MICHIGAN
STATE HIGHWAY DEPARTMENT
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INVESTIGATION

of

HINGED BAR MAT

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The Bethlehem Steel Company have submitted a sample of hinged bar mats of their own patent for consideration and approval of the Michigan State Highway Department for use in concrete pavements. They propose this type of mat for convenience in shipping and handling because it can be folded at the center by means of a specially designed hinge. The total weight of the mat is comparable to that of ordinary bar mats and also the fabrication is similar in every respect except for the hinge. A careful study has been made of the hinged mat to determine if it would meet the Department's requirements in all respects.

The tests covered by the study include those required by the Michigan State Highway Department in the 1942 Standard Specifications for Road and Bridge Construction plus additional tests designed to bring out desirable or undesirable features of the hinge. Since the hinge is the principle feature differing from the regular bar mat, its performance was most closely observed.

The investigation disclosed that the present hinge construction will not develop the full strength of the transverse rod and also it is by no means comparable in strength to a lap joint. It was also discovered that the method of clipping the bars together should be improved in order to prevent lateral shifting of the longitudinal bars. The hinged feature has considerable merit but must be improved before it should be permitted to be used in concrete pavements.

This report presents in detail the nature of the work performed and the results obtained from the various tests included in the investigation.

THE HINGED MAT

A series of pictures is shown to give a general idea of the fabricated mat.

Figure 1 presents a general view of the mat showing the hinge construction through the center. When the mat is installed in the pavement the hinge would be parallel to the center-line of the pavement and in the center of each traffic lane. The bars are all uniformly spaced except the first longitudinal bars on either side of the hinge. In Figure 1 the bar on the left of the hinge is spaced at 6 inches and the one on the right is spaced at 8 inches while the remainder of the longitudinal bars are spaced at 7 inch centers. Apparently the reason for this is to allow the longitudinal bars to mismatch when folded in order to provide a thinner bundle as shown in Figure 2. As a result one half of the mat is approximately 2 inches wider than the other.

Figure 3 shows the mat partially folded and demonstrates free movement at the hinge. The hinge normally cannot be disjointed unless the clips are loosened thereby freeing the transverse bars completely.

Figures 4 and 5 show the hinge in the open and folded position respectively. Figure 5 shows also the mismatching of both the longitudinal and transverse bars.

The method of clipping the transverse and longitudinal bars is also shown in Figure 5. Figure 6 shows the clip itself. The method of clipping influences the manner in which one bar may slip along the other under the loading specified in the A.S.T.M. Designation: A-134-37. This matter will be discussed later.

Figure 1. View showing hinge construction in center of mat.

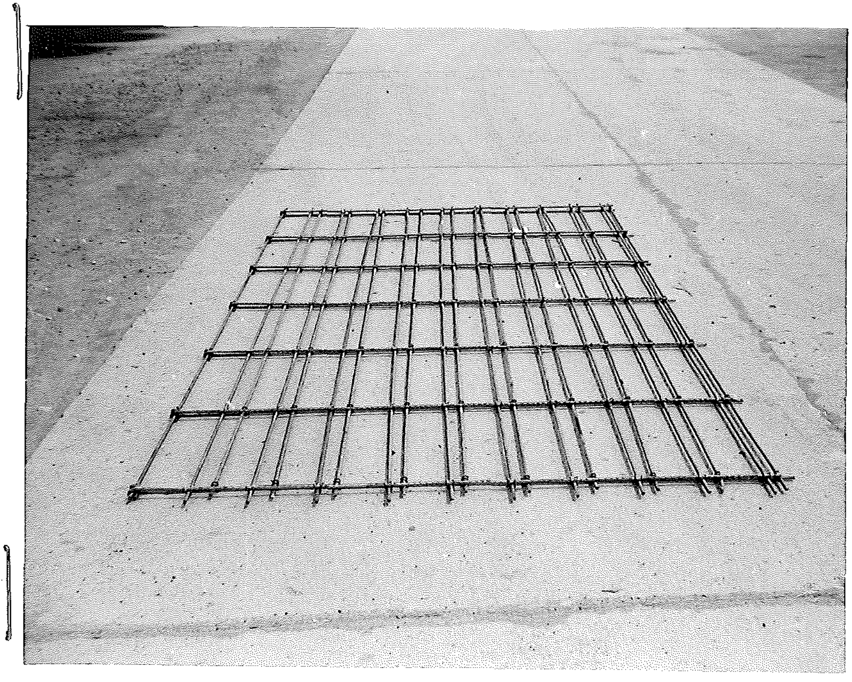

Figure 2. View of mat when folded.

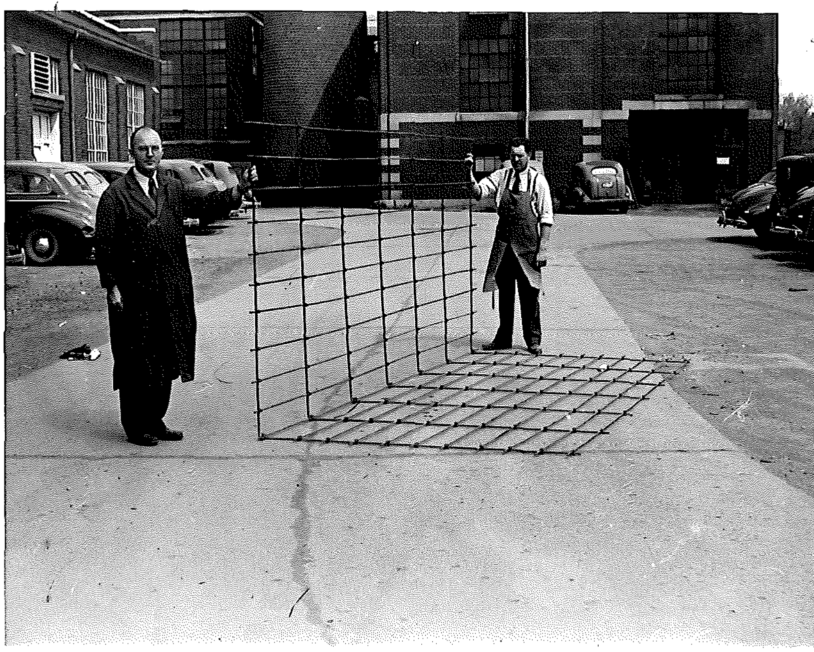

Figure 3. Unfolding hinged mat.

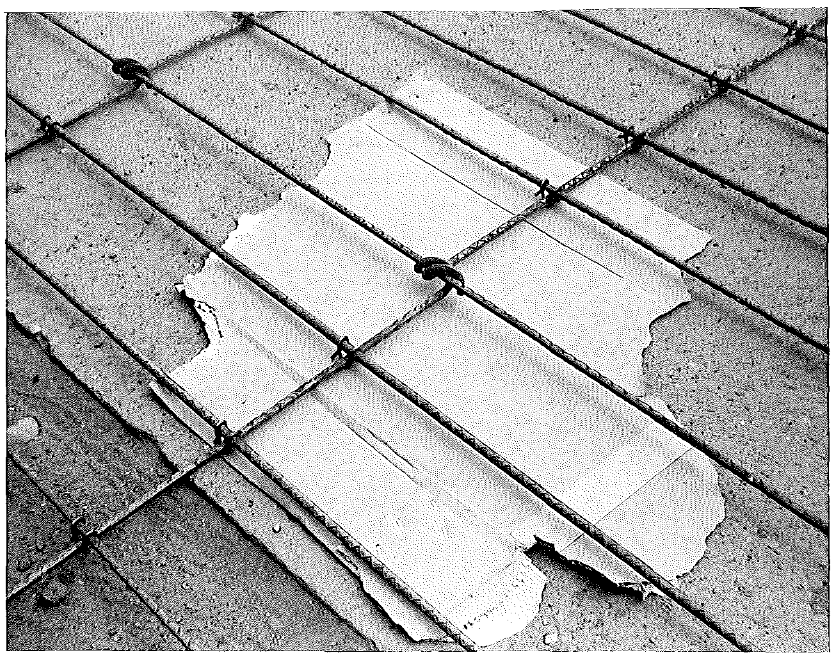

Figure 4. View showing how hinge is fabricated.

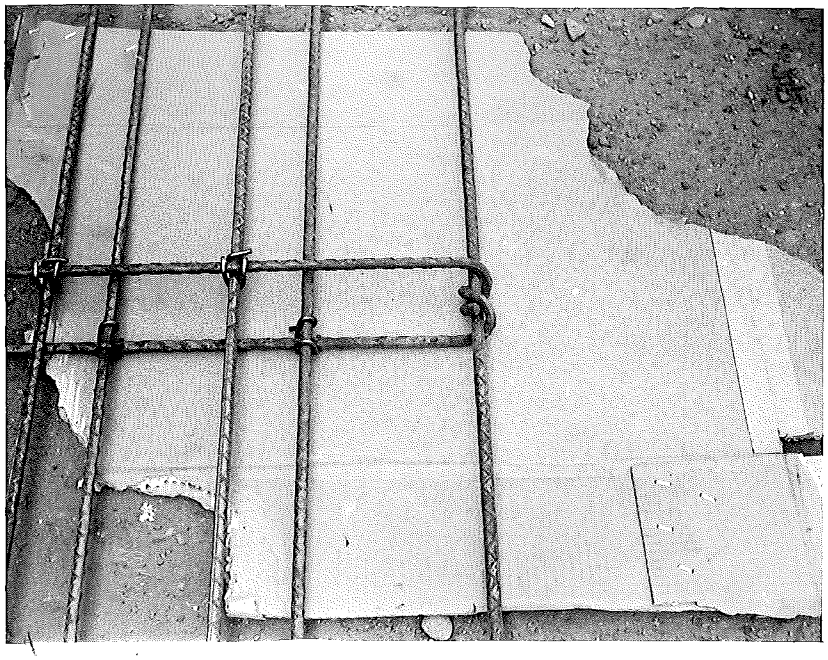

Figure 5. View of hinge in folded position.

Figure 6. Metal clip for holding bars in place.

PHYSICAL EXAMINATION OF BAR MAT

The results from the examination of the bar mat, which are given in Table I indicate that it meets the requirements of the Michigan State Highway Department, 1942 Road and Bridge Specifications relative to dimensions, weight, and cross section area of the steel. The bars meet the physical requirements for the grade of steel indicated. The clips meet the slippage requirements along the longitudinal bars but fail in slippage along the transverse bars and also in the load test for the determination of loosening effect.

EXAMINATION OF CLIPS

The slippage test on the clips was performed by exerting a lateral force first on the transverse bars and then on the longitudinal bars by means of a calibrated spring balance. The apparent reason for slippage along the transverse bar but not along the longitudinal bar is believed to be due to the manner in which the clip is installed. The clip appears to be shop bent in three places before installing but field bent in the fourth at the time of fabrication of the mat. A close examination of Figures 4 and 5 shows that all clips are placed one way and that the end most clearly visible is the one which is used in making the final field bend. This operation tends to form a better bight around the longitudinal bar than around the transverse bar thus resulting in no slippage along the longitudinal bar. The shop bent portions are made only for convenience and exert no more than enough pressure to merely hold the bars in contact. One method of reducing slippage would be to reverse the clips on alternate intersections in order that the bight of the field bend may engage the transverse as well as the longitudinal bars.

TABLE I

SUMMARY OF TEST DATA ON BAR MAT

Dimensions and Weight of Mat

		Dept's Requirements
Dimensions of Mat, feet	12x13.5	11-2/3' x 13-1/2'
Weight of Mat, pounds	137.0	134.3
Weight of Mat, pounds per 100 sq. ft. of pavement	91.3	89.5
Weight of Mat, pounds per sq. yd. of pavement	8.2	8.1
Average spacing of longitudinal bars, inches	7.0	7.0
Average spacing of transverse bars, inches	25-3/4	12.0
Average projection of longitudinal bars beyond the last transverse bar, inches	4-1/16	3.0
Average projection of transverse bars beyond the last longitudinal bar, inches	1-3/4	1.0

Efficiency of Clips

Slippage of clips along transverse bars, A.S.T.M. 184, percent slipped	50
Slippage of clips along longitudinal bars, A.S.T.M. 184, percent slipped	0
Load test of clips perpendicular to plane of mat, A.S.T.M. 184, percent loosened	100
Load test of clips perpendicular to plane of mat, complete separation, pounds	968

Physical Characteristics of Steel in Bars

Position	Longitudinal	Transverse
Class	Deformed	Deformed
Grade	Hard	Intermediate
Area, sq. in.	0.108	0.108
Diameters, in.	3/8	3/8

Tensile Strength, lbs. sq. in.	83,300	72,950
Yield Point, lbs. sq. in.	54,800	51,450
Elongation in 8 in., percent	20.3	25.8
Cold bend test	Passes	Passes

The method of installing the clip may be the reason why the clip fails also in the loosening test. Figures 7 and 8 show the manner in which this test was performed. Weights were suspended on a rod attached to a plate to which was fastened two eye bolts. The eye bolts were hooked over one of the reinforcing bars while the other attached bar was placed across the top of a built up frame. The loosening effect was determined when the two bars pulled apart sufficiently to permit slipping a thin piece of paper between them.

Since it was necessary to cut one bar which tended to loosen the clipped connection, later tests were performed in a similar manner except that the bars were not cut from the mat. The whole mat was placed over the framework and each joint tested separately by hooking a yoke over the lower bar upon which the weights were suspended.

EXAMINATION OF HINGE

Sections of the bar mat including the hinge were cut for examination of the hinge under tension. Figure 9 shows a section which contains three hinges. One hinge is in the testing machine, the one in the foreground has been tested and the middle one remains to be tested. Figure 10 shows the middle hinge after test and the distortion due to loading. The hinge was considered to have failed when it took no additional load on the testing machine to cause further deformation. The average strength of the three hinges was 1988 pounds which represents a development of approximately 25 percent of the ultimate strength of the bar itself.

Two hinges were embedded in concrete cylinders for tensile strength tests and two in concrete beams for test in modulus of rupture. Also two

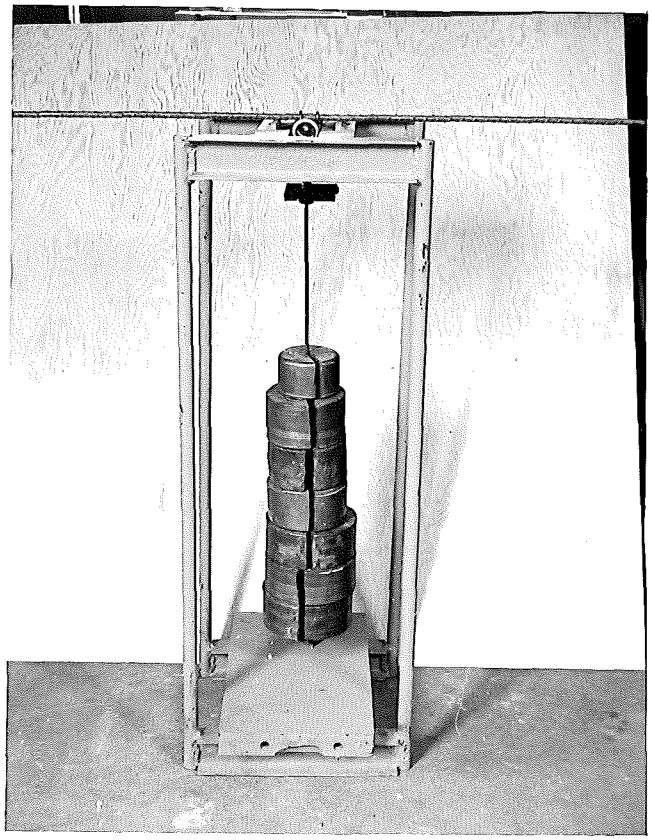

Figure 7. Method of testing clip under tension.

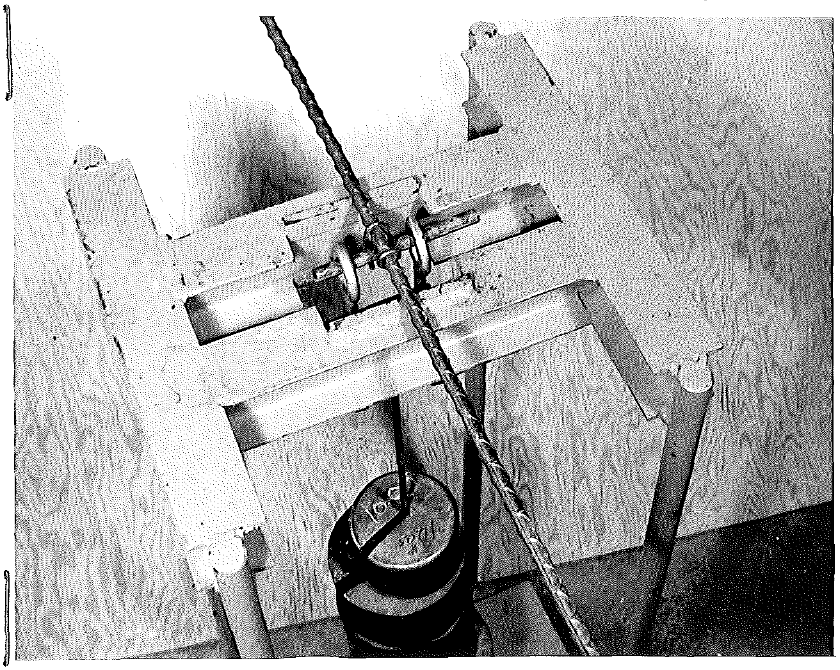

Figure 8. Close view of clip under tension.

Figure 9. Testing hinge in tension

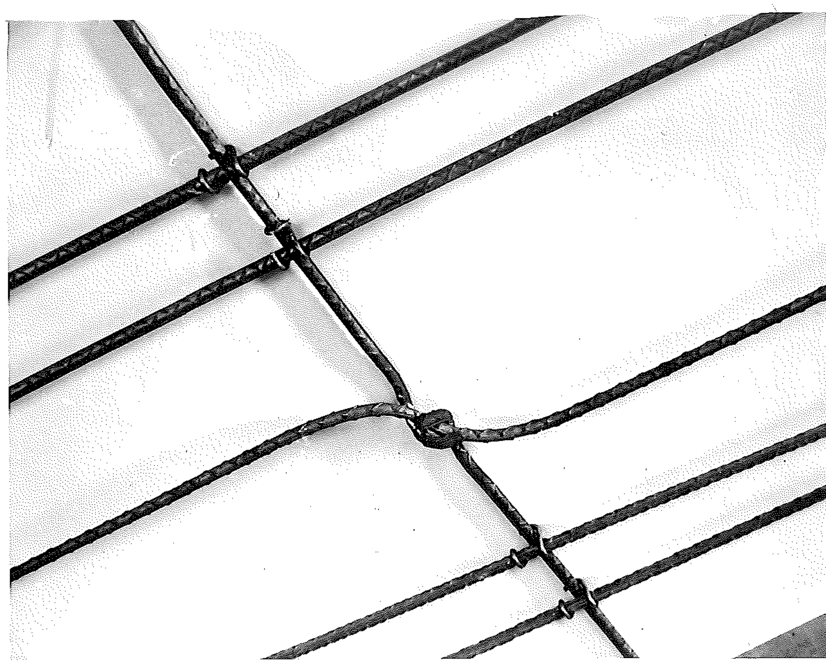

Figure 10. Distortion of hinge under tension.

transverse bars with forty diameter lap were molded in each of two concrete cylinders. A single transverse bar was also installed in a concrete beam for comparison with the hinge joint. One plain concrete beam and four plain concrete cylinders were cast for control strength of concrete.

The bars containing the hinge and the forty diameter lap were cut long enough to extend through the cylinders to provide for the engagement of the jaws in the testing machine. These were tested in tension. In casting of specimens the bars containing the hinge and the single transverse bar for modulus of rupture were placed in the beam molds and suspended 2 inches from the bottom by wire bar chairs. Directly beneath the hinges and in the center of the beams 2 inch by 1/8 inch premolded fiber strips were installed to provide planes of weakness to insure breakage of the concrete at the hinge or at the center in the case of the single bar. The third point loading method was used in breaking the beams.

The method of testing the embedded hinge in tension is shown in Figure 11. The picture was taken after the crack in the concrete had occurred. In this test the yield point of the hinge bars occurred outside of the concrete cylinder before the concrete broke as shown in the first column, Table II. At the moment of failure of the concrete the loads were as shown in the third column of Table II. The second column of Table II is the yield point of the steel while the third column is the strength reduced to pounds per square inch of the cross section of the concrete. No further strength was developed by the hinge after the concrete failed. Figure 12 shows the cylinder containing the hinge after it has been pulled open for observation.

Figure 13 shows the cylinder containing the bars lapped forty diameters. In this test the concrete failed to break thereby developing the ultimate

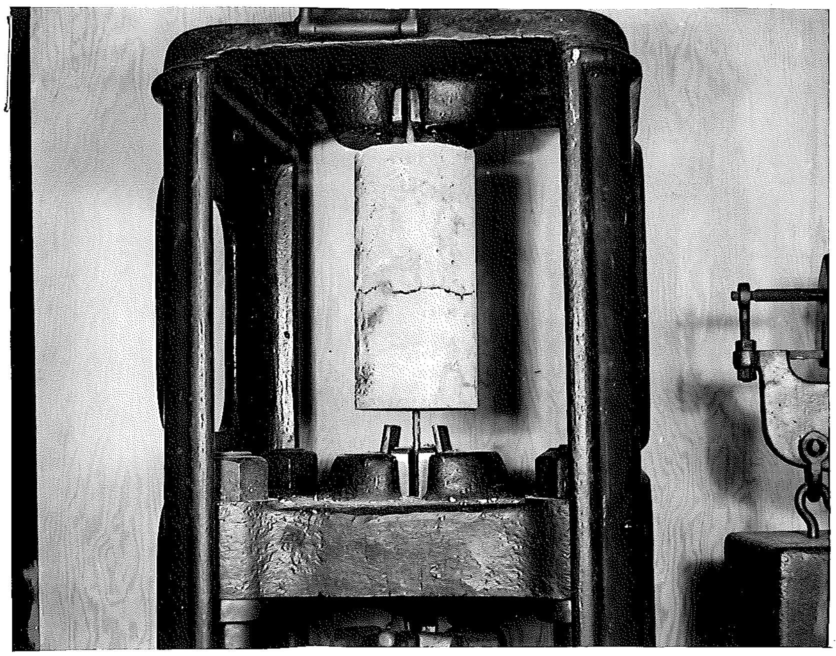

Figure 11. Cracking of concrete specimen containing hinge.

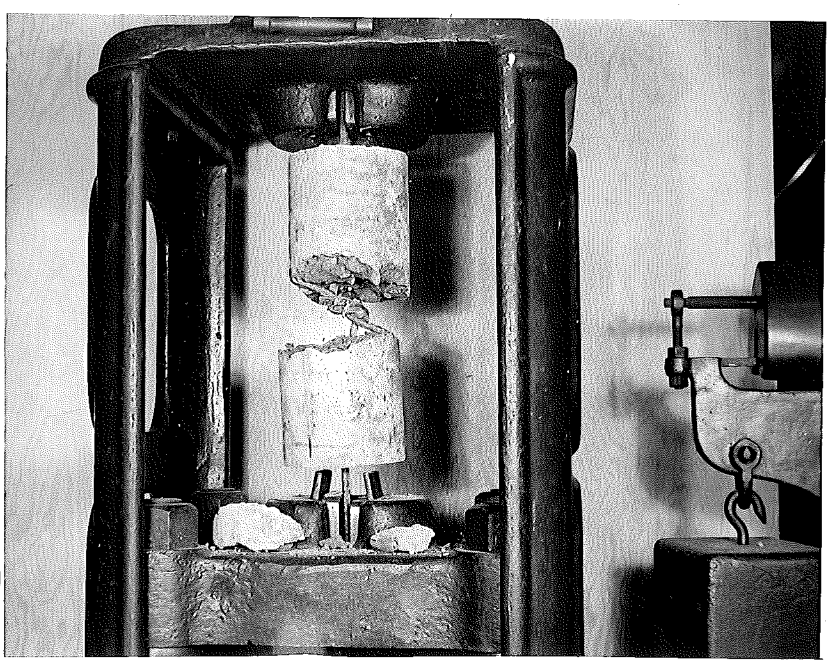

Figure 12. Typical failure of hinge.

TABLE II

RESULTS OF TENSION TESTS ON HINGE

(Transverse Bars)

Arrangement of Specimen	Load to Produce Yield point of Steel		Load to Produce Failure in Concrete		Load to Produce Failure of Hinge	
	Total lbs.	Yield point p. s. i.	Total lbs.	p. s. i.	Total lbs.	p. s. i.
	(1)	(2)	(3)	(4)	(5)	(6)
Hinge Bar Embedded	5325	49,300	6660	235	Hinge pulled out when concrete failed.	
Hinge Bar Embedded	5660	52,400	7000	247	Hinge pulled out when concrete failed	
Average	5493	50,850	6830	241		

strength of the steel which broke outside of the cylinder. The test results are shown in Table III.

To compare the characteristics of the hinge in concrete with those of a plain bar under similar circumstances, beams were cast containing the two types and tested in flexure using the third point loading method. In both cases the steel was embedded in the 6"x8"x36" beams at a height of 2 inches from the bottom. To facilitate testing a 2" transverse plane of weakness was created at the bottom of the beam midway between the two ends. All test specimens were cured in a fog and broken at 7 days.

Figure 14 illustrates the manner in which the specimens containing the hinge failed. When the concrete failed in tension under an average load of 5120 pounds, as given in Table IV, no additional tensile strength was developed by the hinge.

The specimen containing the single 3/8" rod developed a crack at a total applied load of 13,700 pounds. Figures 15 and 16 show the condition of the beam at the appearance of the first crack and at ultimate failure respectively.

The results from the tests show that when the concrete cracks the hinge offers no further structural strength. Furthermore, there is evidence from the tests that the construction of the hinge may constitute a source of weakness in the concrete section at the hinge.

The compressive strength of the concrete used in the specimens is given in Table V.

SUPPLEMENTARY TESTS AND STUDIES

A test was made to determine the rigidity of the mat at the hinge by stretching and compressing the sections of the mat when unfolded. Very little

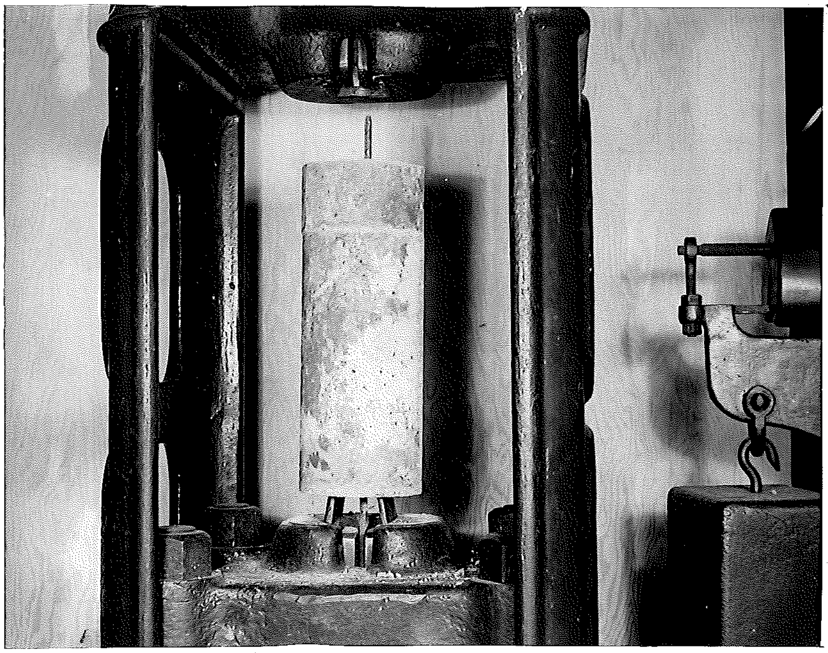

Figure 13. Bond test of lapped bars.

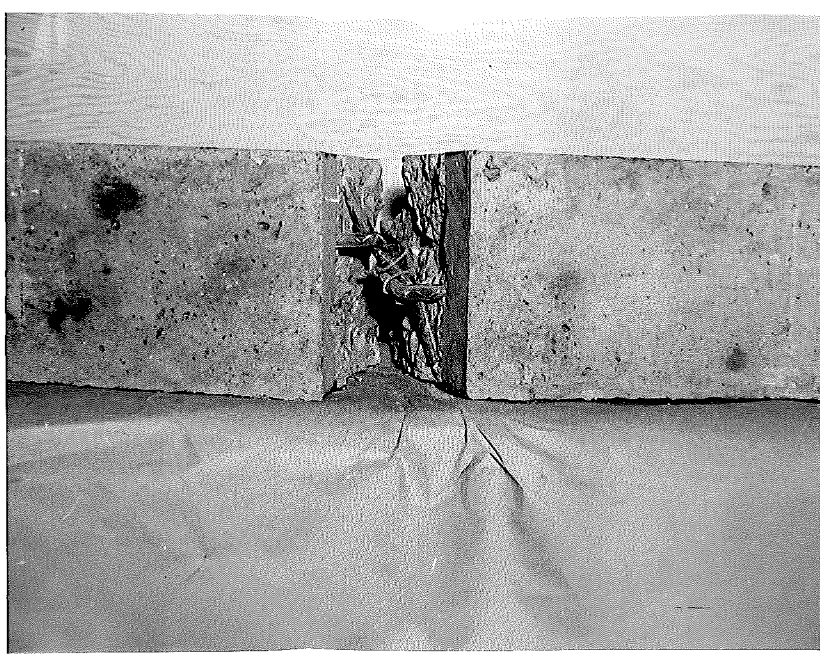

Figure 14. Failure of hinge in modulus of rupture test.

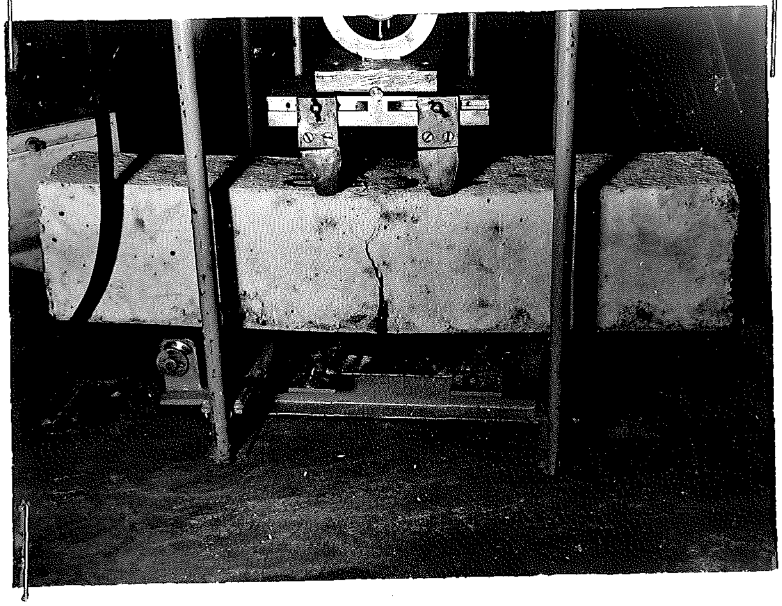

Figure 15. Failure of concrete specimen containing continuous bar

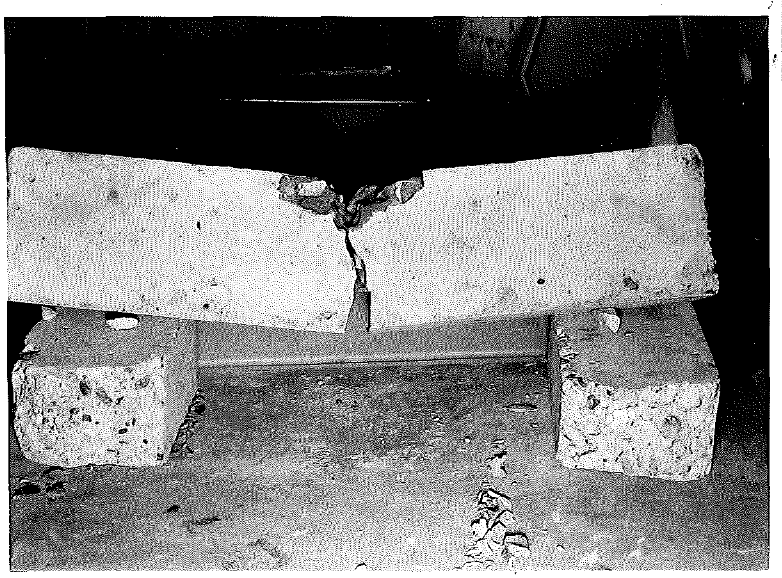

Figure 16. Specimen with continuous bar. Concrete failed in compression. Bar still unbroken.

TABLE III

RESULTS OF TENSION TESTS ON LAP JOINT

(Transverse Bars)

Arrangement of Specimen	Load to Produce Yield point of Steel		Load to Produce Failure in Concrete		Load to Produce Failure in Steel	
	Total lbs.	Yield point p. s. i.	Total lbs.	p.s.i.	Total lbs.	p.s.i.
	(1)	(2)	(3)	(4)	(5)	(6)
Bars Embedded 40 Diameter Lap	5420	50,200	No failure in bond		7800	72,200
Bars Embedded 40 Diameter Lap	6110	56,500	No failure in bond		8230	76,200
Average	5765	53,350			8015	74,200

TABLE IV

Behavior of Beam Specimens with Hinge and with Continuous Bar.

	Total Load to Produce Cracking Pounds
Hinge Embedded	5280
Hinge Embedded	4960
Average	5120
Continuous Bar	13700

TABLE V

Compressive Strength of Plain Concrete Specimens

Cylinder	Compressive Strength p.s.i.
1	2650
2	2740
3	2370
4	2370
Average	2533

measurable movement resulted because the design of the hinge holds the two sections quite intimately connected.

Another test to determine the possibility of wracking the mat through handling when in an unfolded condition was made by holding the mat firmly along one side and wracking in the plane of the mat as far as possible. This was repeated holding the opposite edge. The average total movement of one edge with reference to the other was 24 inches. This movement may be attributed to the looseness of the clips because none was evident relative to the hinge.

Data concerning the amount of transverse steel required in pavements of different thickness, as well as the tensile force which may be expected at the location of the hinge are presented in Table VI.

In view of these calculated values and taking into consideration the fact that the hinge in itself has practically no structural strength, it is obvious that the hinge as constructed is not a satisfactory substitute for continuous bar reinforcement.

CONCLUSIONS

The hinged bar mat may be considered as substantially meeting the requirements of the Michigan State Highway Department, 1942 Road and Bridge Specifications with the following exceptions.

One failure was found to be slippage of the clips along the transverse bars due to the method of bending and installing. Another failure occurred in loosening of the clip under a load perpendicular to the plane of the mat, which also may be traced to the method of fabricating and installing the clip and finally the hinge does not develop the strength of the steel bar in direct tension regardless of whether or not it is embedded in concrete.

TABLE VI

COMPUTATION OF TRANSVERSE STEEL IN PAVEMENTS

Transverse Unit Friction Pull:

At longitudinal joint per unit length $P_T = 1/2\ Wh\ y\ fs$

At Middle of Lane per Unit Length $P'_T = 1/4\ (2P_T) = 1/2\ P_T$

At Third of Width W per unit length $P''_T = 1/3\ (2P_T) = 2/3\ P_T$

For Pavement Width W = 24 ft.

Friction Coefficient f = 1.5

Unit Weight y = 150 lbs. per cu. ft.

Safety Factor S = 1.25

Yield Point = 50,000 p.s.i.

Thickness of Slab = h

Slab Thickness h in inches	Pull lbs./ft. pav.	Steel Area per ft. sq. in.	U.S. Gage Steel Spaced one foot	Diameter of Steel - in. Spaced one foot
8"	(P_T = 2250	0.0450	3	0.244
	(P'_T = 1125	0.0225	7	0.177
	(P''_T = 1500	0.0300	5	0.207
9"	(P_T = 2540	0.0506	2	0.263
	(P'_T = 1270	0.0254	6	0.192
	(P''_T = 1690	0.0338	5	0.207
10"	(P_T = 2815	0.0563	1	0.283
	(P'_T = 1408	0.0282	6	0.192
	(P''_T = 1877	0.0375	4	0.225

d = 1/2" dowels 40" apart at longitudinal joint amount to $\frac{0.1963}{3.33} = 0.059$ square inches per foot.

The first longitudinal bar on either side of the hinge was not equally spaced although only one was outside the specified one inch tolerance.

The size and spacing of transverse bars does not meet the requirements of the standard plan in that they are specified at 1/4 inch diameter rods spaced at 12 inch centers while those in the mat were 3/8 inch diameter rods spaced at 25 3/4 inch centers.

The weight of the mat meets all requirements.

The physical tests on the individual bars show the steel to be within the specified strength requirements.

ADDITIONAL REMARKS

The spacing of the longitudinal bars may have been designed to provide better folding but in any case they could easily be made to more closely meet all spacing requirements.

The weakness in the clip installation may be overcome by better fabricating practices as many approved ordinary bar mats are clipped in a similar manner.

The idea of using a hinge joint in bar mat construction has merit. However, it is believed that the efficiency of the hinge could no doubt be greatly improved by fabricating it in a different manner.