ft of Pavement (in feet)	Ave Length of Trans Cracks per 100 ft of Pavement (in feet)	Remarks
Non-reinforced	7,281	2,950	5,215	40 5	71 6	Open Cracks
Reinforced, ½ in square bars, 3 ft centers	4,400	230	2,280	5 2	51 8	Tight Cracks

Project 31

Parts of this project were reinforced with ½-in square bar steel placed 3 ft on centers in both directions and located 2 in below the top of the pavement The tie-bar spacing was 2 ft Table IV gives a summary of the data

As was the case in Project 147 Re , the longitudinal cracks were approximately 3 ft from the centerline. Again, as in

Project 147 Re , the longitudinal cracks, in the non-reinforced portions, were often on both sides of the center joint

The entire length of this project was not surveyed, and therefore it is impossible to give exact data on the maximum conditions of longitudinal cracking, but there are several places where longitudinal cracking on both sides of the centerline extends for several hundred feet

It is important to note the abrupt beginning of the longitudinal cracking in the project where it joints Project 332-B Figures 4 and 5 show this condition

ANALYSIS OF SOIL SAMPLES

The soils of this region are typical Colby silt-loam, with its three-layer soil column Samples of the various soil layers were analyzed according to the methods of the Bureau of Public Roads (See Table V)

The relationship between the longitudinal pavement cracking and the soil layer on which it rests is not definite because of the many variables that exist However, it may be said in general that where the slab rests on Layer No 5, comparatively little longitudinal cracking results

In Projects 147-S and 332-B, the road slab was placed, in most of the length of the projects, on the old graveled surface (No 7 soil), and while these projects (147-S and 332-B) did not show as much longitudinal cracking as did Projects 147-Re′ and 31, it is not known whether this lessened cracking was due to the presence of the old road under the concrete slab or to the fact that the tie-bar spacing was 4 ft This latter phase will be discussed in subsequent paragraphs

Figure 5 shows the juncture of Project 332-B with Project 31 and illustrates the difference in longitudinal cracking of these two projects

TABLE IV

PROJECT 31

	Length of Pavement (in feet)	Total Length of Long Cracks (in feet)	Total Length of Trans Cracks (in feet)	Ave Length of Long Cracks per 100 ft of Pavement (in feet)	Ave Length of Trans Cracks per 100 ft of Pavement (in feet)	Remarks
Non-reinforced	322	400	165	124 2	51 2	Open Cracks
Reinforced ½ in square bars	1,713	145	425	8 4	24 9	Tight Cracks

THEORY OF LONGITUDINAL CRACKING

The longitudinal cracking of concrete road slabs can be caused by several conditions One is the uneven settling of fills, i e , one side of the road-bed may settle more than the other and thus cause a longitudinal rupture of the concrete Another cause is the placing of the concrete slab on a hard core of the old and underlying gravel surface This condition might cause two longitudinal cracks to develop because the outer edges of the slab would not have the same degree of support as the central portion Still another cause is rapid drying of the freshly poured concrete.

It is doubtful, however, if any of the above causes enter to any extent in the area surveyed, for those causes would produce only transient cracking, and on State Trunk Highway 13 the longitudinal

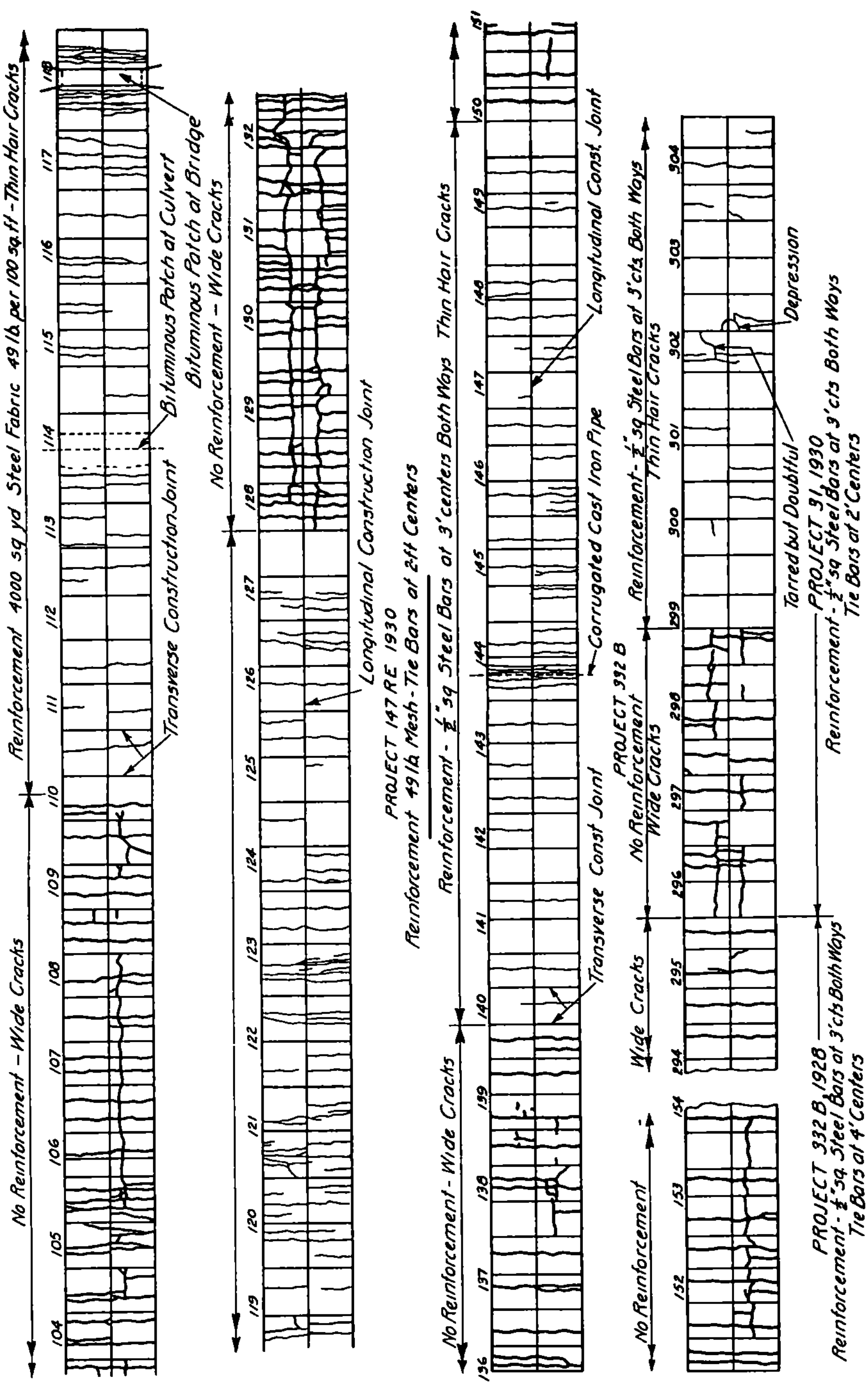

Figure 4. Survey of Cracks in Concrete Pavements. Clark and Taylor Counties, Wisconsin

Figure 5. Junction of Project 332-B and Project 31. Project 332-B in foreground. Constructed 1928. Four-foot tie-bar spacing. Project 31 in rear. Constructed 1930. Two-foot tie-bar spacing.

TABLE V

SOIL ANALYSIS

Layer No.	Liquid Limit	Plastic Index	Shrinkage		Moisture Equivalent		Remarks
			Limit	Ratio	Centrifuge	Field	
Physical							
1 Top-soil	36.5	9.0	16.7	1.51	29.0	35.8	Grayish brown; friable; depth variable
3 Mottled silt-loam	28.2	5.5	13.5	1.69	16.5	22.4	Colby silt loam; usual depth 36″ or more
5 Dense clay loam with pebbles	30.5	12.4	17.1	1.87	16.4	20.3	Bottom layer of Colby column
6 Grayish clay loam	45.9	20.9	31.1	1.73	33.0	38.1	Marsh border soil from low lands
7 Sandy silt, coarse material	28.0	6.6	15.2	1.71	19.1	21.5	Probable remains of gravel surfacing
No. 1 Fill	27.5	8.3	16.9	1.67	15.2	23.0	Full of pebbles

Mechanical Analysis

Layer No.	Part Larger Than 2 mm. %	Coarse Sand, 2.0 to 0.25 mm. %	Fine Sand, 0.25 to 0.05 mm. %	Silt, 0.05 to 0.005 mm. %	Clay Smaller Than 0.0005 mm. %	Colloids Smaller Than 0.0001 mm. %
1	0.0	6.4	13.6	55.0	25.0	0.0
3	1.9	7.9	14.2	57.0	19.0	0.0
5	6.7	18.3	26.0	29.0	20.0	0.0
6	0.0	1.3	11.7	54.0	33.0	0.0
7	11.8	28.3	19.9	29.0	11.0	0.0
No. 1 Fill	11.4	25.3	21.3	30.0	12.0	0.0

cracking may be called continuous, for the cracks extend for several hundred feet without a break

Since the roads that exhibit excessive longitudinal cracking are confined to the area of the Colby silt-loam soils, it is evident that sub-grade conditions are the basic reasons for failure in this case The

An important item to bear in mind is that the modern thickened-edge pavement is constructed with a longitudinal center joint, the two slabs being laced together with tie-bars that prevent any lateral movement of the two slabs These tie-bars act to stiffen the central portion of the road slab

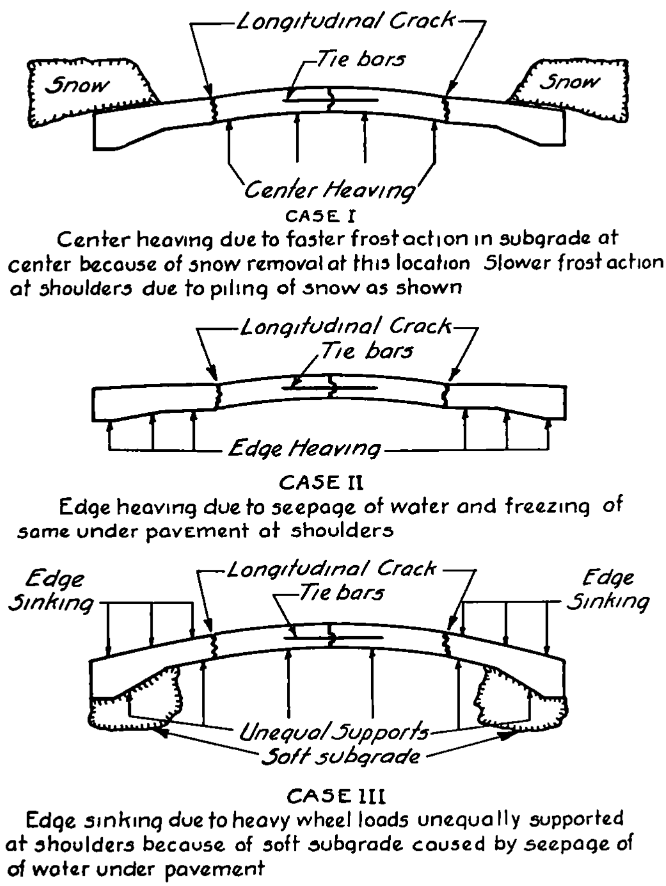

Figure 6. Theory of Longitudinal Cracking of Concrete Pavements

Colby silt-loam is a type of soil that is conducive to frost heaving, and this action is probably the real reason for the longitudinal cracking of the concrete pavements in this area

There are three conditions of the sub-grade in the winter and early spring months that can cause longitudinal cracking See Figure 6.

Case 1 In many years, snow falls to a considerable depth before the ground freezes To clear the snow from the road, it is pushed beyond the edges of the slab When severe freezing weather arrives, the center of the road is clear, but the edges of the slab may be covered with snow Furthermore, the central portion of the slab is thinner than the edges, and the rate of freezing below the slab would be different at the center and the edges The action of freezing, on the Colby silt-loam soil, then produces a heaving of the central area of the road, and, due to the stiffening effect of the tie-bars, this portion of the slab is lifted more or less as a unit This warping action will cause a longitudinal rupture of the concrete somewhere beyond the ends of the tie-bars Where the tie-bars were placed 2 ft apart, the average distance of the longitudinal crack from the center joint was approximately 3 ft , while in those projects where the tie-bars were spaced 4 ft apart, the longitudinal cracks were approximately 4 to 4½ ft from the center joint and were more irregular in their positions than those where the tie-bar spacing was 2 ft

Case 2 It is not inconceivable that in some cases the edges of the slab would be heaved by frost action before the central portion was heaved If this is true, then the stiffening effect of the tie-bars would cause a longitudinal rupture of the concrete in much the same fashion as indicated in Case 1.

Case 3 During the late spring months, when the subgrade thaws, the heaved slabs tend to return to their original position. The thawing of the sub-grade, however, may not be uniform across its width, and this coupled with the effects of heavily loaded vehicles and soft sub-grade at the edges, will also tend to produce longitudinal cracking if the central portion of the slab is stiffened by the tie-bars

It is probable that the greatest contributing cause of these longitudinal cracks is that of Case 1, as it is not uncommon to see, in the spring, discolored water issuing from the center joint Furthermore, accurate pavement cross-sections of these two projects show a peak at the centerline. Figure 7 shows two pavement cross-sections, one where there are two longitudinal cracks in a non-reinforced section, and the other a bar reinforced section

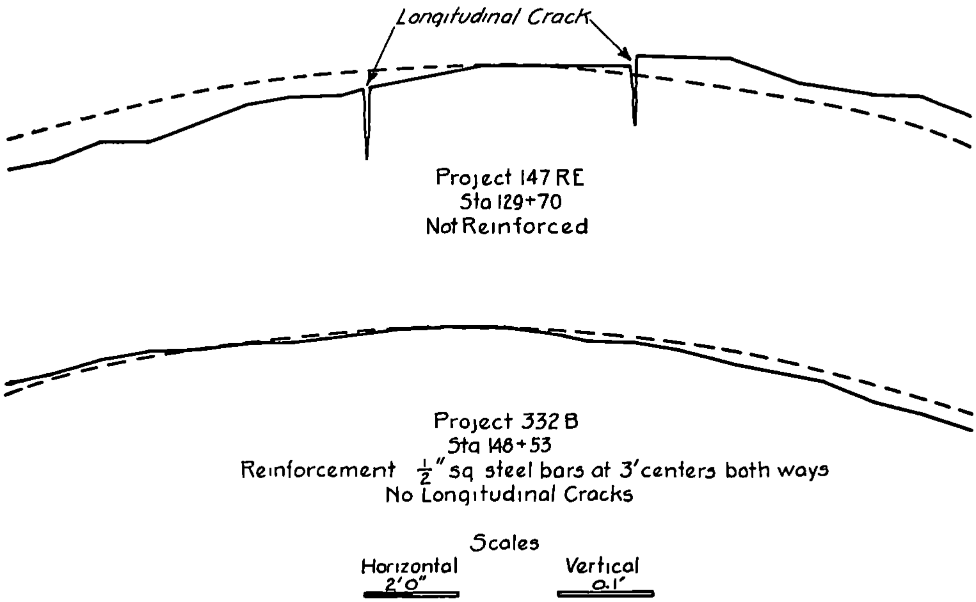

Figure 7. Pavement Cross-sections. The dotted lines show the theoretical cross-sections of the pavements when constructed The solid lines show the cross-sections in 1935

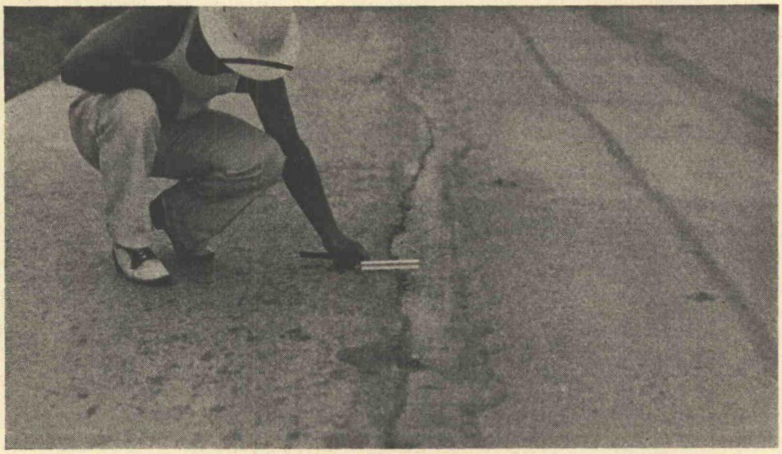

Figure 8. Typical Cracking Non-Reinforced Concrete Pavement. S.T.H. 13, Clark and Taylor Counties, Wisconsin. (Maximum width of longitudinal cracks 3 to 4 inches)

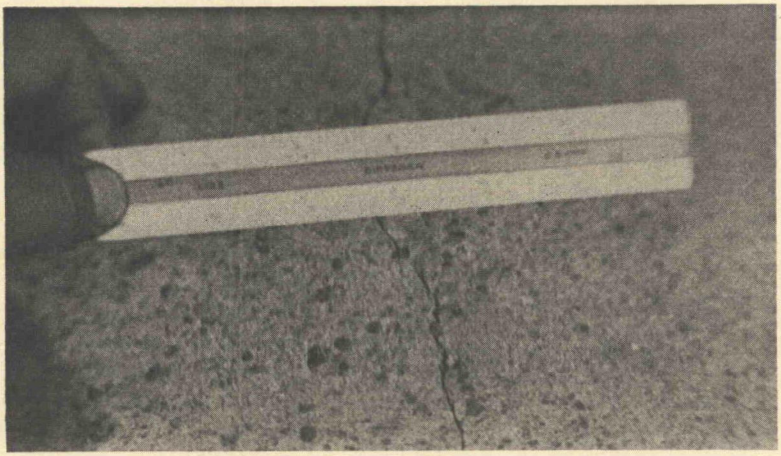

Figure 9. Typical cracking of mesh reinforced concrete pavement. S.T.H. 13, Clark and Taylor Counties, Wisconsin. (All cracks in reinforced sections were extremely narrow)

RESULTS OF SURVEY

The survey of the concrete pavements of this north-central area of Wisconsin, and particularly, the survey of State Trunk Highway 13 from Abbotsford to Medford, indicates that:

(1) Excessive longitudinal cracking is confined to the area of Colby silt-loam soils.

(2) The amount of longitudinal cracking is diminished when the so-called "high line" profile is used. By this is meant the elevation of the roadbed above the surrounding country by obtaining the fill material from wide ditches at either side

of the roadway (A good example of this is State Trunk Highway 29 east of Abbotsford, where longitudinal cracking is not prevalent)

(3) Reinforcing was effective in the reduction of both longitudinal and transverse cracking Table VI shows the reduction

(4) The mesh reinforcement, in this study, reduced transverse cracking 44 per cent of that in the non-reinforced portions, while the bar mat reduced this cracking 27 per cent It is to be noted that the length of transverse cracking, per 100 ft of pavement, where mesh and bar mat reinforcing were used is the same (approximately 51 feet of transverse cracks per 100 feet of pavement), but the percentage of reduction of cracking is different

(5) The longitudinal cracks in all non-reinforced sections were open, and, in some cases, were 3 or 4 in wide at the top of the slab due to spalling

(6) The width of cracking (both longitudinal and transverse) in the reinforced sections was fine in all cases, in fact, in many cases these cracks were so fine that it was difficult to trace them on the pavement surface

(7) It is probable that the 2-ft spacing of the tie-bars stiffened the central portion of the slab more than did the 4-ft spacing A greater stiffness would cause more longitudinal cracks to form

(Projects 147-Re and 31 had 2-ft tie-bar spacing and the longitudinal cracks were more prevalent than in Projects 147-S and 332-B, where the tie-bar spacing was 4 ft See Figure 3

TABLE VI

EFFECT OF REINFORCEMENT ON CRACKING

Project No	Age, Years	Type of Reinforcing	Tie-bar Spacing	Length of Long Cracks per 100 ft of Pavement	Length of Trans Cracks per 100 ft of Pavement	Reduction of Trans Cracks
			feet	*feet*	*feet*	*per cent*
147-Re	5	None	2	88	91	
		49-lb mesh	2	4 2	51 4	44
147S & 332B	7	None	4	40 5	71	
		½-in bar mat	4	5 2	51 8	27

Data for Project 31 not shown because of inadequate data for non-reinforced portions

CONCLUSIONS

From the results of this study it is possible to draw several conclusions:

1 Concrete pavements built in the area of Colby silt-loam soils must be so designed and constructed as to successfully resist the distortion caused by frost movements of the sub-grade

2 A "high level" profile should be adopted in these areas

3 All concrete road slabs in these areas should be reinforced with mesh reinforcement

4 A reconsideration of the design of the longitudinal joint is necessary The present design, employing embedded tie-bars spaced two feet on centers, stiffens the central portion of the slab and resists bending at the longitudinal joint

The longitudinal joint should be so designed as to maintain the central edges of the slab at the same elevation yet permit bending at the joint when a warping action is present