1949

Efficiency of various types of reinforcement in controlling opening of cracks in concrete pavements

Frederick Richard Heartz

Department:

Recommended Citation

Heartz, Frederick Richard, "Efficiency of various types of reinforcement in controlling opening of cracks in concrete pavements" (1949). *Masters Theses*. 4848.
https://scholarsmine.mst.edu/masters_theses/4848

EFFICIENCY OF VARIOUS TYPES OF REINFORCEMENT IN CONTROLLING OPENING OF CRACKS IN CONCRETE PAVEMENTS

BY

FREDERICK R. HEARTZ

A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

Degree of

MASTER OF SCIENCE, CIVIL ENGINEERING

Rolla, Missouri

1949

Approved by E. W. Carlton

Professor of Structural Engineering

Acknowledgment

The author wishes to express his sincere appreciation to Professor E. W. Carlton of the Civil Engineering Department, Missouri School of Mines and Metallurgy, for suggesting the problem and for his valuable advice and criticisms and to thank the other members of the Civil Engineering Department who assisted in obtaining data for this thesis.

Sincere thanks are due to Mr. William Van Breemen, Engineer of Special Assignments, New Jersey Highway Department for his generosity in furnishing the specifications for the test beams and the data he obtained in similar tests. Thanks are also due to the Wire Reinforcement Institute for their courtesy in furnishing the materials necessary to carry out the required tests.

Table of Contents

List of Illustrations

List of Tables

Introduction

Concrete as a paving material has proven very successful. Its structural strength, desirable surface characteristics, durability and economy make it suitable for the highest type pavement. However, cracking, a serious defect in early concrete roads, has not yet been completely brought under control.

The first concrete pavement was built in Bellefontaine, Ohio, in 1893, but widespread use of concrete as a paving material did not occur until the arrival of the automobile and rubber tire. Wayne County, Michigan, in 1909, started construction on the first of an extensive system of concrete county roads, after which the use of concrete for pavements developed rapidly. The automotive industry made great strides in its early years while the highway departments tried to provide suitable roads. Increasing speeds and heavier loads necessitated constant changes in design.

At first, concrete pavements were poorly designed and constructed. However, due to extensive research, the quality of the Portland Cement, the design of the concrete mix, and the equipment for placing the concrete were greatly improved in a relatively short time. Also, elaborate studies of the structural action of concrete pavements produced a wealth of valuable data. A concrete pavement can now be designed to meet almost any requirement. By thickening certain sections of the slab which may be subjected to greater stresses than other sections, and by proper spacing of joints, a uniform structural strength may be economically balanced throughout the slab.

The stresses are greater at the outer edges of the slab because, in the case of edge loading, the maximum stress is uni-directional and parallel to the slab edge; whereas, in the case of interior loading, the maximum stress acts radially from the load as a center and is equal in all directions. Therefore, it is common practice to thicken the edges of the pavement to aid in the distribution of these stresses. The thickened edge is of little value, however, unless the slab is reinforced. The chief function of the reinforcing is to control the cracking. Longitudinal cracking may be almost completely eliminated by dividing the slab into comparatively narrow strips, but transverse cracks are not as easily controlled. Clifford Older has the following to say concerning transverse cracks: (1)

"Transverse cracks may or may not detract from immediate serviceability, but their influence on ultimate life and annual maintenance cost is of serious concern for two primary reasons.

"First, they transverse the thin mid-portion of thickened edge slabs or bases; and therefore, if not thoroughly doweled or prevented from widening during contraction, they expose the adjacent slab edges to destructive live load stresses.

"Second, if not prevented from widening by bonded wire mesh or bars or kept permanently sealed by other means, nightly and seasonal contraction encourages the more or less rapid filling of the open

---

(1) Clifford Older, Crack Occurrence and Control in Concrete Pavement, Engineering News-Record, p. 50, July 9, 1931

cracks with incompressible silt or soil. Upon re-expansion, cracks wholly or partly filled with soil cannot again completely close and the adjacent sections or a whole series of them will be pushed toward the nearest expansion joints. This action repeated many times during the early life of the pavement sooner or later completely closes the expansion joints and defeats their purpose of relieving the pavement from excessive compression stresses when the temperature or moisture content rises and the pavement expands. Crack control is, therefore, a matter of prime importance."

When sufficient reinforcing is used, these cracks are held closely together and load transfer is possible by aggregate interlock action. Thus instead of a few wide cracks, a number of fine cracks are formed and they act as hinged joints creating a more or less flexible pavement. None of the load carrying capacity of the pavement is lost if these cracks are kept tightly closed. The Highway Research Board claims that if these cracks are not greater than .027 inches, the load transfer capacity will not be lost and dirt will not fill the cracks. The use of reinforcement has also been found to give good protection against the detrimental effects of unpredictable conditions which cause tension in the concrete and thus a possible failure.

In 1931 and 1932 tests were conducted by the Michigan Highway Department (2) to determine the effectiveness of aggregate interlock

---

(2) A. C. Benkelman, Tests of Aggregate Interlock at Joints and Cracks, Engineering News-Record, p. 227, Aug. 24, 1933

in transferring shear and the value of reinforcing in increasing the bond of cracks and joints. Loads were applied alternately at cracks in the summer, fall, and winter and the amount of deflection measured in each case. They found that in the summer the cracks in plain pavement transferred 35 per cent of the load, the cracks in the mesh reinforced pavement 48 per cent, and the cracks in the bar-mat reinforced pavement 48 per cent. In the fall the corresponding values were 10, 47, and 49 per cent respectively and in the winter 12, 49, and 48 per cent. From these tests, Mr. Benkelman draws the following conclusions:

"In case of the mesh and bar-mat reinforced pavement, average values of transfer for the summer, fall, and winter loadings indicate that the steel has served in a most remarkable manner to hold the slabs formed by the cracks tightly together. There is no effect, whatsoever, shown by the alternation of load. This fact strongly indicates that when roughened edges of two slabs are held firmly together, the aggregate interlock may be expected to function perfectly and permanently as a load-transfer medium."

The critical property which usually limits the structural capacity of concrete pavements is its flexural or so-called "modulus of rupture" strength. This strength usually varies from 600 to 800 psi. Approximately fifty per cent is considered a conservative working strength. There are many stress producing conditions to which a concrete pavement may be exposed. The most important ones are warping due to differential temperature, and wheel loads. Differential temperature alone can cause stresses of 400 psi or greater.

Wheel loads may cause 200 to 300 psi. Thus it is seen that these two conditions alone can cause flexural stresses of 600 to 700 psi. (3)

---

(3) Royall D. Bradbury, Reinforced Concrete Pavements, p. 5, Wire Reinforcement Institute, 1938

Increasing the slab thickness will reduce the stresses due to wheel loads, but on the other hand, it will increase the stresses due to differential temperature. Thus it is apparent that slab thickness alone cannot be used to control the intensity of flexural stresses. Reinforcing, therefore, plays an important role in controlling these flexural stresses.

Welded wire fabric reinforcing, one of the most common types of reinforcement for concrete pavements, consists of parallel longitudinal wires across which are transverse wires, electrically welded at each intersection, thus forming a mesh with square or rectangular openings. The size and spacing of the longitudinal and transverse wires are varied to give many different types of wire reinforcement. Some combinations of longitudinal and transverse wires seem to be more advantageous than others in regard to the control of crack opening, slip, etc. Numerous tests are being made to determine the best combinations. The author has attempted in this thesis to determine some of the more favorable combinations which are most effective in preventing crack opening. Although the tests are by no means complete, they do give some definite and useful data on the subject. This type of test was suggested by the New Jersey State Highway Department.

Object of Investigation

To date very little work has been done on the subject of the amount of crack opening for different loads on concrete pavement. It is a known fact that these cracks must be held together sufficiently to have aggregate interlocking action if the pavement is to transfer loads from one edge of a crack to the other. The maximum permissable opening has been set at .027 inches by the Highway Research Board.

The author has attempted in this investigation (1) to determine the effect of different spacing and different sizes of longitudinal and transverse wires in controlling crack opening in concrete pavements; (2) to obtain data which will aid in the design of reinforcing for highway pavements to control cracking and prevent the loss of aggregate interlock action; (3) to determine the limiting size and spacing of transverse wires of wire mesh reinforcing.

A preliminary test on the effect of pickeling reinforcing rods in acid was also made to determine if some such method could be used to increase allowable bond stresses.

There are several questionable factors in regard to the correct amount of reinforcing steel to be used in concrete pavements for highways. The Wire Reinforcement Institute has an extensive research program in progress to further the use of wire mesh reinforcing by eliminating some of the guesswork in regard to the amount of reinforcing required in concrete highway slabs.

The first series of tests in this program was performed at the Missouri School of Mines and Metallurgy by Mr. E. A. Weinel.(4) His problem was to ascertain the effect on bond of varying the length of embeddment and the mechanical anchorage value of transverse wires in welded wire fabric. For the tests on bond, single lengths of plain wire were embedded varying lengths and pull-out tests were performed. For the anchorage tests, Mr. Weinel used a single length of longitudinal and a single length of transverse wire. The surface of the longitudinal wire was greased to release the bond, thus testing only the mechanical anchorage of the transverse wires. He concluded that the transverse wires of the welded wire fabric, acting as anchorage, did not allow appreciable slip until the welds failed in shear. These tests also proved that a single weld was capable of developing about 90% of the tensile strength of a single longitudinal wire, provided the weld was sound.

Mr. A. A. Becker conducted the second series of tests on welded wire reinforcement.(5) These tests were similar to Mr. Weinel's

---

(4) E. A. Weinel, The Mechanical Anchorage Value of the Transverse Wires in Welded Wire Fabric, Missouri School of Mines and Metallurgy, 1948

(5) A. A. Becker, Interrelationship of Transverse Anchorage and Adhesive Bond in Welded Wire Reinforcement, Missouri School of Mines and Metallurgy, 1949

except that the longitudinal wires were not greased and a more exhaustive study was made. The results of these tests seemed to indicate that the adhesive bond on the longitudinal wires plus the mechanical anchorage of the transverse wires in most cases was considerably greater than the tensile strength of the longitudinal wires. The amount of slip for different types of wire mesh due to uniformly increasing loads was plotted on graphs. The amount of elongation was found to be negligible and was, therefore, neglected in determining slip. Mr. Becker also conducted a series of experiments to determine the effect of two and four weeks rust on the bond. These tests will be used as a comparison for the pickeling tests in this paper.

In line with the preceding experiments, the author hopes to add valuable data which may be used to give a more thorough knowledge of the use of welded wire mesh. This research problem is part of the Wire Reinforcement Institute's program, and it is believed that the information obtained should be of value in that it will aid in the actual design of pavements to control cracking when wire fabric is used as reinforcing.

Materials Used in Test Beams

All test beams were poured and tested in the materials laboratory of the Civil Engineering Department of the Missouri School of Mines and Metallurgy. The materials used are described as follows:

Reinforcing: The wire used in this investigation was furnished by the following members of the Wire Reinforcement Institute, Inc.: American Steel and Wire Company, Colorado Fuel and Iron Corporation, Pittsburgh Steel Products Company, Truscon Steel Company, Laclede Steel Company, and Keystone Steel and Wire Company. The mesh was all new, cold-drawn, structural steel wire in sheets. Cold-drawn wire has no definite yield point at, or near, its elastic limit. Therefore, it tends to resist stress throughout its entire strength range without revealing any sudden excessive elongation such as develops in a hot rolled bar at about 60 to 65 per cent of its ultimate strength. Cold-drawn wire is, therefore, much better than hot rolled wire as concrete pavement reinforcing because it will tend to prevent excessive cracking due to elongation, since the steel can be stressed almost to the ultimate before any appreciable elongation occurs. The wire used in the tests satisfied the ASTM Specifications for cold-drawn wire. Part of these specifications in brief are as follows:

Tensile strength, min. psi — 70,000
Yield point, min. psi -- 0.8 tensile strength
Reduction of area, min. per cent — 30

The same wire mesh was used by Mr. Becker in his investigations and found to have the following properties (average values):

Tensile Strength	80,000 psi
Yield Stress	75,000 psi
Per Cent Reduction of Area	60 per cent
Per Cent Elongation	3 per cent
Per Cent Carbon	.12 per cent
Per Cent Manganese	.42 per cent
Per Cent Phosphorus	.012 per cent
Per Cent Sulphur	.025 per cent

Test specimens were cut from sheets of wire mesh, the transverse wires being about 3 inches long. The wire was free from rust. The following gauges of wire were tested: longitudinal wires:- #00, #2, and #6; transverse wires:- #2, #3, #4, #6, and #8. #00 gauge wire was used for the pickeling tests.

Concrete: The concrete was made according to the specifications for class A concrete set up by the Missouri State Highway Department. The mix was designed to give an ultimate strength of about 3,000 psi. Approved Pacific sand and standard $\frac{3}{4}$ inch limestone, the same as that used by the Missouri State Highway Department, was used in these tests. Commercial brands of standard and air-entraining Portland cement were used. The same mix that was used by Mr. Becker(6) was found suitable for these tests. A 1:2.2:3.2 mix with 6$\frac{1}{4}$ gallons of water per sack of cement was mixed in a 3 cu. ft. mixer. A compression cylinder, six inches in diameter by twelve inches in height, was cast for each batch of concrete. The average compressive strength was over 3,300 psi.

---

(6) Becker, op. cit., p. 7

Forms: The forms were made from ¾ inch plywood and the sides were lined with galvanized tin to permit re-use. The ends were drilled for four hook bolts which were cast in the ends of the beams for use in testing. A partition of galvanized tin was placed in the center of the form making two separate sections of concrete. Wire supports were used to hold the reinforcing in place during the pouring. The forms were oiled with used motor oil before each pour.

Pickeled Steel: The steel used for the preliminary test to determine the effects of pickeling on bond stress was cut from plain #00 gauge wire. Pieces about one inch long were placed first in a cold and then in a hot, ten per cent solution of sulphuric acid for different intervals of time. A ten per cent solution was used because that is a standard solution and can be used commercially. From the results of these tests, it was decided to try rods which had been submerged in hot sulphuric acid, ten per cent solution, for five, ten, and fifteen minutes. Three of each were embedded in concrete cylinders six inches in diameter and twelve inches in height for pull-out tests. These cylinders were cured 28 days.

Test Beams and Testing Apparatus

Special beams were cast for determining the amount of crack opening for different loads using various combinations of wire fabric for reinforcing. (See Fig. 1.) These beams were so designed that when a load was applied at the hooks on each end, the reinforcing was the only thing that held the beam together at the mid-point. A partition of galvanized tin completely destroyed any tension in the concrete. This partition was thoroughly greased with cup grease to prevent any bond between it and the concrete. The beams were forty-two inches long and the reinforcing was cut as long as possible, no transverse wires being placed at the mid-point of the beam. Three beams were cast of each type containing the following reinforcing:

Test No.	Long. Wire	Trans. Wire	Manufacture
1	1 - #00 - 6"	#3 - 6"	Truscon
2	1 - # 2 - 6"	#4 - 12"	Truscon
3	1 - # 2 - 6"	#8 - 6"	Truscon
4	1 - # 2 - 2"	#2 - 6"	Pittsburgh Steel
5	1 - # 2 - 4"	#2 - 4"	Pittsburgh Steel
6	1 - # 2 - 4"	#8 - 6"	Colo. Fuel & Iron
7	1 - # 2 - 3"	#8 - 8"	Keystone Steel
8	1 - # 2 - 3"	#2 - 6"	American Steel
9	1 - # 2 - 3"	#4 - 4"	American Steel
10	1 - # 2 - 4"	#8 - 12"	Colo. Fuel & Iron
11	1 - # 2 - 3"	#2 - 12"	American Steel
12	1 - # 6 - 6"	#6 - 6"	Laclede Steel

For dimensions and location of the reinforcing see the sketch, Fig. 1. The transverse wires were approximately three inches long and symetrically spaced about the mid-point of the beams.

Because of the width of the beams, 5½", only a few types of wire mesh with two longitudinal wires could be tested. These tests should give some indication, however, as to the effect of more than one longitudinal wire. Several beams with two longitudinal rods were cast but could not be tested at this time because the testing machine was broken.

The beams were tested in a 200,000 pound Tinius-Olsen testing machine. The machine has three load scales, a 10,000, a 100,000, and a 200,000 pound scale. The 10,000 pound scale was used in order to obtain the greatest accuracy for reading the load. After the beam was placed in the testing machine, two Ames dials were clamped to the upper half of the beam and wooden blocks were clamped to the lower half to act as stops for the dials. The loads were applied by increments and readings were taken on the Ames dials after each increment. The average readings on these dials measured the actual crack opening at the mid-point when the load was applied.

Pickeling Experiment

The steel for this test was pickeled in a ten per cent solution of hot sulphuric acid. A total of nine tests were made, three at five minutes, three at ten minutes, and three at fifteen minutes in the hot sulphuric acid. These rods were embedded six inches in concrete cylinders six inches in diameter and twelve inches in height. After curing twenty-eight days, a pull-out test was performed on a 20,000 pound Emery-Southwark testing machine which is located in the Materials Laboratory of the Civil Engineering Department at the Missouri School of Mines and Metallurgy. A test cylinder was poured at the same time to determine the ultimate strength of the concrete.

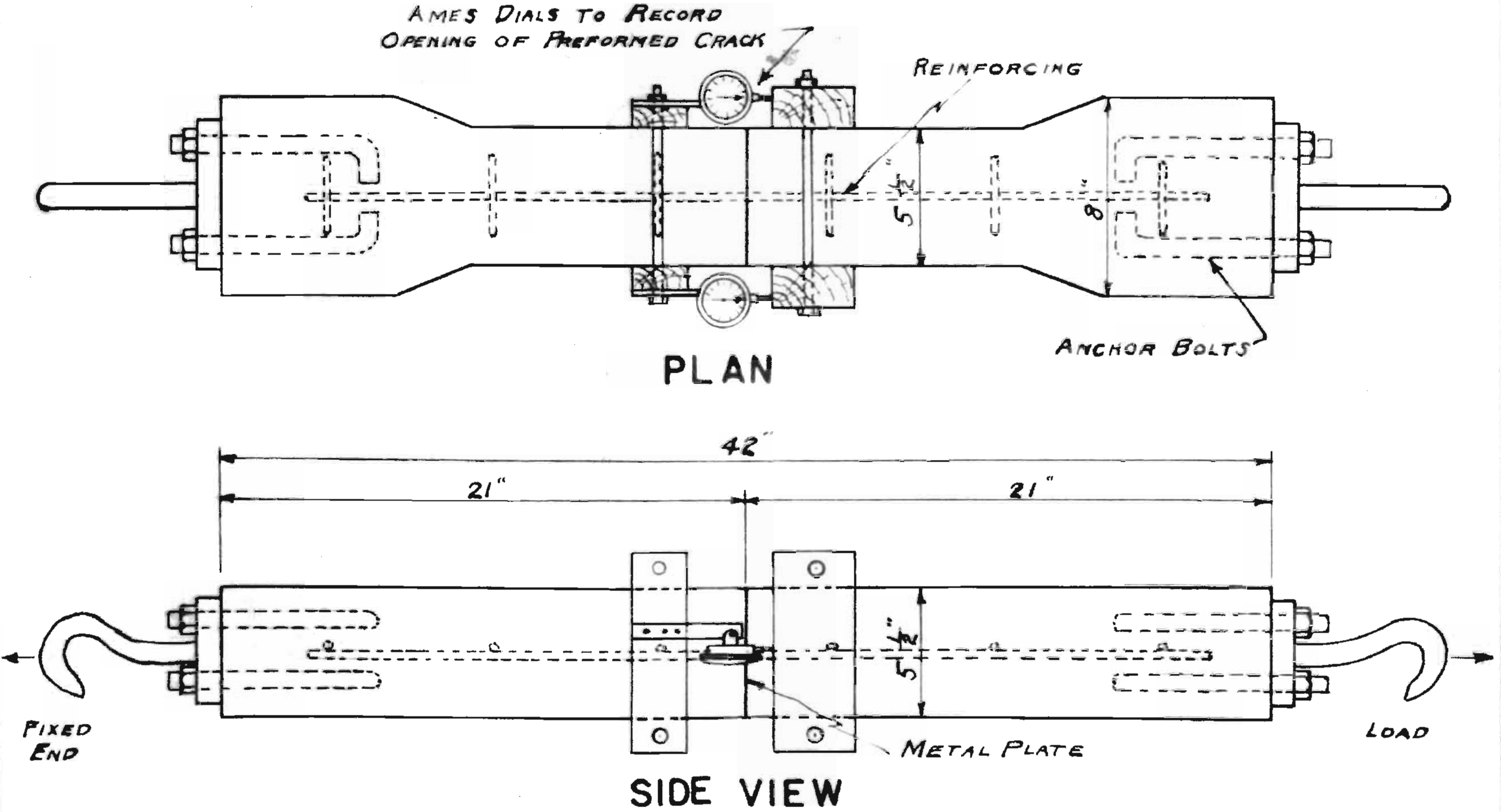


FIG. 1

SKETCH OF TEST BEAM

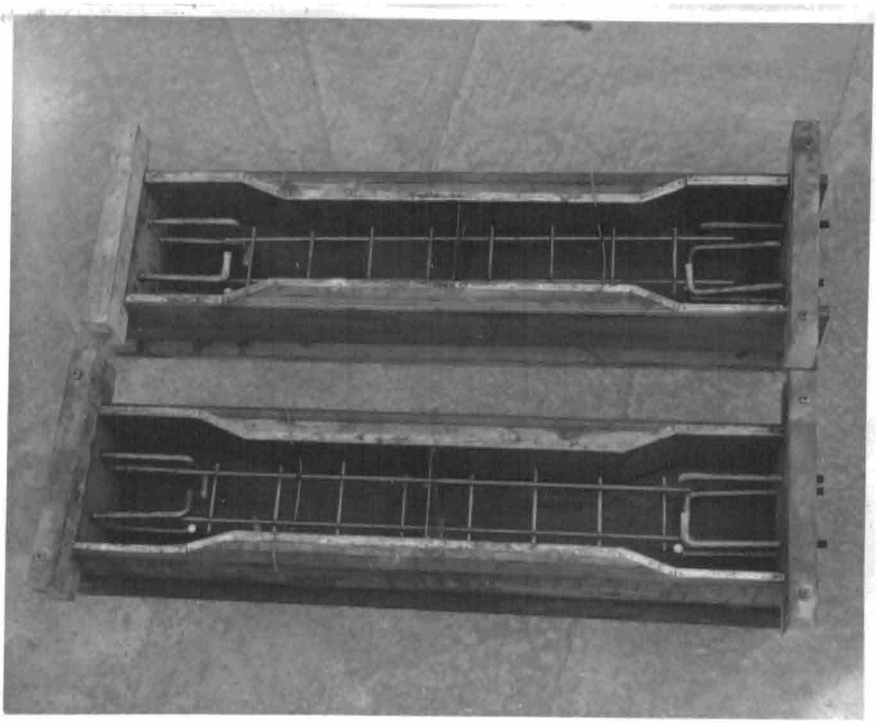


Fig. 2

View showing forms ready for pouring. These beams were reinforced with two longitudinal wires. However, they could not be tested at this time due to a failure of the testing machine.

Laboratory Procedure

After the forms were constructed they were assembled and oiled with motor oil. The partition was greased and inserted between two rows of finish nails which were used to hold it in place. The partition was in two pieces to permit the reinforcing to be placed through it. The bottom half was inserted and the reinforcing placed on top of it; then the top half was placed over the reinforcing. Specially shaped wire supports were used to hold the reinforcing in place while the beam was being cast. After the hook bolts were placed in the ends, the forms were ready for pouring. (See Fig. 2.)

The concrete was mixed in a three cubic foot tilt mixer, one mixer full being enough to cast three beams, all with the same reinforcing. A test cylinder was cast for each series of three beams. Thus one batch poured three identical beams and a test cylinder. The concrete was carefully rodded when placed in the forms. As was stated before, a 1 : 2.2 : 3.2 mix with $6\frac{1}{4}$ gallons of water per sack of cement was used. This concrete was found to average about 3300 psi in compression after twenty-eight days.

The forms were stripped about two days after pouring and the beams were either placed in a moist closet or submerged in a tank of water for at least twenty-eight days. They were then ready for testing.

Specially designed hooks were bolted on the anchor bolts and the beam lifted into the 200,000 pound Tinius Olsen testing machine.

The top hook was fastened to a fixed head and the bottom to a movable head. U-bolts were designed to accommodate these hooks and were bolted to the fixed and movable heads of the testing machine. The gauges, Ames dials, described as Left and Right in the data sheets were fastened to wooden strips and clamped to the sides of the beam by means of bolts. These gauges were clamped to the fixed end of the beam. Thicker wooden strips were clamped to the movable end to act as stops for the Ames dials. These were carefully adjusted to register the amount of crack opening between the two halves of the beam. By placing these dials on the center line in one direction and by having two dials, one on each side of the beam, the average amount of crack opening was readily determined.

The beam was then ready for the load, which was applied in increments and the left and right dials read after each increment. Two hundred pound increments were used in most of the tests. These loads were applied until the crack was opened too wide to be of any practical value. In most cases the crack was opening very rapidly at the end of the test. The load was then removed. Loads were applied a second time in some cases but the information was thought to be of little value and was, therefore, discarded. The beams were smashed up with a sledge hammer to permit re-use of the anchor bolts. In no case were the beams tested to failure.

The tests for the effect of pickeling on the bond stress of reinforcing were conducted on a 20,000 pound Emery-Southwark testing machine. A special rack was used to hold the rods in place while the cylinders were filled with concrete. After curing in the moist closet, they were placed in the testing machine in an inverted position as shown in Fig. 3, and loads were applied at the rate of five hundred pounds a minute until the maximum value for bond was reached. The total load divided by the bond area gave the unit bond stress in psi.

Fig. 3

View showing a typical test of the effect of pickeling on the bond stress. A cylinder is being tested in the Emery-Southwark, 20,000 pound testing machine. Mr. Becker is at the right taking data and the author is at the controls.

DATA SHEET 1A

Beam # 1A Date Poured - Dec. 21, 1948 Date Tested - Feb. 11, 1949

Steel Manufacturer - Truscon Compressive Strength - 3000 psi

Long. Wire 1 - #00 - 6" Transverse Wire #3 - 6"

Table of Elongation in Inches

Load	Beam A						
in Lbs.	Lt. Dial	Rt. Dial					Average
0	.000	.000					.0000
200	.001	.000					.0005
400	.000	.001					.0005
600	.001	.002					.0015
800	.001	.002					.0015
1000	.001	.003					.0020
1200	.002	.003					.0025
1400	.002	.004					.0030
1600	.002	.004					.0030
1800	.003	.005					.0040
2000	.003	.005					.0040
2200	.004	.006					.0050
2400	.004	.007					.0055
2600	.005	.008					.0065
2800	.005	.009					.0070
3000	.006	.010					.0080
3200	.006	.010					.0080
3400	.007	.011					.0090
3600	.008	.012					.0100
3800	.010	.013					.0115
4000	.011	.014					.0125
4200	.012	.015					.0135
4400	.013	.016					.0145
4600	.015	.017					.0160
4800	.017	.018					.0175
5000	.018	.020					.0190
5200	.020	.021					.0205
5400	.022	.022					.0220
5600	.024	.024					.0240
5800	.026	.026					.0260
6000	.030	.029					.0295

DATA SHEET 1B

Beam # 1B   Date Poured - Dec. 21, 1948   Date Tested - Feb. 18, 1949

Steel Manufacturer - Truscon   Compressive Strength - 3000 psi

Long. Wire 1 - #00 - 6"   Transverse Wire #3 - 6"

Table of Elongation in Inches							
Load in Lbs.			Beam B				
			Lt. Dial	Rt. Dial			Average
0			.000	.000			.0000
200			.000	.000			.0000
400			.000	.000			.0000
600			.001	.000			.0005
800			.001	.001			.0010
1000			.001	.001			.0010
1500			.002	.002			.0020
2000			.003	.004			.0035
2500			.004	.005			.0045
3000			.005	.007			.0060
3500			.006	.009			.0075
4000			.007	.011			.0090
4500			.009	.016			.0125
5000			.012	.020			.0160
5500			.015	.025			.0200
6000			.022	.032			.0270

DATA SHEET 1C

Beam # 1C Date Poured - Dec. 21, 1948 Date Tested - Feb. 18, 1949

Steel Manufacturer - Truscon Compressive Strength - 3000 psi

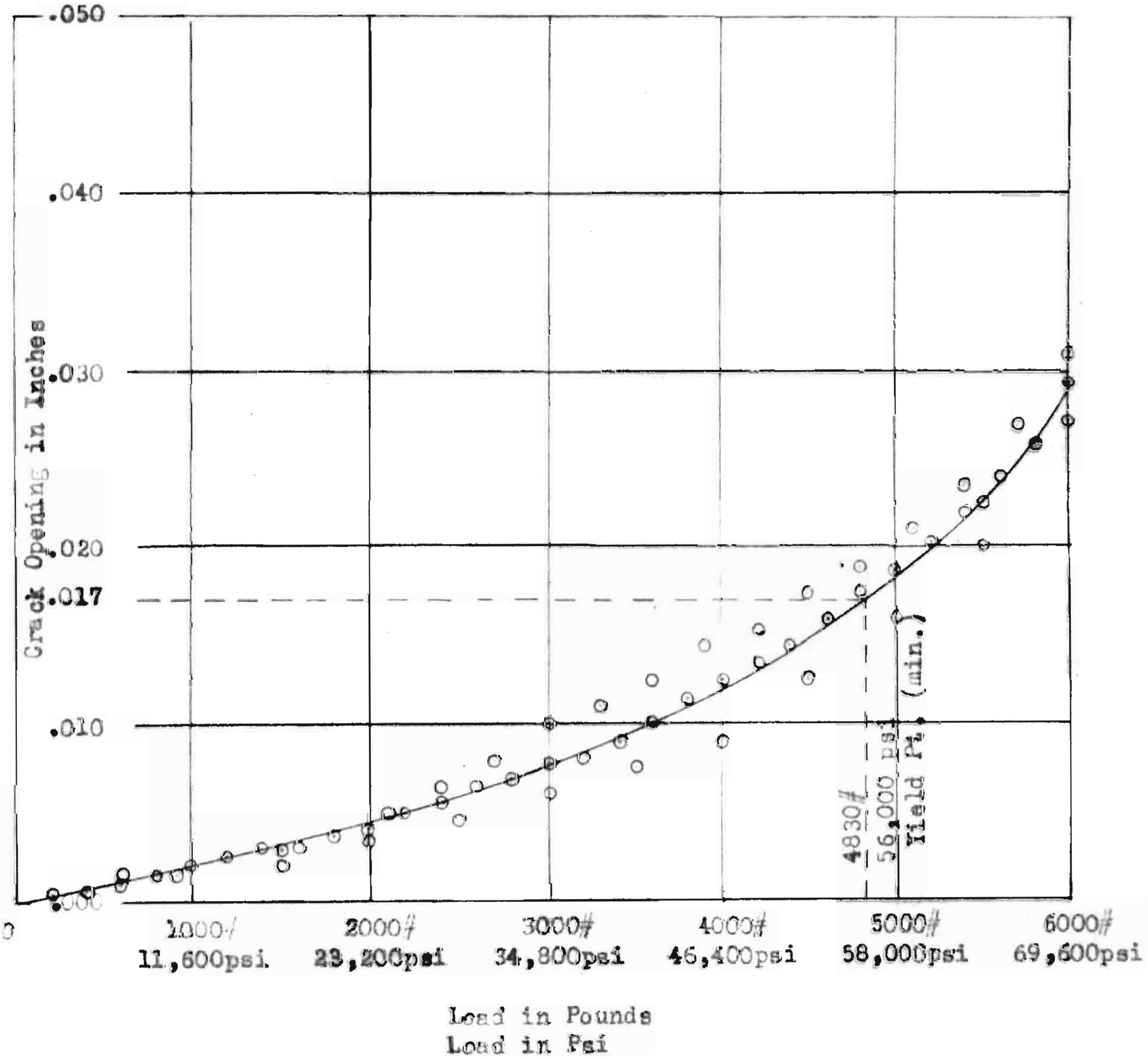
Long. Wire 1 - #00 - 6" Transverse Wire #3 - 6"

Table of Elongation in Inches

Load in Lbs.					Beam C		
					Lt. Dial	Rt. Dial	Average
0					.000	.000	.0000
300					.000	.000	.0000
600					.002	.000	.0010
900					.004	-.001	.0015
1200					.007	-.002	.0025
1500					.008	-.002	.0030
1800					.010	-.003	.0035
2100					.013	-.003	.0050
2400					.017	-.004	.0065
2700					.020	-.004	.0080
3000					.023	-.003	.0100
3300					.025	-.003	.0110
3600					.028	-.003	.0125
3900					.031	-.002	.0145
4200					.033	-.002	.0155
4500					.036	-.001	.0175
4800					.039	-.001	.0190
5100					.042	-.000	.0210
5400					.046	.001	.0235
5700					.051	.003	.0270
6000					.057	.005	.0310

GRAPH OF CRACK OPENING FOR VARIOUS LOADS

PLATE 1



Beam	Description	Steel Manufacturer	Position of Transverse Wire
# 1	Long.Wire 1-#00-6" Tran.Wire #3-6"	Truscon	3" from center

Comp. Str. of Concrete	Age	Date of Test	Crack Opening at 3000 lbs.	Load to Open Crack .01"
3000 psi	7 wks.	Feb. 18, '49	.008"	3600 # 41,600 psi

DATA SHEET 2

Beam # - 2 Date poured - Dec. 21, 1948 Date Tested - Feb. 11, 1949

Steel Manufacturer - Truscon Compressive Strength - 3000 psi

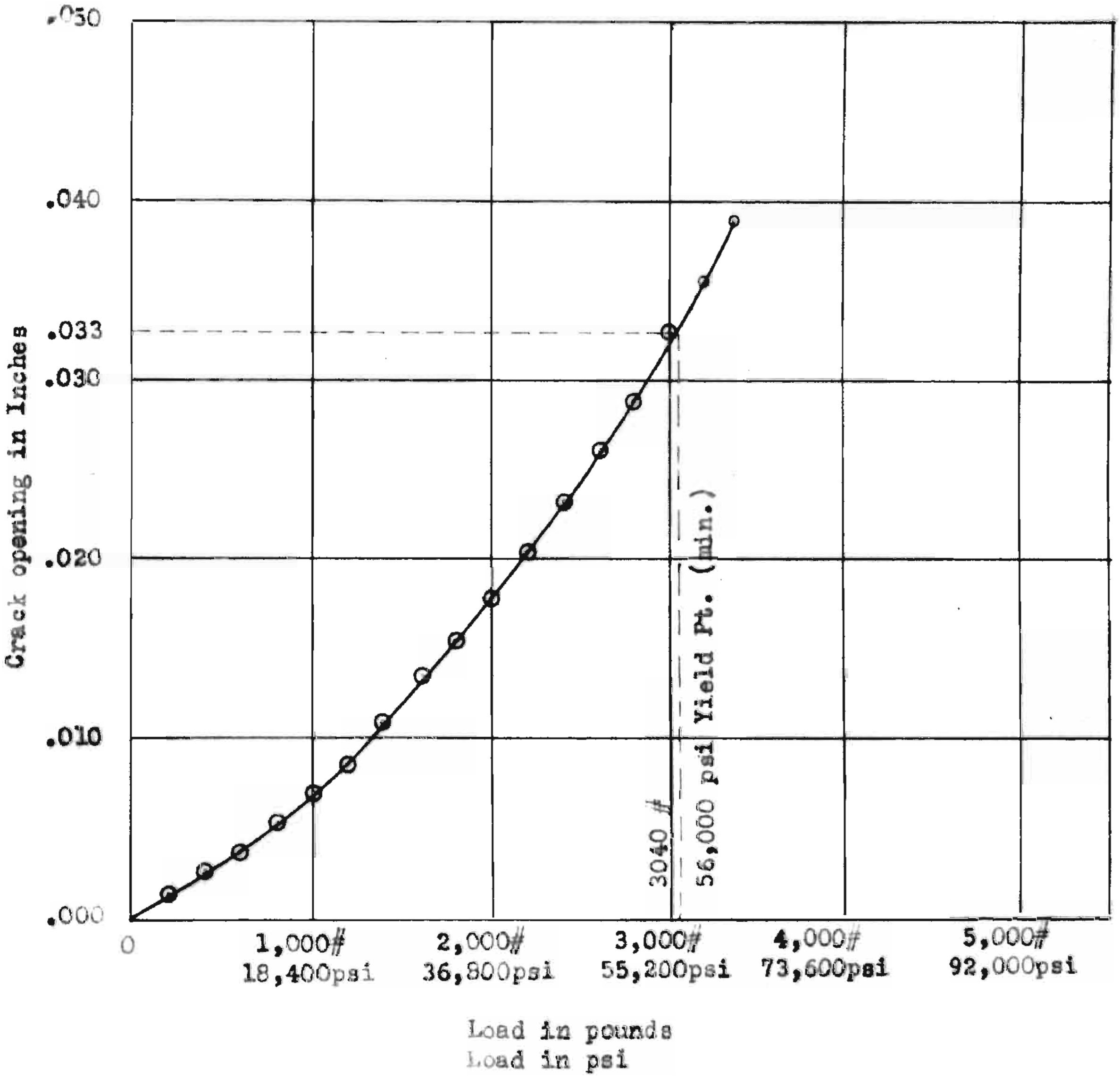
Long. Wire - 1 - #2 - 6" Transverse Wire - #4 - 12"

Table of Elongation in Inches

Load in Lbs.	Beam A		Beam B		Beam C		
	Lt. Dial	Rt. Dial	Lt. Dial	Rt. Dial	Lt. Dial	Rt. Dial	Average
0	.000	.000	.000	.000	.000	.000	.0000
200	.000	.003	.000	.000	.006	-.001	.0013
400	.000	.006	.001	.001	.010	-.002	.0027
600	-.001	.009	.002	.002	.014	-.003	.0038
800	-.001	.012	.003	.002	.019	-.004	.0052
1000	-.001	.018	.004	.003	.022	-.004	.0070
1200	.000	.022	.005	.004	.027	-.004	.0087
1400	.001	.026	.006	.006	.031	-.004	.0110
1600	.002	.033	.008	.008	.034	-.003	.0137
1800	.003	.037	.010	.009	.038	-.003	.0157
2000	.003	.040	.013	.012	.041	-.001	.0180
2200	.004	.042	.016	.015	.045	.000	.0207
2400	.006	.049	.018	.017	.048	.002	.0233
2600	.008	.056	.020	.019	.051	.004	.0263
2800	.009	.060	.023	.022	.055	.005	.0290
3000	.011	.066	.026	.025	.060	.009	.0328
3200			.029	.028	.068	.014	.0348
3400			.033	.034	.076	.020	.0408

GRAPH OF CRACK OPENING FOR VARIOUS LOADS

PLATE 2



Beam	Description	Steel Manufacturer	Position of Transverse Wire
# 2	Long.Wire 1-#2-6" Tran.Wire #4-12"	Truscon	6" from center

Comp. Str. of Concrete	Age	Date of Test	Crack opening at 3000 lbs.	Load to Open Crack .01"
3000 psi	8 wks.	Feb. 18,'49	.033"	1300 # 23,900 psi

DATA SHEET 3

Beam # 3 Date Poured - Dec. 24, 1948 Date Tested - Feb. 25, 1949

Steel Manufacturer - Truscon Compressive Strength - 3870 psi

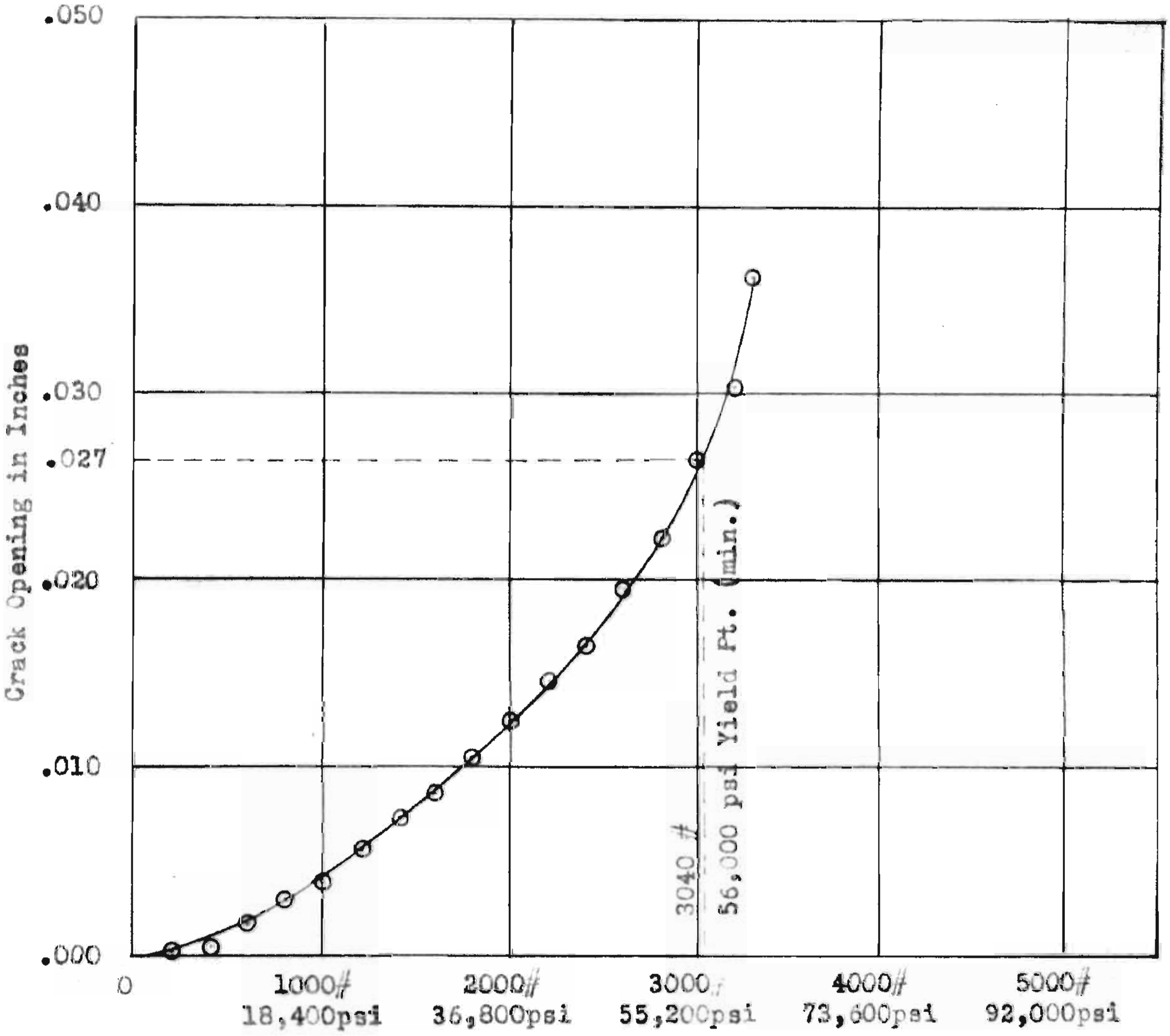
Long. Wire - 1-#2 - 6" Transverse Wire - #8 - 6"

Table of Elongation in Inches

Load in Lbs.	Beam A		Beam B		Beam B		
	Lt. Dial	Rt. Dial	Lt. Dial	Rt. Dial	Lt. Dial	Rt. Dial	Average
0	.000	.000	.000	.000	.000	.000	.0000
200	.001	.000	.000	.000	.001	.000	.0003
400	.003	.000	--	--	.001	.000	.0005
600	.005	.000	.001	.001	.002	.002	.0018
800	.007	.000	.003	.002	.003	.003	.0030
1000	.009	.000	.004	.003	.004	.004	.0040
1200	.014	.001	.005	.004	.005	.005	.0057
1400	.018	.001	.006	.006	.006	.007	.0073
1600	.021	.002	.008	.007	.007	.008	.0088
1800	.025	.003	.010	.009	.008	.009	.0107
2000	.027	.005	.011	.010	.010	.012	.0125
2200	.030	.007	.013	.014	.011	.014	.0148
2400	.033	.009	.014	.015	.012	.017	.0167
2600	.036	.012	.018	.018	.014	.020	.0197
2800	.039	.015	.020	.021	.015	.024	.0223
3000	.043	.018	.023	.024	.017	.028	.0268
3200	.047	.022	.026	.027	.025	.036	.0305
3400	.053	.029	.032	.032	--	-	.0365
3600	.071	.047	.044	.044	--	--	.0515

GRAPH OF CRACK OPENING FOR VARIOUS LOADS

PLATE 3



Load in Pounds
Load in Psi

Beam	Description	Steel Manufacturer	Position of Transverse Wire
# 3	Long. Wire 1-#2-6" Tran. Wire #8-6"	Truscon	3" from center

Comp. Str. of Concrete	Age	Date of Test	Crack Opening at 3000 lbs.	Load to Open Crack .01"
3870 psi	9 wks.	Feb. 25,'49	.027"	1800 # 33,100 psi

DATA SHEET 4

Beam # - 4 Date Poured - Dec. 24, 1948 Date Tested - Feb. 25, 1949

Steel Manufacturer - Pittsburgh Steel Compressive Strength - 3870 psi

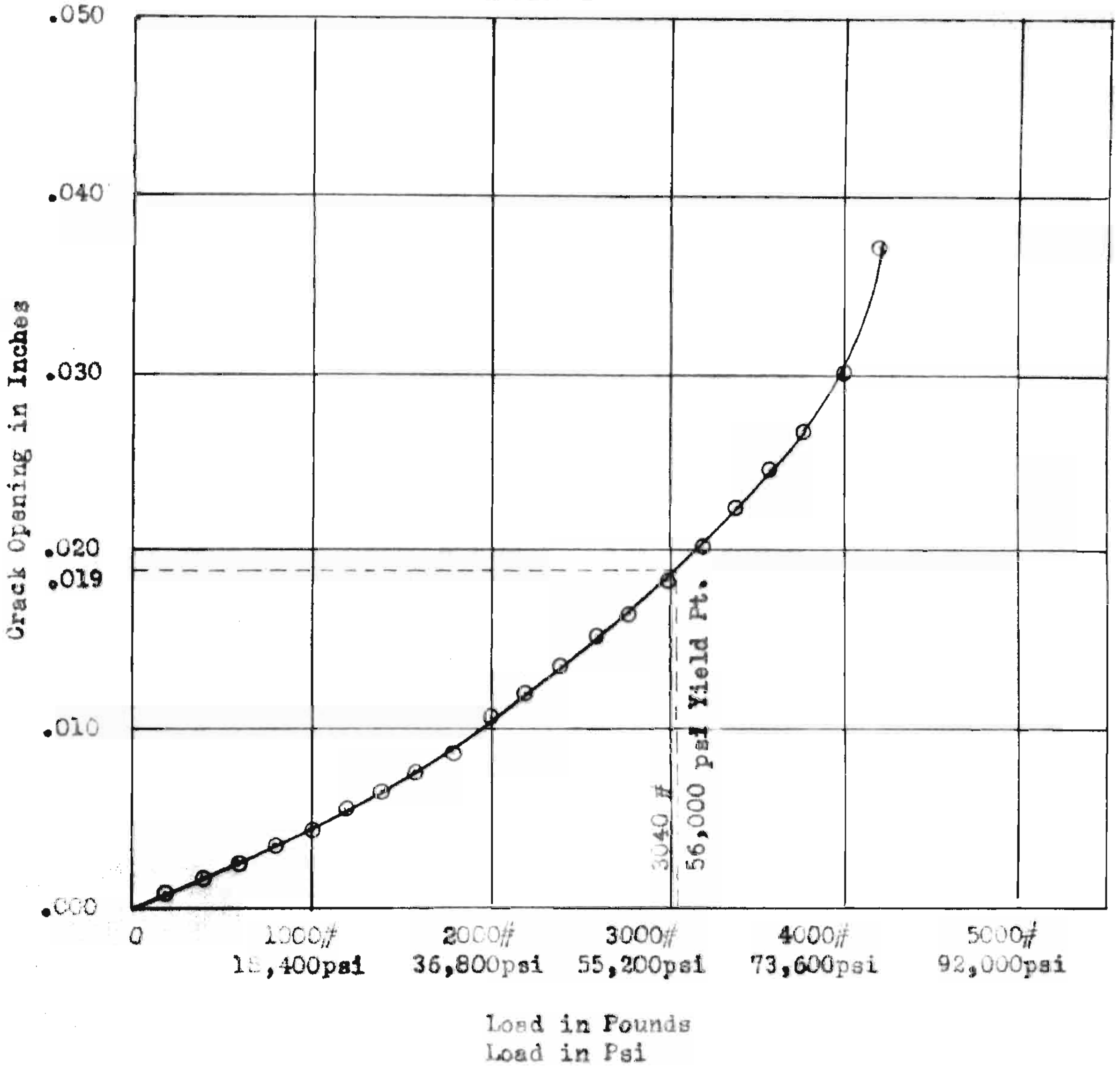
Long. Wire 1 - #2 - 2" Transverse Wire #2 - 6"

Table of Elongation in Inches

Load in Lbs.	Beam A		Beam B		Beam C		
	Lt. Dial	Rt. Dial	Lt. Dial	Rt. Dial	Lt. Dial	Rt. Dial	Average
0	.000	.000	.000	.000	.000	.000	.0000
200	.002	.000	.000	.002	.000	.000	.0007
400	.004	.000	.000	.003	.001	.001	.0015
600	.006	.000	.000	.005	.002	.001	.0023
800	.007	.001	-.001	.008	.003	.002	.0033
1000	.008	.002	-.002	.010	.004	.003	.0042
1200	.010	.003	-.002	.013	.005	.004	.0055
1400	.011	.004	-.002	.015	.006	.005	.0065
1600	.012	.006	-.002	.017	.007	.006	.0077
1800	.013	.007	-.001	.019	.008	.007	.0088
2000	.015	.009	.001	.022	.010	.008	.0108
2200	.017	.010	.002	.024	.011	.008	.0120
2400	.019	.012	.004	.026	.013	.009	.0138
2600	.021	.013	.005	.028	.016	.009	.0153
2800	.023	.015	.006	.030	.018	.009	.0168
3000	.025	.016	.008	.032	.021	.009	.0185
3200	.027	.018	.009	.034	.024	.010	.0203
3400	.030	.021	.011	.036	.027	.012	.0226
3600	.034	.021	.014	.039	.029	.013	.0250
3800	.038	.022	--	--	.032	.016	.0270
4000	.043	.023	--	--	.035	.019	.0300
4200	.051	.024	--	--	-	--	.0375
4400	.059	.032	--	--	--	--	.0455

GRAPH OF CRACK OPENING FOR VARIOUS LOADS

PLATE 4



Beam	Description	Steel Manufacturer	Position of Transverse Wire
# 4	Long.Wire 1-#2-2" Tran.Wire #2-6"	Pittsburgh Steel Products Co.	3" from center

Comp. Str. of Concrete	Age	Date of Test	Crack Opening at 3000 lbs.	Load to Open Crack .01"
3870 psi	9 wks.	Feb. 25,'49	.019"	2000 # 36,800 psi

DATA SHEET 5

Beam # - 5 Date Poured - Dec. 29, 1948 Date Tested - March 17, 1949

Steel Manufacturer - Pittsburgh Steel Compressive Strength - 3550 psi

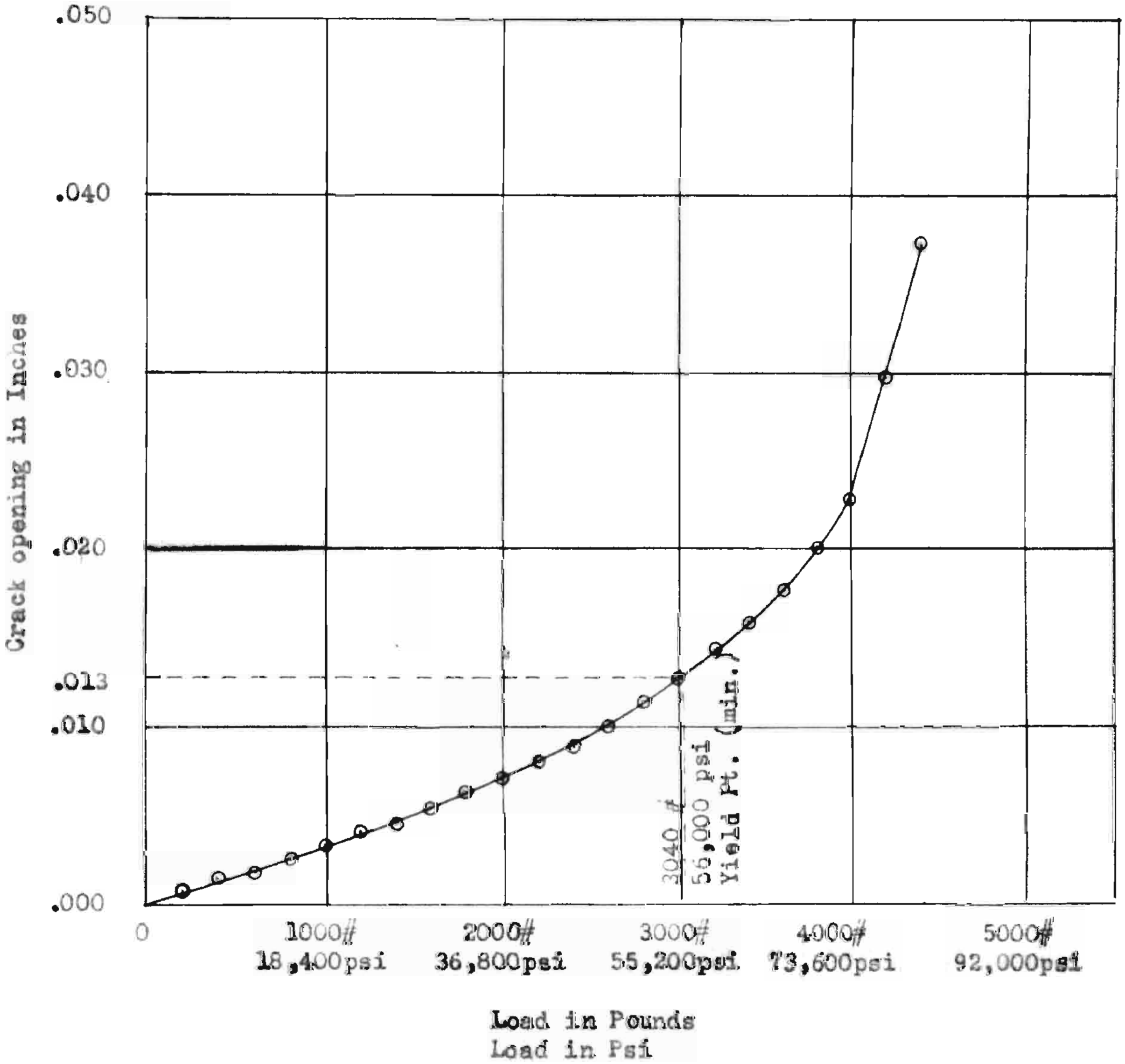
Long. Wire 1 - #2 - 4" Transverse Wire #2 - 4"

Table of Elongation in Inches

Load in Lbs.	Beam A		Beam B		Beam C		
	Lt. Dial	Rt. Dial	Lt. Dial	Rt. Dial	Lt. Dial	Rt. Dial	Average
0	.000	.000	.000	.000	.000	.000	.0000
200	.002	.000	.003	-.002	.001	.000	.0007
400	.002	.001	.006	-.003	.003	-.001	.0013
600	.002	.001	.007	-.003	.005	-.001	.0018
800	.002	.002	.010	-.004	.007	-.002	.0025
1000	.002	.003	.011	-.004	.009	-.002	.0032
1200	.003	.004	.014	-.005	.011	-.003	.0040
1400	.003	.004	.015	-.005	.014	-.004	.0045
1600	.004	.005	.017	-.006	.015	-.004	.0052
1800	.005	.005	.020	-.006	.018	-.005	.0062
2000	.006	.006	.022	-.007	.020	-.005	.0070
2200	.006	.007	.025	-.007	.023	-.006	.0080
2400	.007	.008	.027	-.007	.024	-.006	.0088
2600	.008	.009	.030	-.007	.027	-.007	.0100
2800	.009	.010	.032	-.007	.029	-.006	.0112
3000	.010	.012	.034	-.006	.031	-.005	.0127
3200	.011	.014	.036	-.005	.033	-.004	.0142
3400	.012	.016	.038	-.003	.035	-.003	.0158
3600	.013	.019	.041	-.002	.037	-.002	.0177
3800	.014	.023	.043	.000	.040	.000	.0200
4000	.017	.026	.046	.002	.043	.003	.0228
4200	.028	.040	.049	.005	.048	.008	.0297
4400	--	--	.054	.010	.063	.022	.0372
4600	--	--	.072	.027	--	--	.0495

GRAPH OF CRACK OPENING FOR VARIOUS LOADS

PLATE 5



Beam	Description	Steel Manufacturer	Position of Transverse Wire
# 5	Long.Wire 1-#2-4" Tran.Wire #2-4"	Pittsburgh Steel Products Co.	2" from center

Comp. Str. of Concrete	Age	Date of Test	Crack Opening at 3000 lbs.	Load to Open Crack .01"
3550 psi	11 wks.	Mar. 17,'49	.013"	2600 # 47,800 psi

DATA SHEET 6

Beam # 6 Date Poured - Dec. 29, 1948 Date Tested - March 17, 1949

Steel Manufacturer - Colo. Fuel & Iron Corp. Compressive Strength 3550 psi

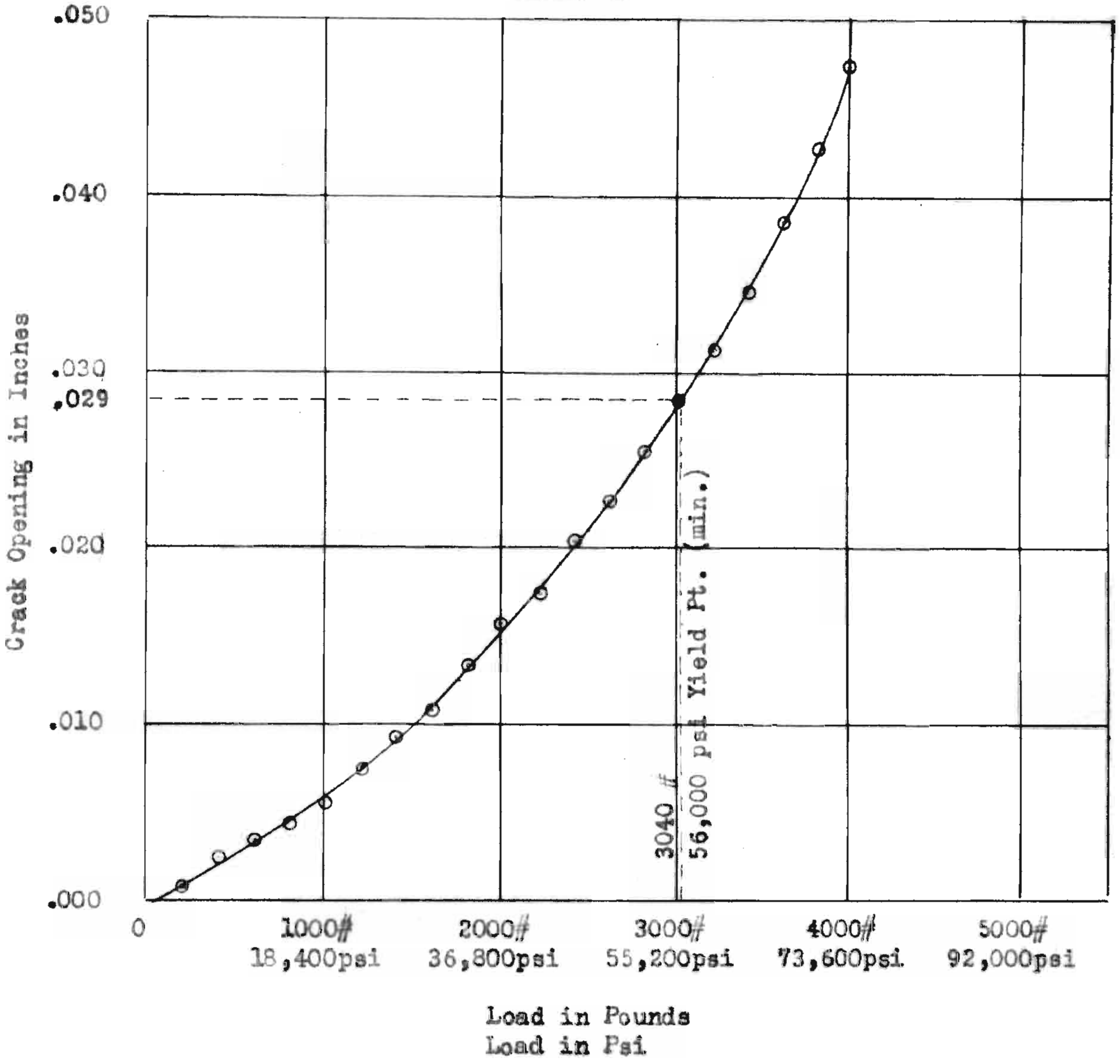
Long. Wire 1 - #2 - 4" Transverse Wire #8 - 6"

Table of Elongation in Inches

Load in Lbs.	Beam A		Beam B		Beam C		
	Lt. Dial	Rt. Dial	Lt. Dial	Rt. Dial	Lt. Dial	Rt. Dial	Average
0	.000	.000	.000	.000	.000	.000	.0000
200	.005	-.002	.002	.000	-.004	.004	.0008
400	.008	-.002	.006	-.001	-.004	.006	.0022
600	.009	-.002	.008	-.001	-.005	.009	.0033
800	.012	-.002	.011	-.002	-.005	.011	.0042
1000	.015	-.003	.015	-.003	-.003	.012	.0055
1200	.019	-.003	.020	-.004	-.002	.014	.0073
1400	.023	-.003	.025	-.005	.000	.015	.0092
1600	.026	-.003	.030	-.006	.002	.016	.0108
1800	.030	-.001	.034	-.007	.005	.019	.0133
2000	.034	-.001	.040	-.008	.008	.021	.0157
2200	.036	.000	.044	-.008	.010	.023	.0175
2400	.042	.001	.050	-.009	.013	.025	.0203
2600	.045	.003	.054	-.008	.016	.027	.0228
2800	.049	.005	.058	-.007	.019	.030	.0257
3000	.052	.006	.062	-.005	.022	.032	.0282
3200	.056	.009	.065	-.002	.025	.035	.0313
3400	.061	.011	.070	.000	.029	.038	.0348
3600	.065	.014	.074	.004	.033	.043	.0387
3800	.070	.017	.079	.007	.037	.046	.0427
4000	.077	.021	.084	.012	.041	.051	.0477
4200	.084	.026	.090	.016	.048	.058	.0537
4400	--	--	.112	.038	.062	.071	.0708

GRAPH OF CRACK OPENING FOR VARIOUS LOADS

PLATE 6



Beam	Description	Steel Manufacturer	Position of Transverse Wire
# 6	Long.Wire 1-#2-4" Tran.Wire #8-6"	Colorado Fuel and Iron Corp.	3" from center

Comp. Str. of Concrete	Age	Date of Test	Crack Opening at 3000 lbs.	Load to Open Crack .01"
3550 psi	11 wks	Mar. 17,'49	.029"	1500 # 27,600 psi

DATA SHEET 7

Beam # 7 Date Poured - March 4, 1949 Date Tested - March 31, 1949

Steel Manufacturer - Keystone Steel & Wire Compressive Strength - 3530 psi

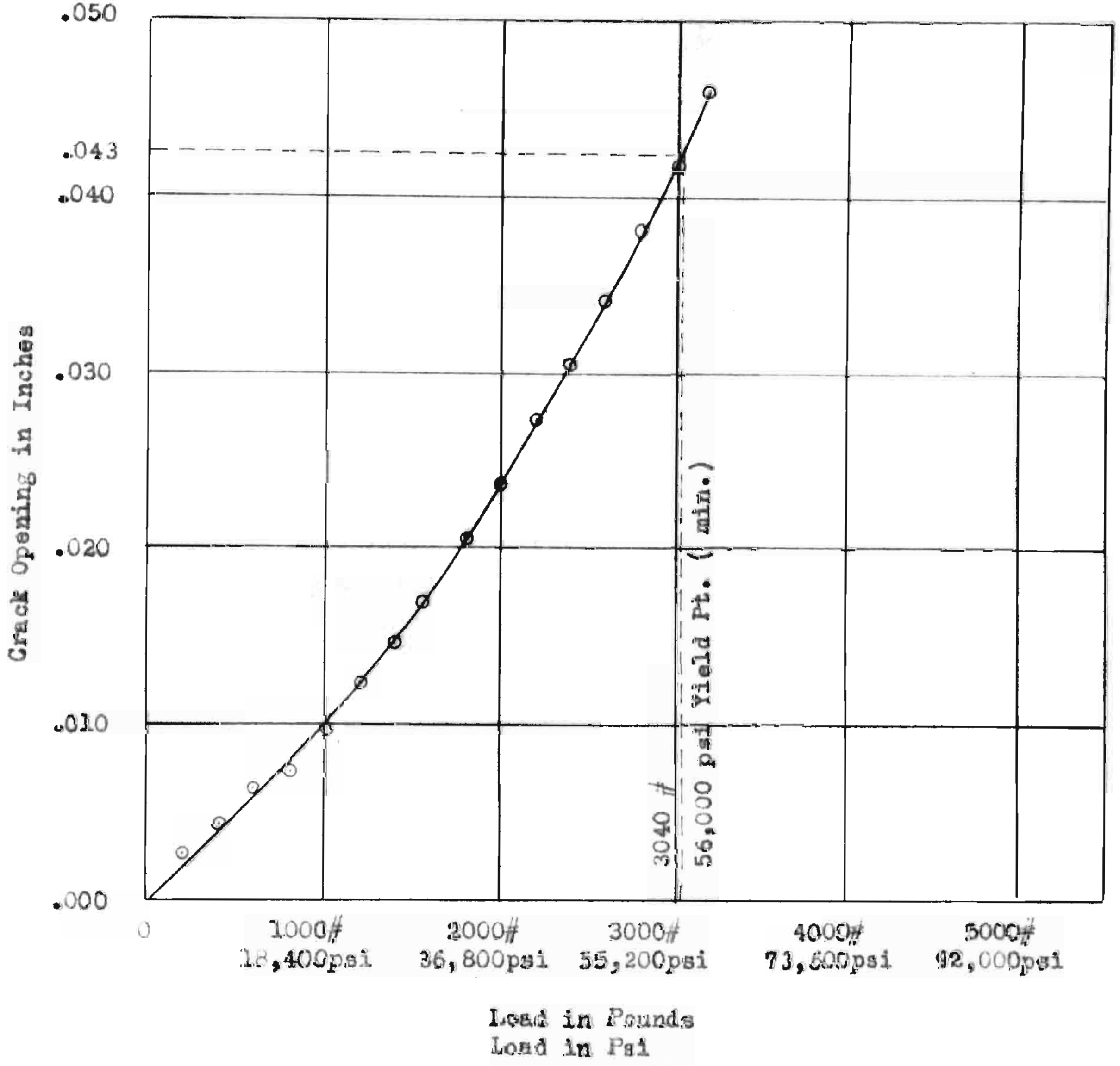
Long. Wire 1 - #2 - 3" Transverse Wire # 8 - 8"

Table of Elongation in Inches

Load in Lbs.	Beam A		Beam B		Beam C		
	Lt. Dial	Rt. Dial	Lt. Dial	Rt. Dial	Lt. Dial	Rt. Dial	Average
0	.000	.000	.000	.000	.000	.000	.0000
200	.009	.000	.002	.001	.005	-.001	.0026
400	.012	-.001	.004	.002	.011	-.002	.0043
600	.015	.000	.006	.004	.014	-.002	.0062
800	.017	.000	.009	.005	.017	-.002	.0077
1000	.021	.001	.013	.006	.019	-.002	.0097
1200	.026	.001	.018	.006	.023	-.001	.0122
1400	.030	.002	.024	.006	.026	.000	.0147
1600	.034	.004	.030	.007	.029	.001	.0175
1800	.039	.006	.036	.007	.032	.003	.0205
2000	.044	.009	.042	.008	.035	.004	.0237
2200	.050	.012	.047	.010	.038	.006	.0272
2400	.055	.015	.051	.013	.041	.008	.0305
2600	.059	.018	.055	.017	.044	.011	.0340
2800	.065	.023	.059	.021	.047	.013	.0380
3000	.070	.026	.063	.024	.051	.016	.0417
3200	.075	.031	.068	.028	.055	.019	.0460
3400	.081	.036	.073	.033	.059	.022	.0507
3600	.086	.041	.078	.037	.063	.025	.0550
3800	.093	.047	.084	.043	.067	.029	.0605

GRAPH OF CRACK OPENING FOR VARIOUS LOADS

PLATE 7



Beam	Description	Steel Manufacturer	Position of Transverse Wire
# 7	Long. Wire 1-#2-3" Tran. Wire #8-8"	Keystone Steel and Wire Company	4" from center

Comp. Str. of Concrete	Age	Date of Test	Crack Opening at 3000 lbs.	Load to Open Crack .01"
3530 psi	4 wks.	Mar. 31, '49	.042"	1000 # 18,400psi

DATA SHEET 8

Beam # 8 Date Poured - March 4, 1949 Date Tested - March 31, 1949

Steel Manufacturer - American Steel & Wire Compressive Strength - 3160 psi

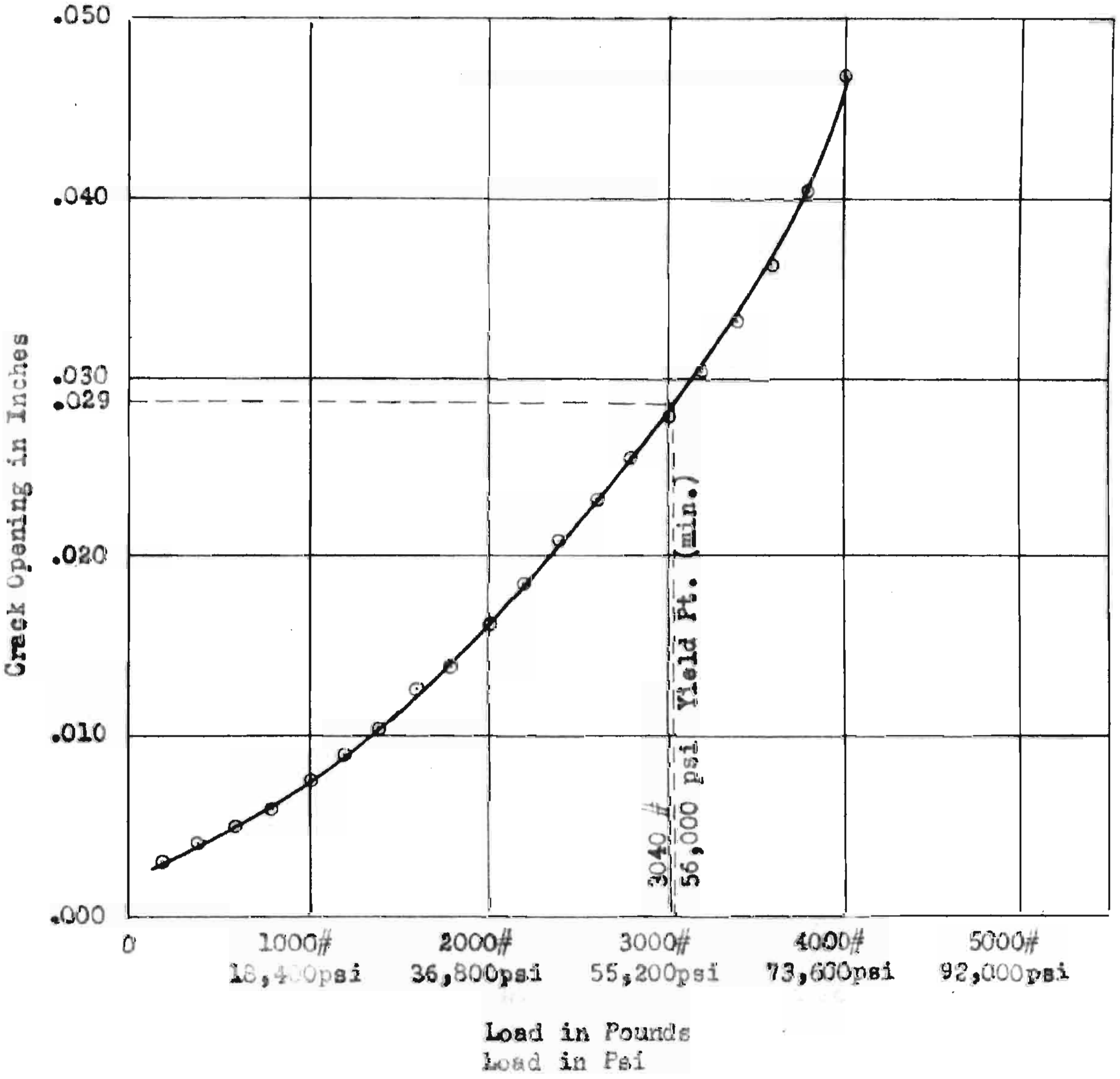
Long. Wire 1 - #2 - 3" Transverse Wire #2 - 6"

Table of Elongation in Inches

Load in Lbs.	Beam A		Beam B		Beam C		
	Lt. Dial	Rt. Dial	Lt. Dial	Rt. Dial	Lt. Dial	Rt. Dial	Average
0	.000	.000	~~.000~~	~~.000~~	.000	.000	.0000
200	.005	.001	~~-.002~~	~~.006~~	.003	.003	.0030
400	.006	.002	~~-.003~~	~~.012~~	.004	.004	.0040
600	.007	.003	~~-.004~~	~~.018~~	.005	.005	.0050
800	.008	.004	~~-.004~~	~~.023~~	.006	.006	.0060
1000	.010	.005	~~-.004~~	~~.029~~	.008	.007	.0075
1200	.012	.005	~~-.004~~	~~.034~~	.010	.009	.0090
1400	.014	.006	~~-.004~~	~~.037~~	.012	.010	.0105
1600	.016	.008	~~-.003~~	~~.040~~	.014	.011	.0127
1800	.018	.010	~~.000~~	~~.041~~	.016	.012	.0140
2000	.021	.012	~~.002~~	~~.043~~	.021	.013	.0162
2200	.024	.014	~~.005~~	~~.044~~	.023	.014	.0187
2400	.026	.016	VOID ~~.007~~ VOID	~~.045~~ VOID	.027	.015	.0210
2600	.028	.018	~~.009~~	~~.046~~	.030	.017	.0232
2800	.031	.020	~~.011~~	~~.047~~	.033	.019	.0258
3000	.034	.022	~~.013~~	~~.047~~	.035	.021	.0280
3200	.036	.025	~~.015~~	~~.048~~	.038	.022	.0302
3400	.040	.028	~~.017~~	~~.049~~	.041	.024	.0332
3600	.043	.031	~~.019~~	~~.051~~	.045	.027	.0365
3800	.047	.035	~~.021~~	~~.052~~	.050	.030	.0405
4000	.053	.041	~~.025~~	~~.054~~	.057	.037	.0470
4200	.064	.051	~~.032~~	~~.061~~	.085	.063	.0658

GRAPH OF CRACK OPENING FOR VARIOUS LOADS

PLATE 8



Beam	Description	Steel Manufacturer	Position of Transverse Wire
# 8	Long.Wire 1-#2-3" Tran.Wire #2-6"	American Steel and Wire Company	3" from center

Comp. Str. of Concrete	Age	Date of Test	Crack Opening at 3000 lbs.	Load to Open Crack .01"
3160 psi	4 wks.	Mar. 30, '49	.028"	1300 # 23,900 psi.

DATA SHEET 9

Beam # 9 **Date Poured** - March 4, 1949 **Date Tested** - March 31, 1949

Steel Manufacturer - American Steel & Wire **Compressive Strength** - 3210 psi

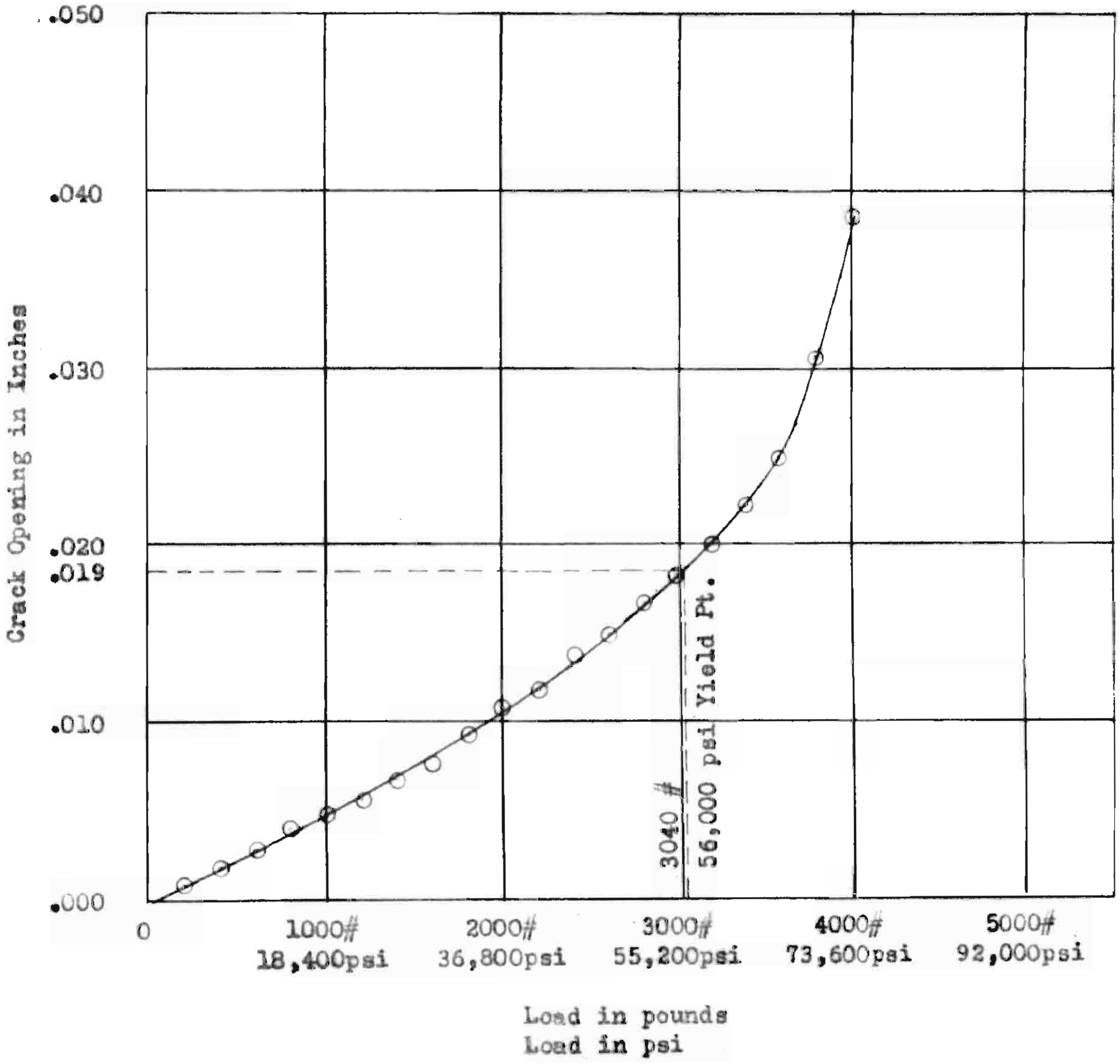
Long. Wire 1 - #2 - 3" **Transverse Wire** #4 - 4"

Table of Elongation in Inches

Load in Lbs.	Beam A		Beam B		Beam C		
	Lt. Dial	Rt. Dial	Lt. Dial	Rt. Dial	Lt. Dial	Rt. Dial	Average
0	.000	.000	.000	.000	.000	.000	.0000
200	-.001	.004	.001	.000	-.001	.002	.0008
400	-.002	.006	.004	.000	-.001	.004	.0018
600	-.002	.008	.006	.000	.000	.005	.0028
800	.000	.008	.009	-.001	.003	.005	.0040
1000	.001	.009	.011	-.001	.002	.006	.0047
1200	.003	.009	.013	-.001	.003	.006	.0055
1400	.004	.010	.016	-.001	.005	.006	.0067
1600	.006	.010	.018	-.001	.007	.006	.0077
1800	.008	.012	.020	.000	.009	.006	.0092
2000	.010	.013	.022	.001	.011	.007	.0107
2200	.011	.014	.024	.002	.013	.007	.0117
2400	.014	.015	.026	.003	.017	.008	.0138
2600	.015	.017	.028	.003	.019	.008	.0150
2800	.017	.018	.030	.006	.021	.009	.0168
3000	.018	.019	.032	.006	.024	.011	.0183
3200	.020	.022	.034	.007	.025	.012	.0200
3400	.022	.024	.037	.009	.028	.013	.0222
3600	.026	.027	.040	.011	.031	.015	.0250
3800	.031	.033	.043	.014	.035	.018	.0307
4000	--	--	.049	.018	.040	.022	.0385

GRAPH OF CRACK OPENING FOR VARIOUS LOADS

PLATE 9



Beam	Description	Steel Manufacturer	Position of Transverse Wire
# 9	Long.Wire 1-#2-3" Tran.Wire #4-4"	American Steel and Wire Company	2" from center

Comp. Str. of Concrete	Age	Date of Test	Crack Opening at 3000 lbs.	Load to Open Crack .01"
3210 psi	4 wks.	Mar. 31,'49	.0185"	1900 # 35,000 psi

DATA SHEET 10

Beam # 10 Date Poured - March 4, 1949 Date Tested - March 31, 1949

Steel Manufacturer - Colorado Fuel & Iron Compressive Strength - 2760 psi

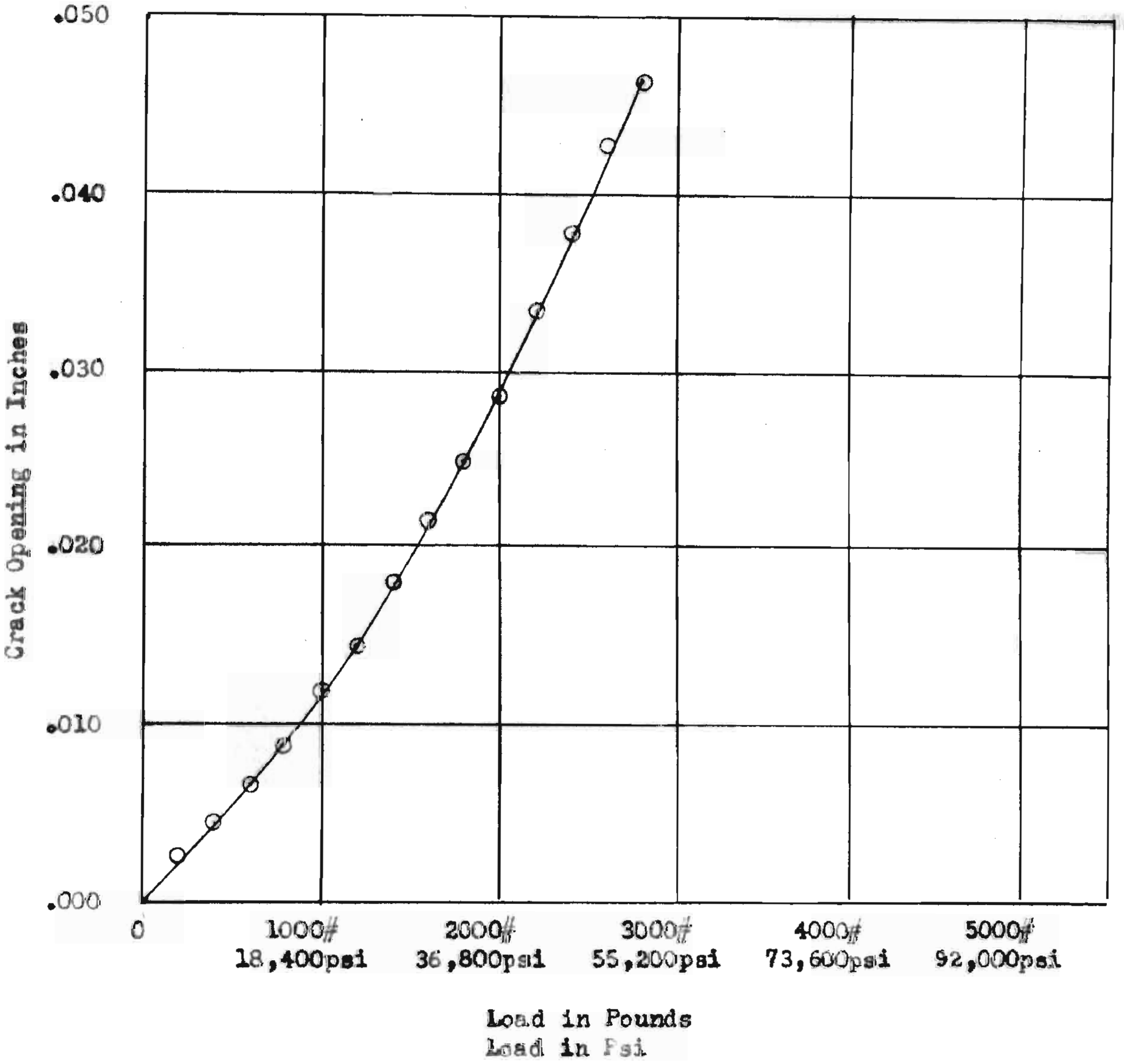
Long. Wire 1 - #2 - 4" Transverse Wire #8 - 12"

Table of Elongation in Inches

Load in Lbs.	Beam A		Beam B		Beam C		
	Lt. Dial	Rt. Dial	Lt. Dial	Rt. Dial	Lt. Dial	Rt. Dial	Average
0	.000	.000	.000	.000	.000	.000	.0000
200	.003	.002	.003	.001	-.003	.007	.0022
400	.004	.003	.006	.004	-.004	.013	.0043
600	.008	.003	.009	.006	-.006	.019	.0065
800	.012	.004	.011	.009	-.007	.023	.0087
1000	.016	.005	.014	.013	-.007	.029	.0117
1200	.022	.006	.018	.015	-.007	.032	.0143
1400	.027	.008	.022	.019	-.004	.036	.0180
1600	.032	.010	.026	.021	.000	.040	.0215
1800	.037	.013	.030	.025	.003	.042	.0250
2000	.041	.016	.035	.029	.007	.045	.0288
2200	.046	.019	.039	.032	.014	.051	.0335
2400	.051	.023	.043	.037	.018	.055	.0380
2600	.056	.027	.048	.041	.023	.059	.0430
2800	.061	.030	.052	.044	.029	.065	.0468
3000	.066	.035	.059	.050	.034	.069	.0522
3200	.071	.039	.065	.055	.040	.075	.0575
3400	.078	.044	.071	.060	.046	.081	.0630

GRAPH OF CRACK OPENING FOR VARIOUS LOADS

PLATE 10



Beam	Description	Steel Manufacturer	Position of Transverse Wire
# 10	Long.Wire 1-#2-4" Tran.Wire #8-12"	Colorado Fuel and Iron Corp.	6" from center

Comp. Str. of Concrete	Age	Date of Test	Crack Opening at 3000 lbs.	Load to Open Crack .01"
2760 psi	4 wks.	Mar. 31,'49	.053"	900 # 16,600 psi

DATA SHEET 11

Beam # 11 Date Poured - March 19, 1949 Date Tested - April 25, 1949

Steel Manufacturer - American Steel & Wire Compressive Strength -

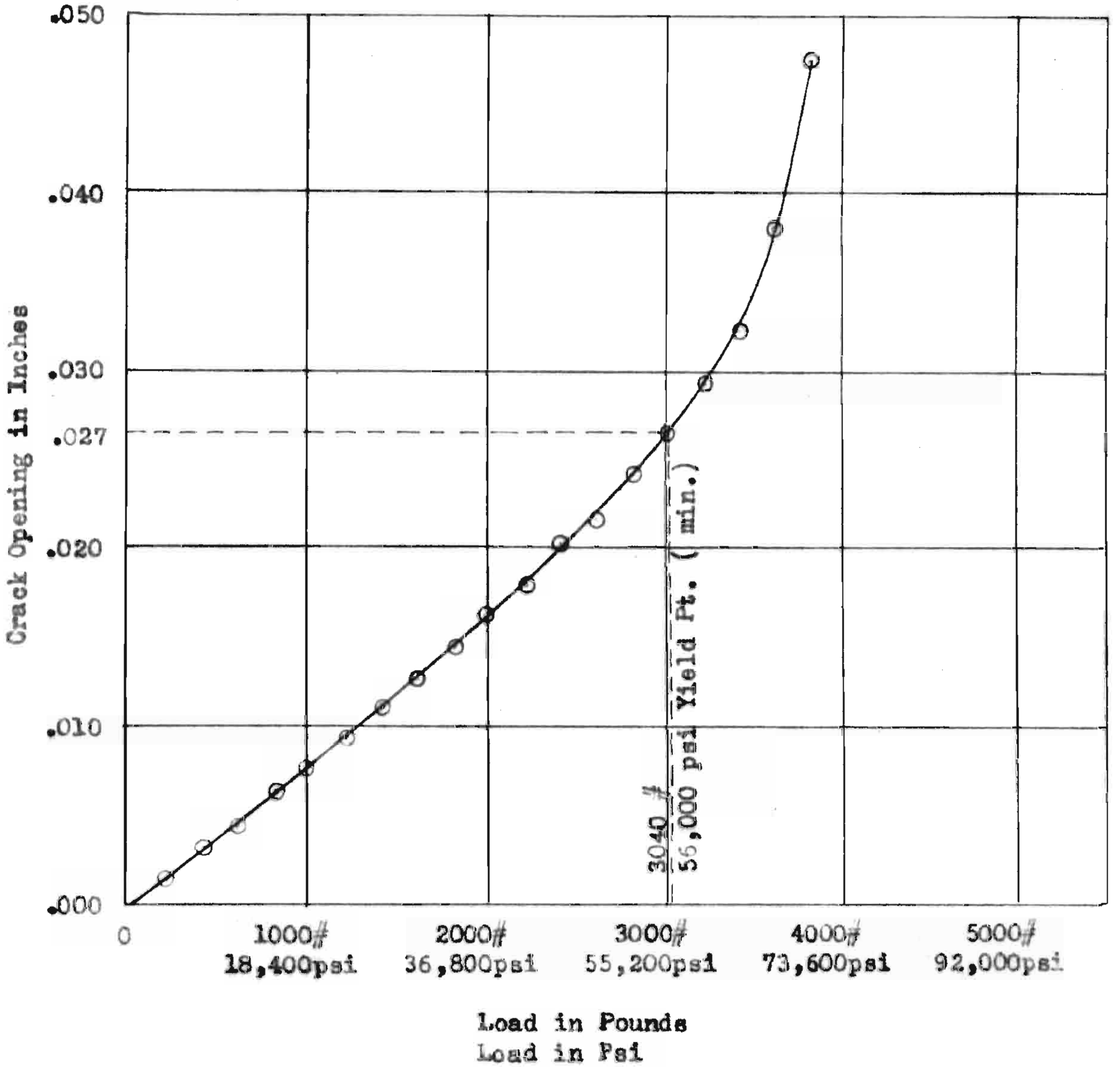
Long. Wire 1 - #2 - 3" Transverse Wire #2 - 12"

Table of Elongation in Inches

Load in Lbs.	Beam A		Beam B		Beam C		
	Lt. Dial	Rt. Dial	Lt. Dial	Rt. Dial	Lt. Dial	Rt. Dial	Average
0	.000	.000	.000	.000	.000	.000	.0000
200	.003	.000	.002	.001	.001	.002	.0015
400	.007	.000	.003	.003	.003	.003	.0032
600	.009	.000	.004	.004	.005	.004	.0043
800	.010	.003	.007	.005	.006	.006	.0062
1000	.010	.006	.009	.006	.008	.007	.0077
1200	.010	.009	.011	.008	.010	.008	.0093
1400	.011	.012	.013	.008	.012	.010	.0110
1600	.013	.014	.015	.009	.012	.014	.0127
1800	.014	.015	.018	.011	.013	.016	.0145
2000	.016	.017	.020	.012	.014	.018	.0162
2200	.018	.019	.023	.012	.016	.020	.0180
2400	.020	.020	.028	.014	.017	.022	.0202
2600	.023	.021	.030	.014	.018	.025	.0218
2800	.027	.023	.034	.014	.020	.028	.0243
3000	.032	.025	.038	.014	.021	.030	.0267
3200	.036	.027	.043	.014	.023	.034	.0295
3400	.038	.029	.049	.015	.025	.038	.0323
3600	.048	.039	.054	.019	.028	.041	.0382
3800	.063	.054	.062	.027	.032	.046	.0477

GRAPH OF CRACK OPENING FOR VARIOUS LOADS

PLATE 11



Beam	Description	Steel Manufacturer	Position of Transverse Wire
# 11	Long.Wire 1-#2-3" Tran.Wire #2-12"	American Steel and Wire Company	6" from center

Comp. Str. of Concrete	Age	Date of Test	Crack Opening at 3000 lbs.	Load to Open Crack .01"
	5 wks.	April 25,'49	.028"	1250 # 23,000 psi

DATA SHEET 12

Beam # 12 Date Poured - March 19,1949 Date Tested - April 23, 1949

Steel Manufacturer - Laclede Steel Compressive Strength -

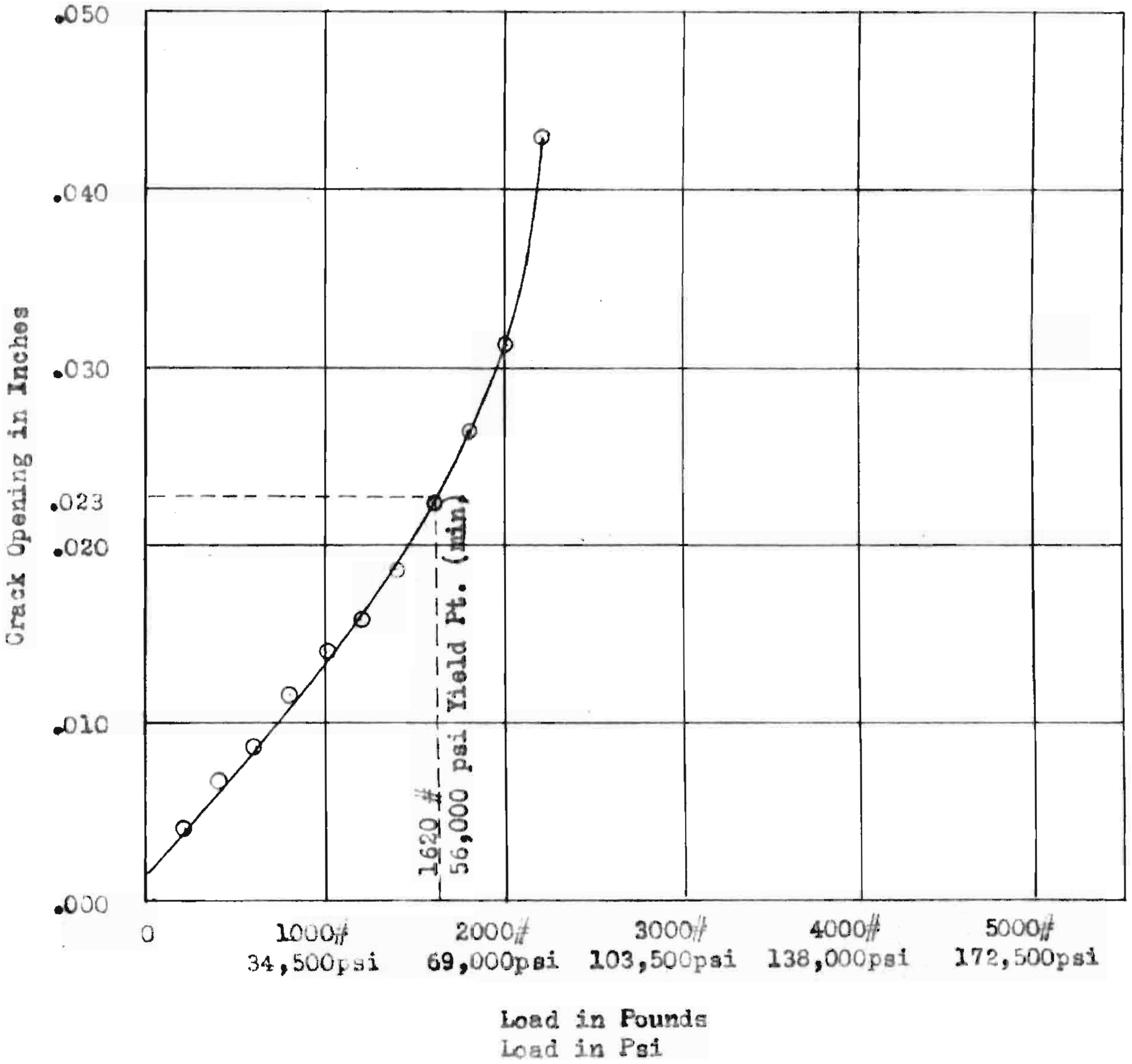
Long. Wire 1 - #6 - 6" Transverse Wire #6 - 6"

Table of Elongation in Inches

Load in Lbs.	Beam A		Beam B		Beam C		
	Lt. Dial	Rt. Dial	Lt. Dial	Rt. Dial	Lt. Dial	Rt. Dial	Average
0	.000	.000	.000	.000	Testing Machine Broken		.0000
200	.012	-.003	.006	.001			.0040
400	.017	-.003	.009	.004			.0067
600	.021	-.003	.011	.006			.0087
800	.025	.000	.012	.009			.0115
1000	.027	.004	.012	.013			.0140
1200	.029	.006	.013	.015			.0158
1400	.033	.008	.016	.018			.0188
1600	.037	.012	.019	.021			.0222
1800	.041	.016	.023	.026			.0265
2000	.043	.017	.031	.034			.0312
2200	.056	.030	--	--			.0430

GRAPH OF CRACK OPENING FOR VARIOUS LOADS

PLATE 12



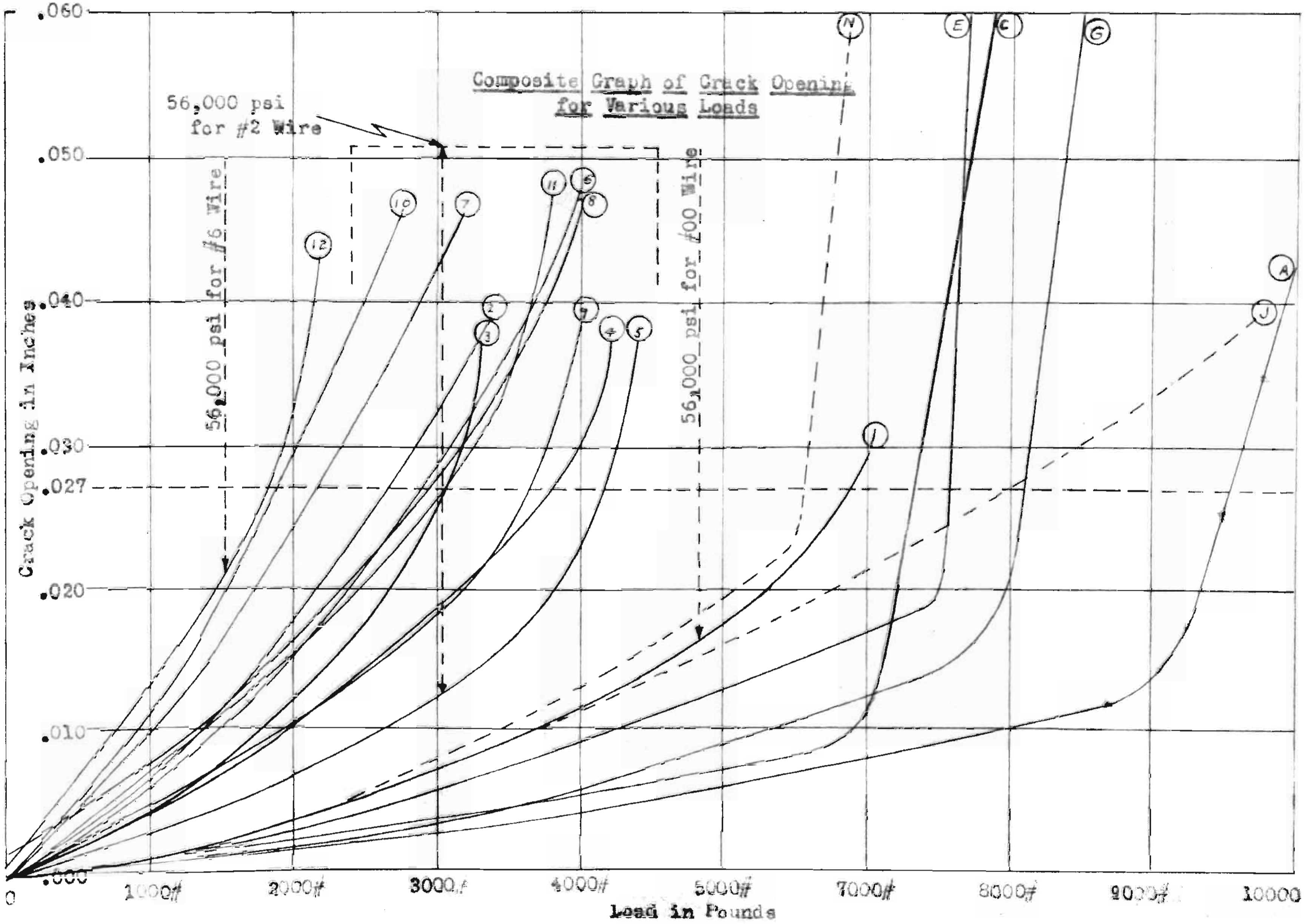
Beam	Description	Steel Manufacturer	Position of Transverse Wire
# 12	Long.Wire 1-#6-6" Tran.Wire #6-6"	Laclede Steel	3" from center

Comp. Str. of Concrete	Age	Date of Test	Crack Opening at 3000 lbs.	Load to Open Crack .01"
	5 wks.	April 23,'49	--	650 # 22,400 psi

COMPOSITE DATA SHEET 13

Beam	Reinforcing	Age	Comp. Str. of Concrete in psi	Steel Mfg.	Load to Open Crack .027" in psi
1	Long.#00- 6" Tran.#3 - 6"	7 wks	3000	Truscon	68,500
2	Long.#2 - 6" Tran.#4 - 12"	8 wks	3000	Truscon	49,800
3	Long.#2 - 6" Tran.#8 - 6"	9 wks	3870	Truscon	56,000
4	Long.#2 - 2" Tran.#2 - 6"	9 wks	3870	Pittsburgh St.	70,000
5	Long.#2 - 4" Tran.#2 - 4"	11 wks	3550	" "	76,500
6	Long.#2 - 4" Tran.#8 - 6"	11 wks	3550	Colo. Fuel	53,800
7	Long.#2 - 3" Tran.#8 - 8"	4 wks	3530	Keystone St.	40,500
8	Long.#2 - 3" Tran.#2 - 6"	4 wks	3160	American St.	53,500
9	Long.#2 - 3" Tran.#4 - 4"	4 wks	3210	" "	68,100
10	Long.#2 - 4" Tran.#8 - 12"	4 wks	2760	Colo. Fuel	35,000
11	Long.#2 - 3" Tran.#2 - 12"	5 wks		American St.	56,000
12	Long.#6 - 6" Tran.#6 - 6"	5 wks		Laclede Steel	63,000
A	3/8" Deformed	4 wks	6270	Inland Steel	86,000
C	3/8" Deformed	20 wks	6140	Bethlehem	66,400
E	3/8" Deformed	20 wks	6510	Carnegie	68,600
G	3/8" Deformed	15 wks	6190	Jones & Laughlin	73,400
J	Long. 3/8"dia. Tran.#5 - 12.2"	20 wks	6490	--------	72,500
N	3/8" Smooth	19 wks	6270	--------	50,300

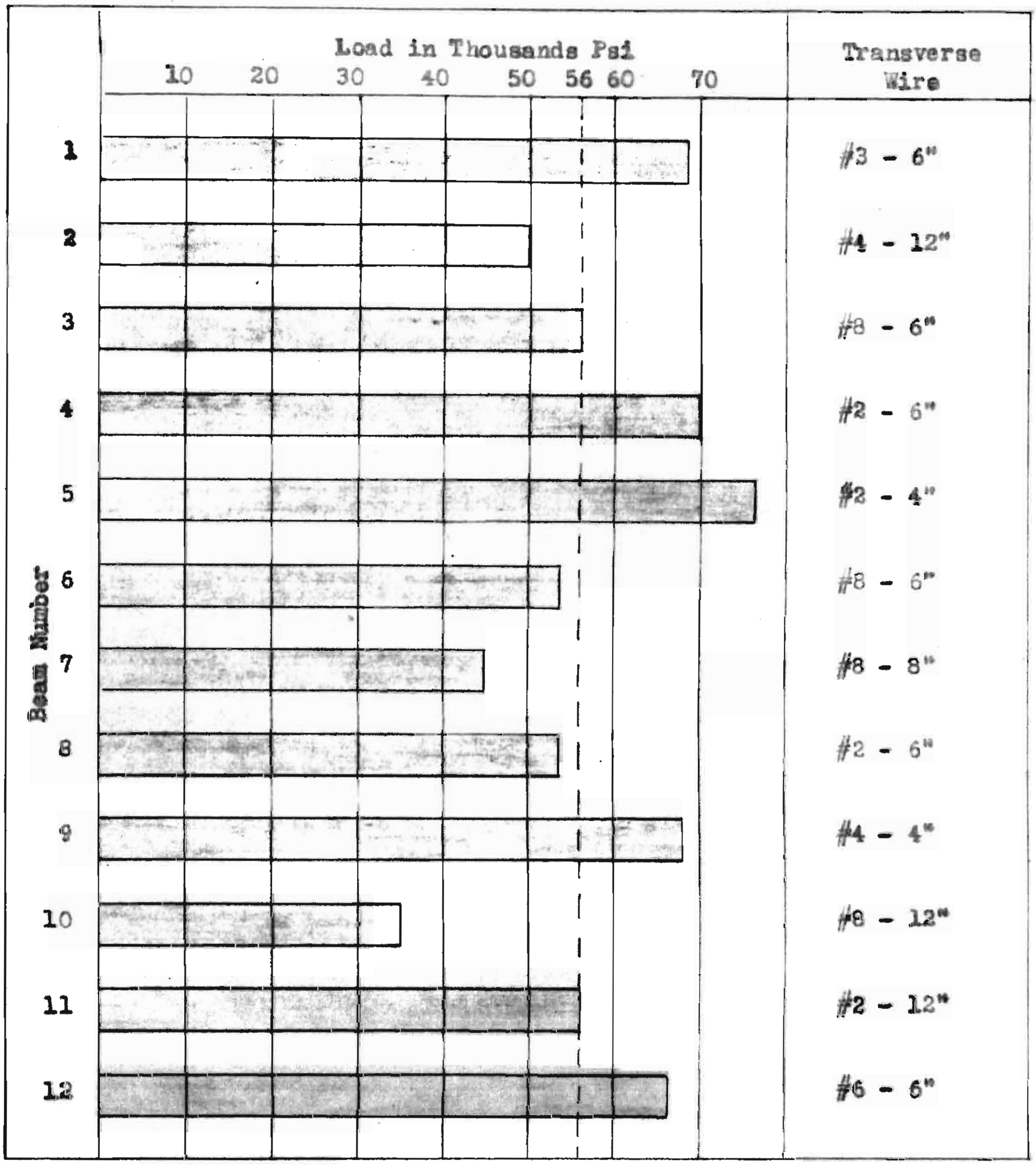
Note: Curves A through N represent some of the beams tested by the New Jersey Highway Department. Further data on these and other beams may be found in their files.



Composite Graph of Crack Opening for Various Loads

PLATE 13

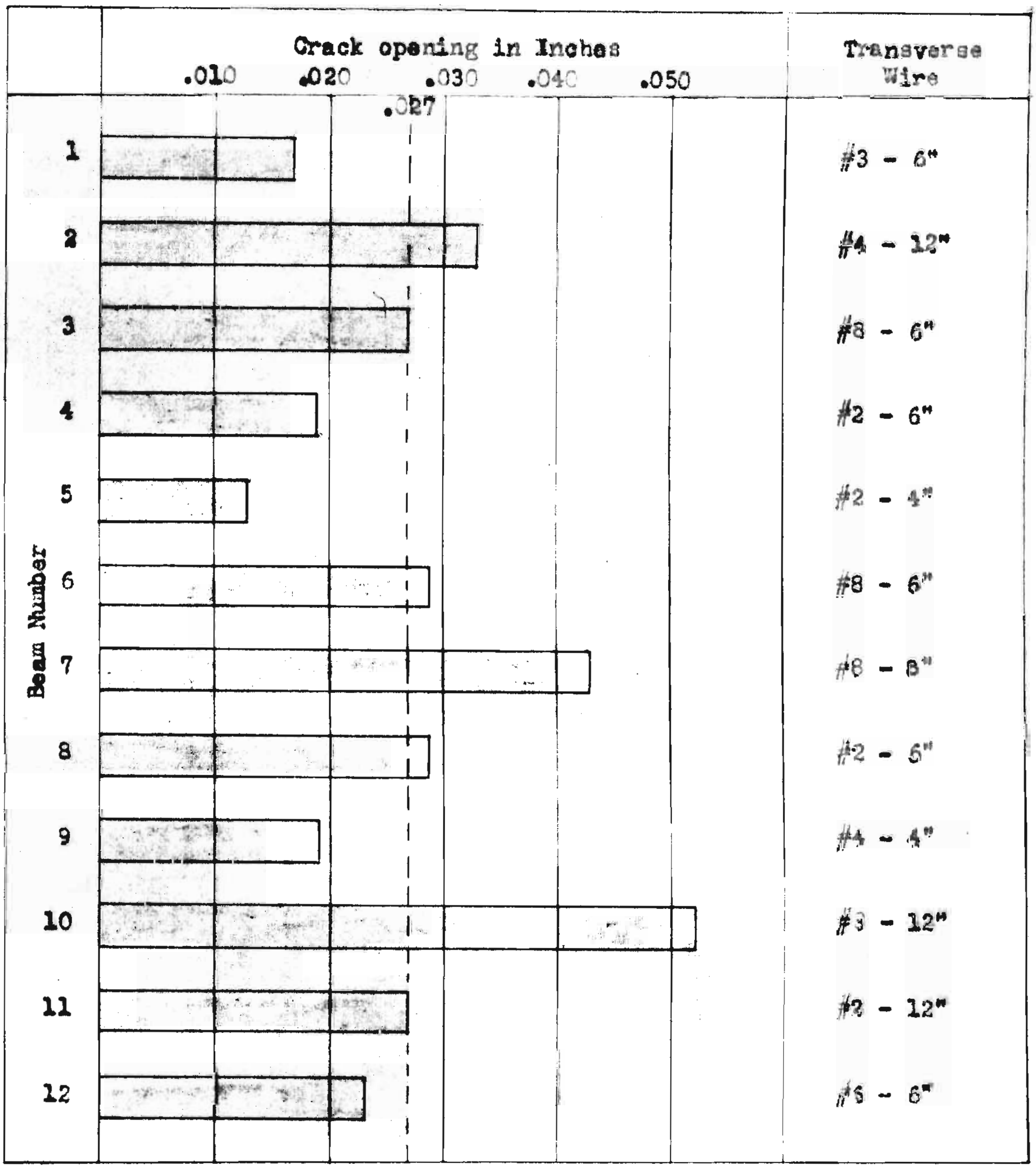
GRAPH OF LOAD IN PSI TO OPEN CRACK .027"



NOTE: All beams have one #2 longitudinal wire except beam number one which has one #00, and beam number twelve which has one #6 wire.

FIG. 4

GRAPH OF CRACK OPENING AT 56,000 PSI



NOTE: All beams have one #2 longitudinal wire except beam number one which has one #00, and beam number twelve which has one #6 wire.

FIG. 5

DATA SHEET FOR FIG. 6

INVESTIGATION OF BOND BY DIRECT PULL-OUT TESTS

Wire Guage	Bond Area	Surface Condition	Length Embedded	Ult. Bond Failure	Unit Bond Psi	Remarks
#00	6.296	Plain	6"	1470 #	234	(7)
#00	6.296	2 - Wks. Rust	6"	3293 #	524	(7)
#00	6.296	4 - Wks. Rust	6"	2780 #	443	(7)
#00	6.296	Pickeled in Hot H_2SO_4 - 5 Min.	6"	2515 #	400	
				~~1510 #~~	~~240~~	Omit
				2110 #	335	
				2312 #	368	Average
#00	6.296	Pickeled in Hot H_2SO_4 - 10 Min.	6"	3150 #	500	
				~~1625 #~~	~~258~~	Omit
				2350 #	373	
				2750 #	436	Average
#00	6.296	Pickeled in Hot H_2SO_4 - 15 Min.	6"	3050 #	485	
				~~2400 #~~	~~381~~	Omit
				3775 #	600	
				3412 #	542	Average

NOTE: Compressive Strength of Concrete - 3430 psi

Load Applied at - 500# per minute

---

(7) Becker, op. cit., p7

GRAPH OF BOND

FOR DIFFERENT SURFACE CONDITIONS

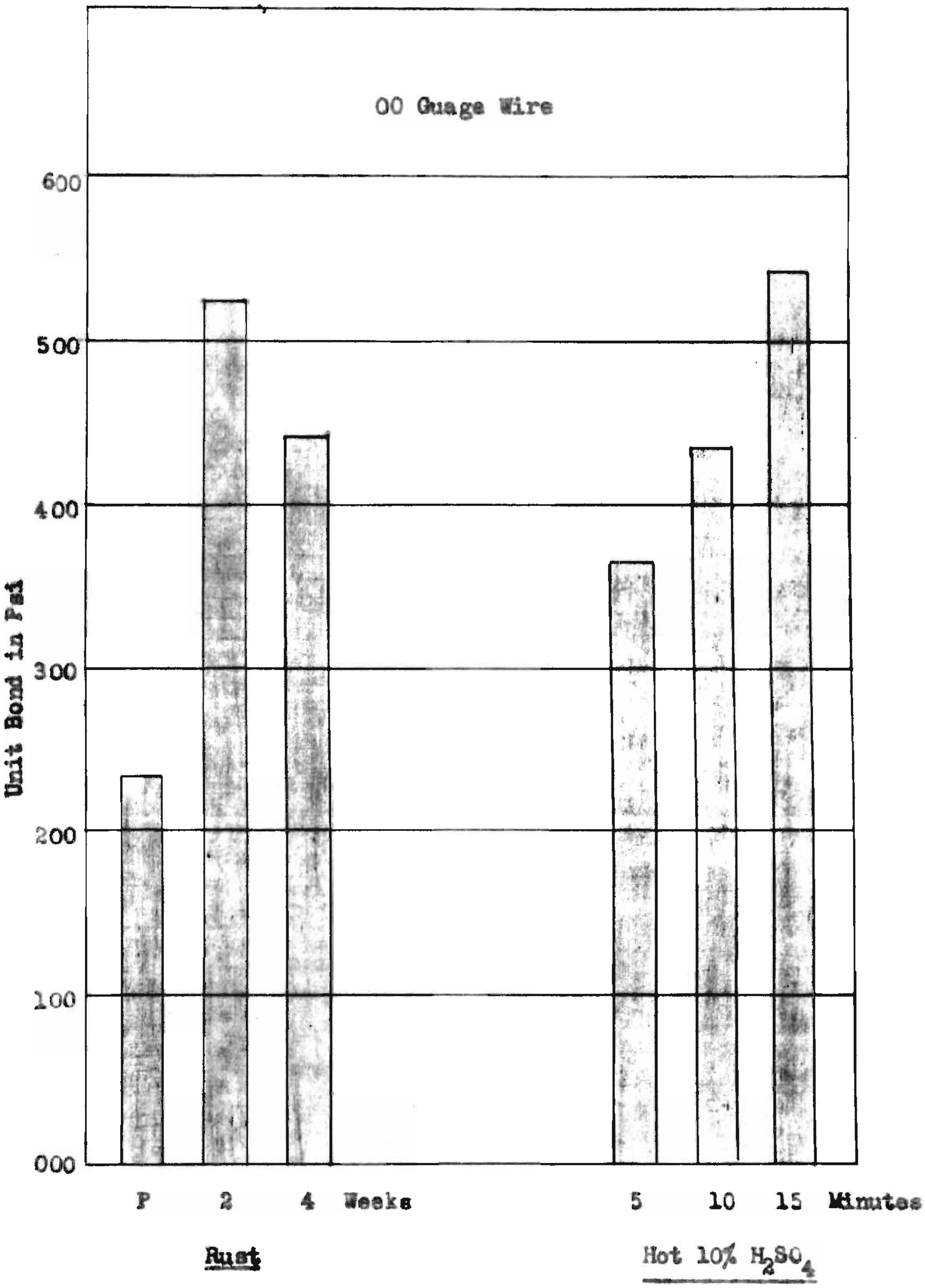


FIG. 6

Results

A series of twelve tests using three identical beams for each test was conducted for the data contained in this thesis. Transverse wires numbered two, three, four, six and eight were spaced at four, six, eight and twelve inches. Three sizes of longitudinal wire were used, numbers 00, two, and six. In all of these tests, only one longitudinal wire was used. Twelve other test beams were cast reinforced with four different types of wire mesh, all with two longitudinal wires. These could not be tested, however, due to a failure of the testing machine. They will probably be tested at a later date and the data used to supplement this thesis. The following companies furnished the wire mesh reinforcement used in these tests: American Steel and Wire, Colorado Fuel and Iron, Keystone Steel and Wire, Laclede Steel, Pittsburgh Steel Products, and Truscon. The beams were loaded by increments until the crack began to open rapidly or until it was greater than .027 inches. As was stated before, the Highway Research Board recommends that the permissible crack opening in concrete pavements be .027 inches. They claim that aggregate interlock action is lost for larger crack openings. To carry these tests to the breaking point would undoubtedly have damaged the Ames dials and would have been very dangerous, since the beams were tested in a vertical position.

As a basis for comparing the results of these tests, a crack opening of .027 inches at a load of 56,000 psi was used, since it seemed desirable to have the maximum crack opening occur when the minimum yield point of the steel is reached. Some of the combinations of wire mesh reinforcement produced results very close to the assumed ideal conditions. From Figure 4, and Figure 5, which are graphs showing the load required to open the crack .027 inches and the crack opening at 56,000 psi, it is readily seen that beams numbered three, six, eight, and eleven with #8 - 6", #8 - 6", #2 - 6", and #2 - 12" transverse wires respectively seem to most closely satisfy the ideal conditions.

Test beams, numbered one, were the only beams which were reinforced with #00 longitudinal wire. The data obtained from each of the three test beams was plotted and an average curve drawn. This data could not be averaged first and a curve plotted, as was done in all the other tests, because different load increments were used on each beam. Therefore, the data for the three beams was plotted and an average curve drawn. A much greater load was required to open the crack in number one test than in any of the other tests due to the larger sized longitudinal wire. The crack was opened about .017 inches when the ultimate stress of 56,000 psi was applied. The stress required to open the crack .027 inches was about 68,500 psi which is well over the minimum required yield point of the steel.

In test beams numbered two, seven and ten reinforced with #4 - 12", #8 - 8", and #8 - 12" transverse wires respectively and one #2 longitudinal wire, the load to open the crack .027 inches was considerably below the allowable 56,000 psi. This can readily be seen in Figure 4. Figure 5 shows these same beams to have excessive crack openings at the yield point, 56,000 psi.

Test beams reinforced with #2 - 4" transverse wires seemed to be the best combination for controlling crack opening. A crack opening of about .013 inches occurred with a load of 56,000 psi. Two series of tests were conducted using #2 - 6" transverse wires, one manufactured by Pittsburgh Steel Products Company and one by American Steel and Wire Company. The beams were numbered four and eight respectively. In beams numbered four, the crack opening was about .019 inches at the yield point of the steel while number eight had a crack opening of .029 inches at 56,000 psi. This difference is difficult to explain. Test beam number 8B was damaged while it was being placed in the testing machine and was, therefore, discarded. However, the other two beams produced almost identical values and it was thought that the average of these two would give an accurate curve. For some unknown reason, this curve did not go through the origin which may account for some of the difference. The findings of the New Jersey Highway Department seemed to indicate that the properties of the reinforcing for controlling cracking varied considerably with the different steel manufacturers. For curves A, C, E, and G on Plate 13, the same reinforcing was used except that it was manufactured by different companies.

Test beams numbered twelve were the only ones in which a number six longitudinal wire was used. The transverse wires were #6 - 6". Although the reinforcing seemed to be very small in amount compared with the other tests, the crack opening at 56,000 psi. was under the permissible .027 inches.

The results of all of the beams tested plus a few of the ones tested by the New Jersey Highway Department are shown on Plate 13. Curve number one with one #00 longitudinal wire and #3 - 6" transverse wires compares favorably with those of the New Jersey Highway Department considering the fact that their curves are for 3/8 inch rods.

The effects of changes in size and spacing of transverse wires is easily seen by studying curves numbered two through eleven since these all have one #2 longitudinal wire. Curves numbered seven and ten show that the pre-formed crack opens rapidly with a relatively small increase in load. These beams contained #8 - 8" and #8 - 12" transverse wires. Curve number twelve appears to compare unfavorably with the others but this test beam had considerably less reinforcing than any of the others, the longitudinal wires having been #6 and the transverse wires having been #6 - 6". Actually, the reinforcing was stressed to the yield point when the crack was opened only about .022 inches.

The results of the pickeling tests to increase the bond proved disappointing. The study was, therefore, quite limited since the results of a few tests seemed to indicate that pickeling would be of little practical value. Three tests were conducted in which the reinforcing rods were pickeled in a hot, ten per cent solution of sulphuric acid for five, ten, and fifteen minutes. Three test specimens were made for each time interval. This was the only pickeling solution tried because it can be used commercially. Other more corrosive solutions would probably be more effective but they could not be economically justified. In each of the groups, there seemed to be one in which the bond was considerably lower than in the other two tests. This one was not used in order to favor the results as much as possible. The average of the two highest tests was compared with previous tests conducted by Mr. A. A. Becker as shown on Figure 6.(7) This graph shows the bond for plain smooth rods, rods with two and four weeks rust, and rods that were pickeled in hot, ten per cent solution of sulphuric acid for five, ten, and fifteen minutes. It can readily be seen from this graph that pickeling fifteen minutes has about the same effect on the bond as two weeks rust.

The results can best be summarized as follows:

1. - In the beams reinforced with #00 longitudinal wire and #3 - 6" transverse wires, the crack opening at the minimum permissible yield point of the steel, 56,000 psi, was well under the permissible maximum of .027 inches.

2. - When #2 longitudinal wire was used, #2 - 4", #2 - 6" and #4 - 4" transverse wires seemed to control the cracking and keep it well under .027 inches when a load of 56,000 psi was applied.

3. - When #2 longitudinal wire was used, #2 - 12" and #8 - 6" transverse wires permitted a crack opening of about .027 inches at the minimum permissible yield point.

4. - When #2 longitudinal wire was used, #4 - 12", #8 - 8", and #8 - 12" were definitely inadequate to control the cracking.

---

(7) Becker, op. cit., p. 7

The crack was opened too wide to permit aggregate interlock action long before the longitudinal steel was stressed to its yield point.

5. - In the beams reinforced with #6 longitudinal wire and #6 - 6" transverse wires, the crack opening was less than the maximum allowable at the minimum permissible yield point of the steel.

6. - Pickeling reinforcing rods in hot sulphuric acid for fifteen minutes had about the same effect on bond as two weeks rust.

Conclusions

Although the number of tests conducted was limited, due to a failure of the testing machine, several different types of wire mesh reinforcements were tested and certain conclusions can be drawn from these tests. Ten of the twelve series of beams tested were reinforced with different sizes and spacings of transverse wires. Three types of longitudinal wires were used.

From Graph 13, it seems that test beams numbered one, reinforced with #00 longitudinal wire and #3 - 6" transverse wires would compare favorably with 3/8 inch deformed rods if the longitudinal wires were spaced a little closer than the deformed rods. Since the minimum permissible yield point of the steel was reached long before the crack was opened .027 inches, possibly a #4 - 6" transverse wire could be used. Further tests should be conducted using #00 longitudinal wires and different sizes and spacings of the transverse wires.

When #2 longitudinal wire and transverse wires of #4 - 12", #8 - 8", and #8 - 12" were tested, the crack opening was above the maximum specified by the Highway Research Board long before the minimum permissible yield point of the steel was reached. Transverse wires of #8 - 6" and #2 - 12" seemed to be at the critical spacing. The maximum permissible crack opening and the minimum yield point occurred at about the same time. It would appear that #8 transverse wires are definitely too small unless they are closely spaced. Even then it probably would not provide sufficient control of cracking. It also appears that twelve inch spacing of all the transverse wires tested was excessive.

The cracking was best controlled with transverse wires of #2 - 4", #2 - 6", and #4 - 4" when #2 longitudinal wire was used. These transverse wires held the crack well below the specified maximum of .027 inches when the minimum yield point of 56,000 psi was reached. Thus it would seem that when #2 longitudinal wire is used the most desirable spacing of #2 transverse wires would be six inches or less and for #4 transverse wires, the spacing should be not greater than four inches.

When #6 longitudinal wires are used, #6 - 6" transverse wires seem to be adequate to keep the crack opening to less than .027 inches until the yield point of the steel is reached. However, this wire mesh would probably not furnish sufficient reinforcement for a concrete pavement.

It can be concluded from the few tests made on pickeled reinforcing that unless a more corrosive substance is used, and this substance can be economically used commercially, it would be impractical to pickel steel reinforcing in order to increase the bond. It is much easier and cheaper to let the reinforcing rust for two weeks and thus obtain almost the same effect as pickeling it in a hot ten per cent solution of sulphuric acid for fifteen minutes.

The conclusions can be summarized as follows:

1. - #00 longitudinal wire with #3 - 6" transverse wires provide adequate control of cracking in concrete pavements. By

spacing the longitudinal wires a little closer than the spacing used for 3/8 inch deformed rod reinforcing about the same amount of crack control in concrete pavements can be expected.

2. - When #2 longitudinal wire is used, #2 transverse wires should be spaced not more than six inches apart.

3. - When #2 longitudinal wire is used, #4 transverse wires should be spaced not more than four inches apart.

4. - When #2 longitudinal wire is used, #8 transverse wires are too small to adequately control cracking unless spaced very closely.

5. - When #6 longitudinal wire is used, transverse wires of #6 - 6" give sufficient control of cracking provided the yield point of the steel is not exceeded.

6. - Pickeling steel is not a practical method of increasing its allowable bond stress.

Bibliography

1. Books:

Bateman, John H., Highway Engineering. N. Y., John Wiley and Sons, Inc., 1948, pp. 313 - 322.

Bradbury, Royall D., Reinforced Concrete Pavements. Washington, D. C., Wire Reinforcement Institute, 1938. 190 p.

Hewes, Laurence I., American Highway Practice, Vol. 2. N. Y., John Wiley and Sons, Inc., 1942, Ch. 6.

2. Periodicals:

Benkelman, A. C., Tests of Aggregate Interlock at Joints and Cracks. Eng. News-Record, p. 227, Aug. 24, 1933.

Older, C., Crack Occurrence and Control in Concrete Pavement. Eng. News-Record, p. 50, July 9, 1931.

3. Publications of Learned Societies:

Portland Cement Association, Design and Control of Concrete Mixes. 9th Ed. 1948.

4. Manual:

American Steel and Wire Company, American Welded Wire Fabric for Concrete Reinforcement. 1948.

5. Unpublished Material:

Becker, Alan A., Interrelationship of Transverse Anchorage and Adhesive Bond in Welded Wire Reinforcement. Thesis, Missouri School of Mines and Metallurgy, Rolla, Missouri, 1949.

Weinel, E. A., The Mechanical Anchorage Value of the Transverse Wires in Welded Wire Fabric. Thesis, Missouri School of Mines and Metallurgy, Rolla, Missouri. 1948.

Vita

Frederick R. Heartz was born May 12, 1921, at Exeter, New Hampshire, the son of Mr. and Mrs. Harold F. Heartz.

His early education was received in grade and high schools of Exeter, New Hampshire. He entered the University of New Hampshire in September, 1940 and was graduated in February, 1944 with the degree of Bachelor of Science in Civil Engineering.

Upon graduation he accepted a position as Junior Engineer with the U. S. Geological Survey, Water Resources Branch and worked in northern New York.

In June, 1944, he was married to Barbara L. Goodrich, daughter of Mr. and Mrs. Almer F. Goodrich of Exeter, New Hampshire.

Soon after he decided that he wanted to get into structural engineering and, therefore, resigned from the above position December, 1944, to take a job with the Oxford Paper Company in Rumford, Maine as a structural designer and draftsman. He was with them until September, 1947, during which time he gained valuable experience in all types of design problems using timber, steel, concrete, and brick. A building program amounting to several million dollars was in progress at that time.

With a desire to get his M. S. degree, he resigned from the Oxford Paper Company September, 1947, and accepted appointment as Instructor of Civil Engineering at Missouri School of Mines and Metallurgy. At the same time, he enrolled as a part time graduate student.