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MICHIGAN
STATE HIGHWAY DEPARTMENT
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State Highway Commissioner

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A MODEL STUDY
of
SLAB ACTION IN CONCRETE PAVEMENTS

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University of Michigan and the
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A MODEL STUDY

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SLAB ACTION IN CONCRETE PAVEMENTS

The study of the destructive effect of loads upon concrete slabs has been in progress for some time. Contributions to the literature have been made by Teller (1), Westergaard (2), Glover (3), and others.* Recent advances in vehicle design necessitated by the heavy loads transported by truck and trailer assemblies have prompted those interested in the preservation of our highways to make further investigations.

Accordingly John S. Worley, Professor of Transportation Engineering at the University of Michigan, W. D. Wise of the Fruehauf Trailer Company, and Charles M. Ziegler, State Highway Commissioner conferred to determine how best to proceed with such a study. Consultation with A. E. White, Director of Engineering Research and E. L. Erickson, Chairman of the Department of Engineering Mechanics resulted in the opinion that a scale model should be quite satisfactory for preliminary work. It should serve as a means of developing technique and also it should indicate trends which could be verified later in a full-size slab.

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(1) Teller, L. W. - The Six Wheel Truck and the Pavement, Public Roads, October, 1925.

(2) Westergaard, H. M. - Stresses in Concrete Pavements Computed by Theoretical Analysis, Proceedings of the Highway Research Board, 1925.

(3) Glover, V. L. - Investigation of the Effect of Wheel Loads Applied to the Pavement by Six Wheel Trucks - Mimeographed Report, Bureau of Materials, State of Illinois Department of Public Works and Buildings, Division of Highways.

* See Bibliography.

W. W. McLaughlin, Testing and Research Engineer for the Highway Department agreed to build a model in the Testing Laboratory at Ann Arbor. J. L. Byers, Testing Supervisor, constructed the slab and loading devices; and E. A. Finney, Assistant Testing and Research Engineer directed the research. Dale Gilliard of the Department of Engineering Mechanics placed the strain gages and assisted with many tests. E. A. Boyd of the Testing Laboratory and the University assumed the responsibility for placing structures necessary to the tests and also assisted with most of the tests.

The destructive effect of loads upon a concrete slab was the principal object of this investigation. Secondary considerations were the determination of the value of the SR-4 electric strain gage as a reliable indicator for stresses in concrete, and a model-prototype comparison for concrete slabs.

A summary of the tests made on the model and the purpose of each is as follows:

1. A single axle was equipped with two, four, and six wheels and loaded to determine the reduction in strain due to an increase in the number of wheels.
2. Two axles were spaced at various distances in an effort to find a spacing which would allow the system to be loaded above the single axle load without increasing the strain.
3. Three axles were spaced at various distances to determine the effect of each axle upon the strains under the other axle.

4. Loads were applied at the interior of the slab, at a longitudinal edge, at an end or transverse edge, and at a corner. The object was to find the relations between strains and deflections at these positions.
5. Single loads on very small areas were applied at a corner, an edge, and at an interior point to obtain data which could be compared with the theoretical values obtained from Westergaard's equations.
6. Strain gages were attached to the under side of the slab for the purpose of comparing the tension at that point with the compression above.
7. Subgrades were changed in an attempt to observe the effects of stiff and soft subgrades upon the strain and deflection readings.
8. Overloads were applied at various positions in order to note the types of failures produced.

The model served the purpose for which it was constructed. It showed that the addition of wheels to an axle is not an expedient method of increasing the loading capacity. It showed that two axles could carry a load more than twice that of a single axle if the proper axle spacing was used. It gave a set of relations between the stresses at the center, edge, and, and corner.

From the study of this model, a better idea of the load-deflection-strain relationship was found. It was seen that strains under wheels at the edge of the slab are dependent upon axle length. Curves from which an optimum spacing for axles can be found were developed.

The slab has been useful in the development of technique for applying loads, for mseasuring deflections, and for the application and reading of electric strain gages. Results from this study are beneficial in the formation of further studies in the problem of loaded pavement slabs.

This is a progress report describing briefly the results of the various tests without detailed theoretical analysis or mathematical consideration. The report is devoted to the properties of the materials tested, discussion of the test equipment and loading technique, measurement of destructive effect and study of failures. Conclusions drawn from the test data are presented.

It is proposed in the course of the investigation to correlate tests results with theory. This treatment will be presented later as a separate report and will express trends to expect in the prototype. Recommendations will be made for improving the test methods and for obtaining other desired data.

DESCRIPTION OF EQUIPMENT AND TEST PROCEDURE

This investigation was a study of the effect of loads, and consequently it was desirable to eliminate other effects as much as possible. Controlled laboratory conditions seemed to be a solution. In an atmosphere of constant temperature and moisture the effects of warping were minimized, and human as well as mechanical errors were lessened by the absence of extreme weather conditions.

Materials:

A wooden form 18 feet by 4 feet by 18 inches deep was built upon a concrete floor in the laboratory. This was filled with a stabilized clay-gravel subgrade material and vibrated to compaction. Bearing plate tests gave a modulus of stiffness of 2200 p. s. i. per inch at 0.05 inches deflection.

A concrete slab 15 feet by 33 inches by 2 inches was cast on this base. This was a one-eighth scale representation of a pavement slab. The aggregate was composed of 3/8 inches pea gravel and sand. Cylinders and flexure beams gave the following results:

Compressive strength at 14 days = 4500 p. s. i.
Compressive strength at 28 days = 4900 p. s. i.
Modulus of elasticity at 1000 p. s. i. = 4,800,000 p. s. i.
Modulus of rupture = 700 p. s. i.

At the conclusion of the investigation on the stabilized subgrade the slab was removed. A six inch layer of sand was placed on the old subgrade, the slab was replaced and loaded to obtain good bearing. The bearing plate test showed that the modulus of stiffness for the new subgrade was 350 p. s. i. per inch.

Equipment:

The instrument used to indicate the state of the strain in the slab was the SR-4 strain gage (4). This is a resistance type gage and the strains are easily read directly in micro-inches per inch by means of a portable strain indicator. These gages were cemented to the slab surface and electrically connected to a selector switch. More than 100 such gages were used on the upper surface of the slab, and three rosettes of three gages each were cemented to the bottom. An array used for the study of the effect of wheel and axle arrangements at the center of the slab is shown in Figure 1, and the arrangement for the corner study is given in Figure 2.

Deflections were measured with Federal one-thousandth dials. These were supported by portable wooden racks which were entirely free from contact with the slab, subgrade or forms. The dial pattern was adjusted to meet the needs of the investigation. Figure 3 is typical of the arrangement for center loading, and Figure 4 illustrates a design used in the edge study.

Application of Loads:

Loads were applied through wooden axle representations and tire impressions reduced to appropriate scale. The actual dimensions are given in Plate I. The center shoes represent an axle with two wheels; the outer pairs, four wheels; and the third shoe was attached inside the first for the six wheel study. Additional shoes, or tire representations, were constructed and slotted to permit installation immediately above the strain gages.

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(4) Nielsen, D. M. - Strain Gages, Electronics, December 1943.

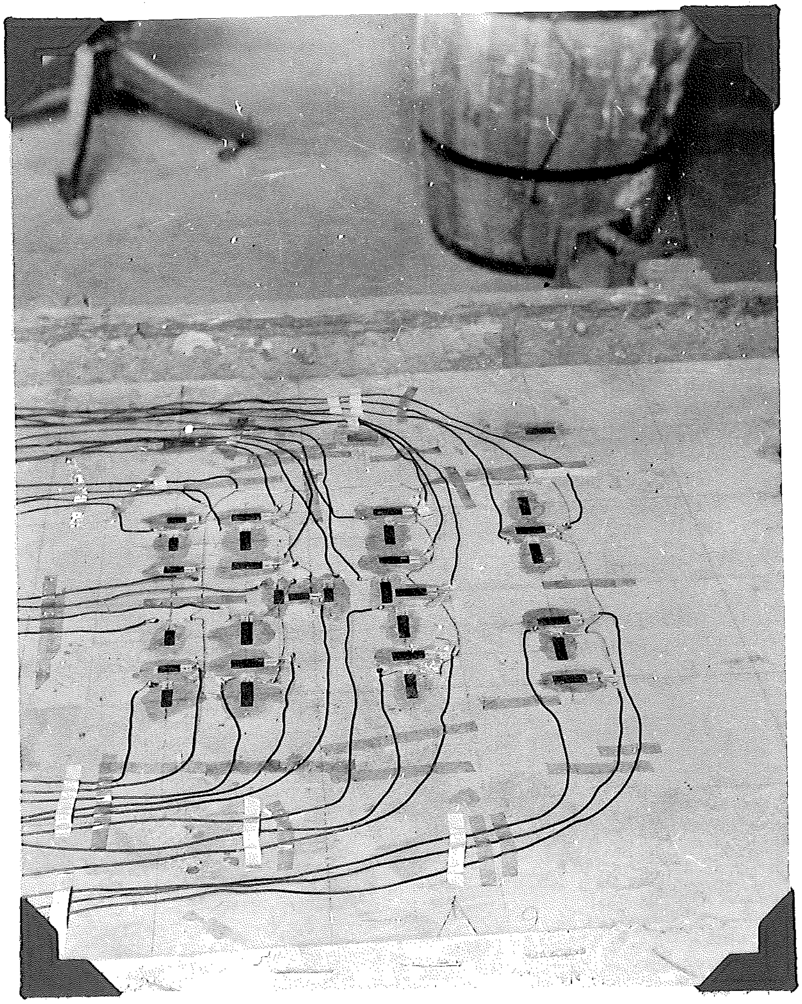


Figure 1. An array of SR-4 electric strain gages attached to the slab for the study of the effect of various wheel and axle arrangements at center of slab.

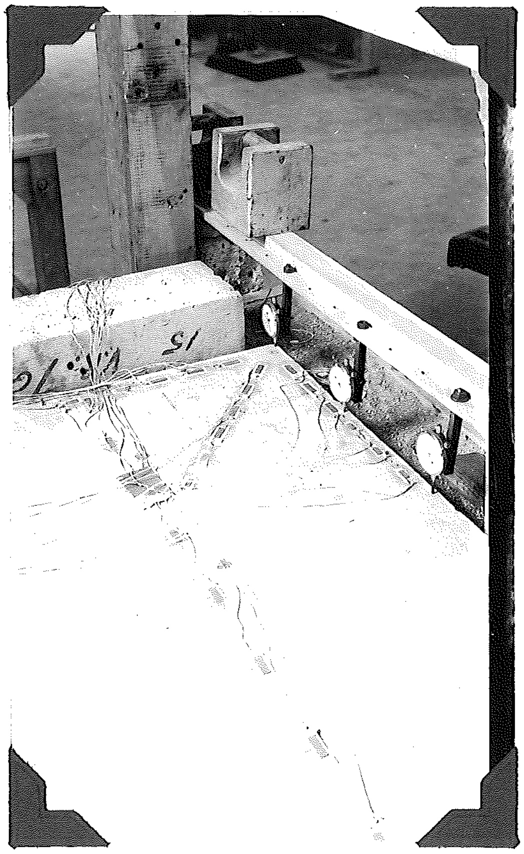


Figure 2. Strain gage layout for the corner study.

Figure 3. Dial arrangement for measuring deflections caused by center loads.

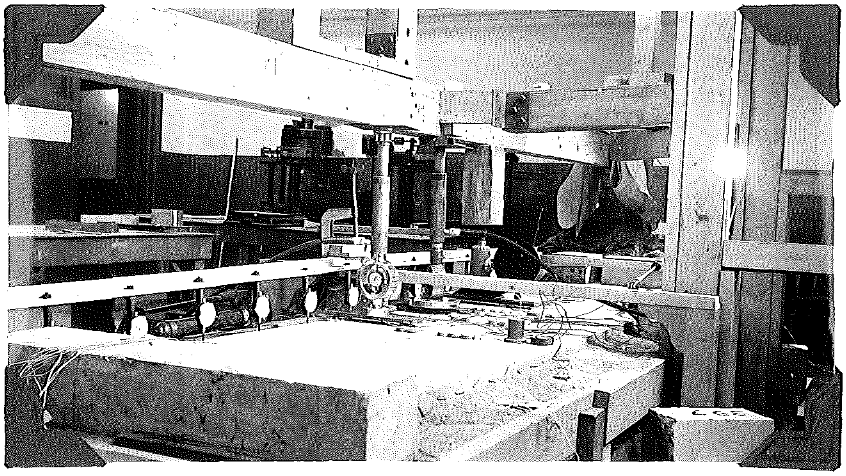
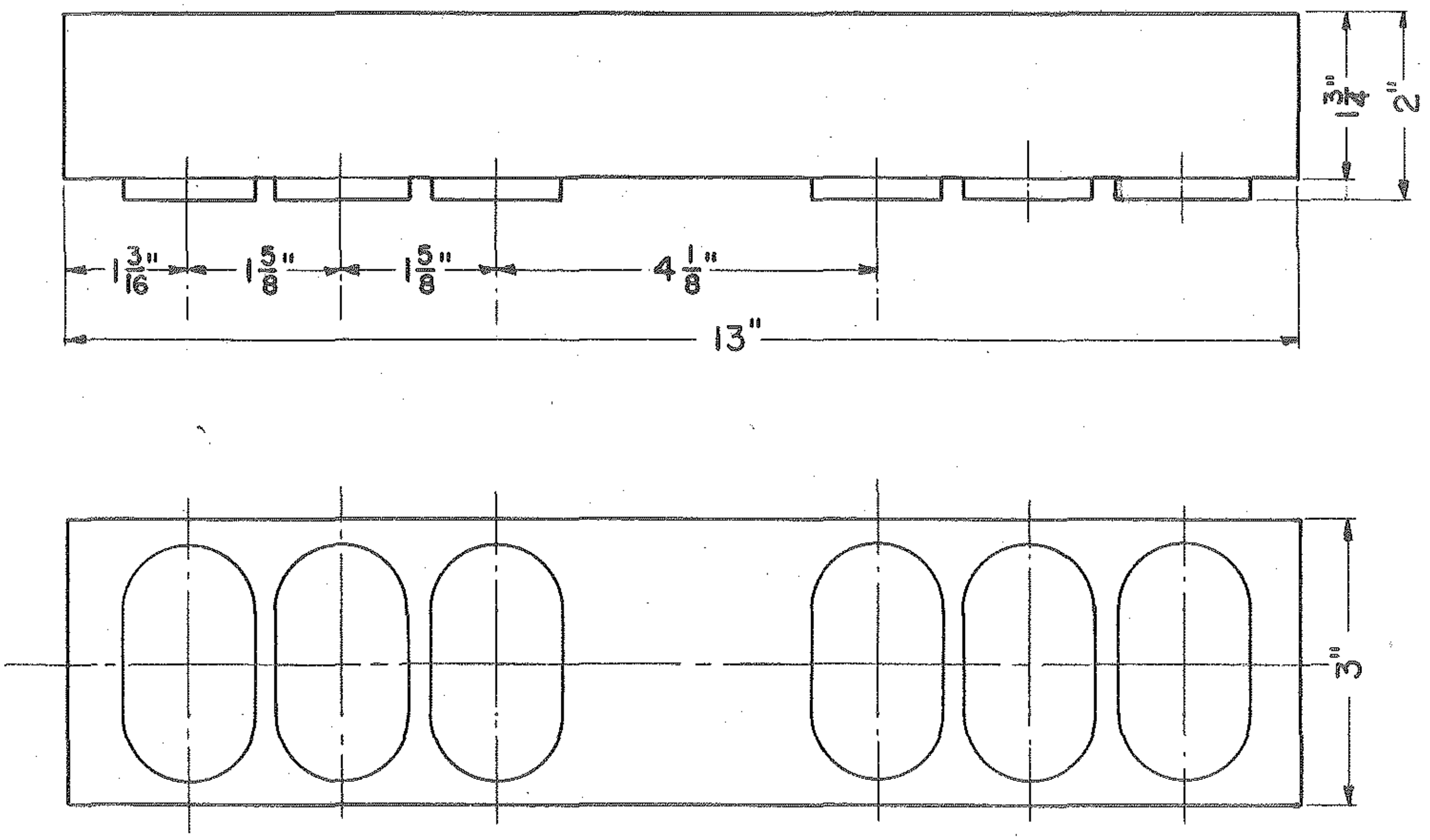
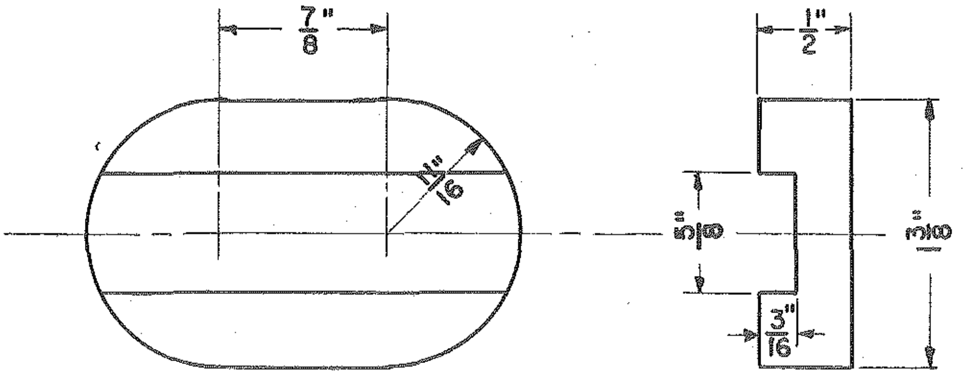


Figure 4. Linear dial pattern used in the measurement of edge deflections.



AXLE ASSEMBLY

SCALE: 1/2" = 1"



TIRE IMPRESSION

SCALE: 1" = 1"

PLATE I

Figure 5. Superstructure and loading beam used to furnish reaction against jack during loading.

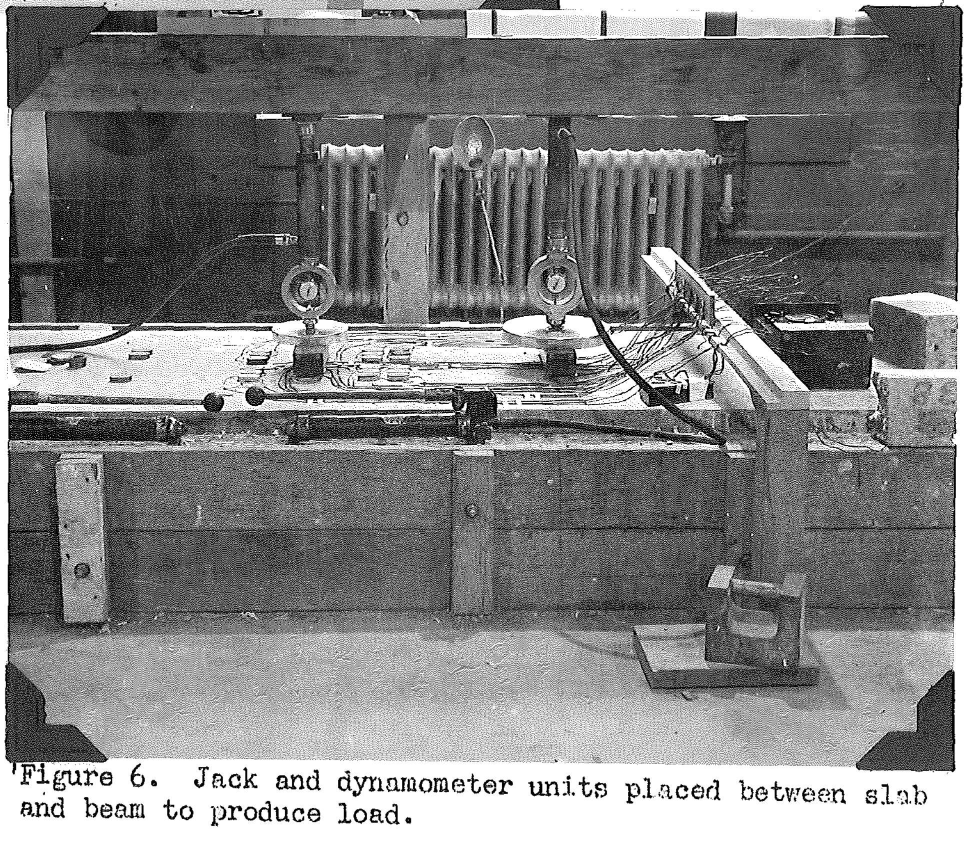


Figure 6. Jack and dynamometer units placed between slab and beam to produce load.

The original loading device was a cantilever beam. This was later replaced by a hydraulic jack. A heavy wooden superstructure and loading beams were built above the slab to provide reaction for the jack when the load was applied. This structure may be seen in Figure 5.

The jacks used to produce the load were the ten-ton Mohawk Porto-power type. The intensity of the load was determined by dynamometer rings equipped with ten-thousandth dials. Two such systems in use at the center of the slab are shown in Figure 6.

The greatest difficulty to overcome was the distribution of the load. As the loading patterns became more complicated by the addition of wheels and axles, the difficulties in alignment became more pronounced. Attempts were made in the initial stages to load several axles with a large metal plate. Results of these experiments were so inconsistent that better methods had to be devised. It was finally decided that each axle required a separate jack, and the problem then reduced to that of obtaining uniform pressure upon all of the wheels under the single axle.

The procedure finally selected was as follows: The grooved shoes were placed over the gages to be read and rubber pads were placed upon them. Thin cardboard shims were then put on top of the rubber pads and the wooden axle assembly was carefully placed upon these. Pressure was applied to the axle block and the shims tested for tightness of fit. Additional shims were inserted above the loose ones until a snug fit was attained. A metal plate now covered the axle block and the jack and dynamometer assembly was put into position.

Loads were kept sufficiently low that the deflection might not exceed 0.05 inches. Excessive loads were required to get appreciable deflection when the slab was on the stabilized base. Good deflection readings were produced on the sand subgrade, however. A limiting factor in the loading was the compressive strength of the wooden wheel impressions. These would withstand about 1000 pounds each without failure.

The rate of loading was not measured. However, the routine established a rather constant rate for all tests except the loads to failure. Deflections were always read at the end of a run after allowing the system to reach stability. The increase in strain readings resulting from the slow settling of the slab after loading during a single test was only 3 to 5 micro-inches. The increase in deflection was not more than 5 thousandths.

MEASUREMENT OF DESTRUCTIVE EFFECT

Highway pavement slabs fail because of excessive tensile stresses in either the upper or lower surface. This fact allows the use of surface strain as an indication of the destructive effect of a load. Experience with surface gage plugs on the Michigan Test Road (5) has proven that the readings are not sufficiently reliable for accurate comparison. The Carlson stress meter (6) has proved satisfactory but was not available. The SR-4 electric gage was investigated and found very satisfactory when applied to steel. Tests on concrete indicate good performance, so it was decided to use these gages for the model slab investigation.

Sets of three gages each, one longitudinal, one lateral and one diagonal, were attached to the bottom of the slab directly beneath corresponding sets on the top. Loads were applied with results as shown in graphs A and B of Plate II. It was anticipated that the strains would be radial and of about equal intensity when the load was impressed through a single wheel. However, the wheel could not be located directly at the point of intersection of the gage lines without destroying the gages. This fact may have caused the discrepancy in the results. Graph B is evidence that the state of tension on the bottom of the slab

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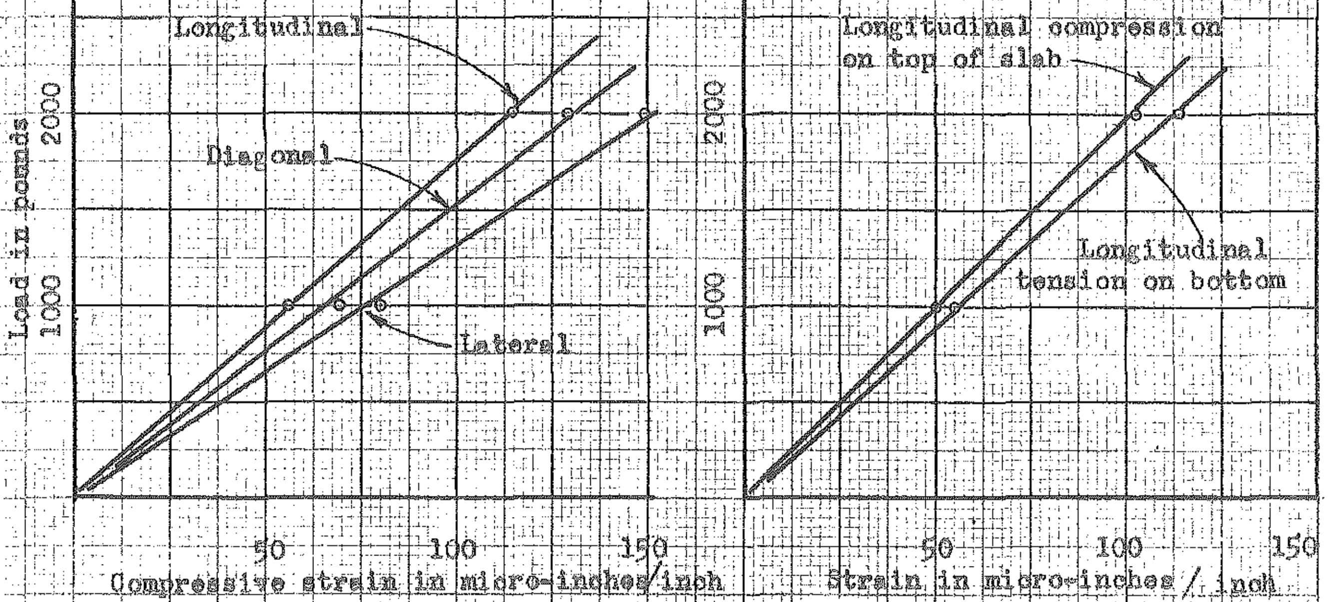
(5) Michigan State Highway Department - The Michigan Test Road, 1942.

(6) Carlson, R. W. - "Five Years Improvement of the Elastic Wire Strain Meters." Engineering News Record, May 16, 1935.

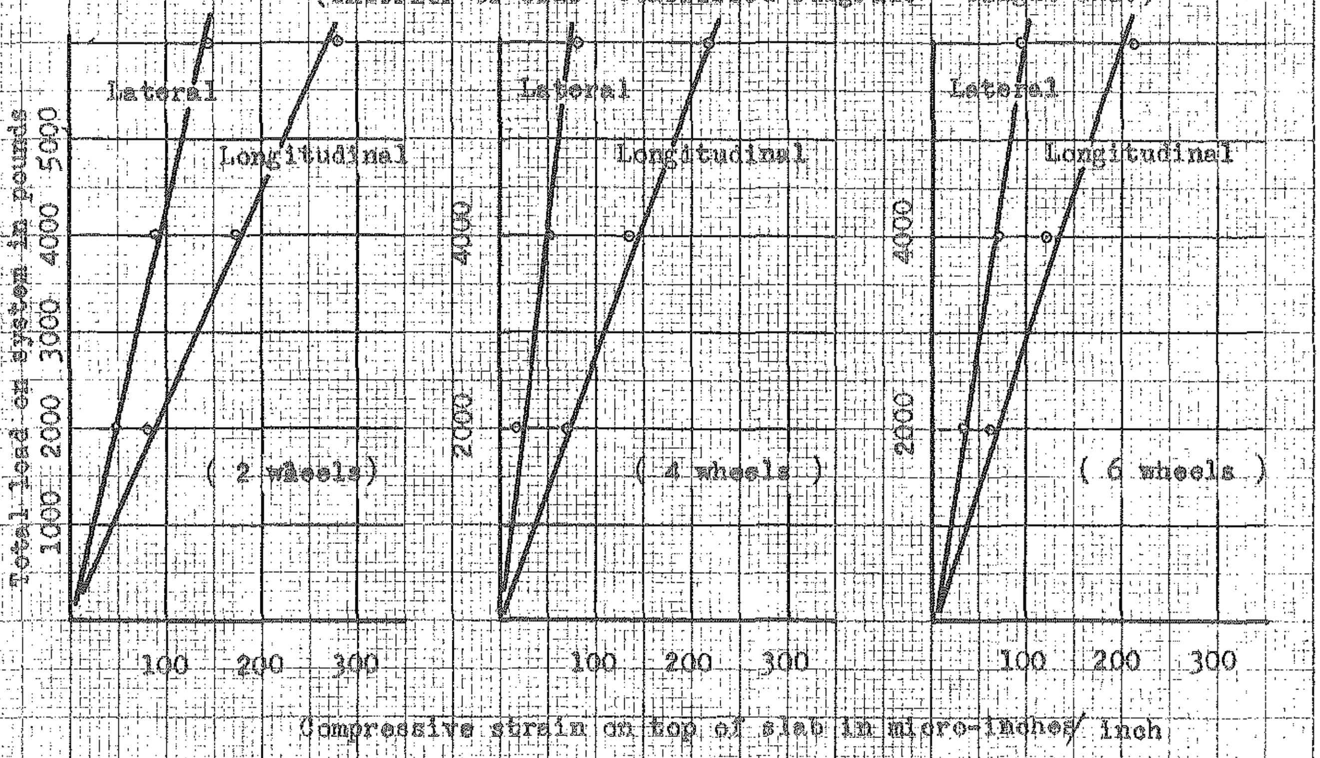
(A) Comparison of strain values in three directions due to single wheel loading.

(B) Relation between strains on top and bottom of slab.

(Interior of slab - Sand subgrade)



(C) Comparison of lateral and longitudinal strain under 3 types of loading.
(Interior of slab- Stabilized subgrade - Single axle)



STUDY TO DETERMINE DIRECTION OF MAXIMUM STRAIN

PLATE II

under a load is well indicated by the compression reading on the top. This is very advantageous because of the difficulty of attaching gages to the bottom, and the ease with which they may be cemented to the top.

Graphs C, Plate II, are the result of efforts to compare strain values in the lateral and longitudinal direction for single axle loading. It is readily seen that in no case is the lateral strain more than 50% of that in the longitudinal directions. Further studies with two and three axles show an increase in this ratio to as much as 70%. See Plate III. Computation by Fremont(7) based on theory indicates that on a 7 inch slab this ratio is about 80%.

Since the excess of longitudinal strain values over lateral strain is marked, it was thought that the maximum strain must be in a direction close to the longitudinal, and within the limits of error of this investigation these longitudinal strain readings would be representative of the state of stress of the pavement for any loading system. Difficulty in the use of rosette arrangements precluded the possibility of their use in this model study, but the single gage could basily be straddled by a grooved block. These facts led to the adoption of the grooved block and longitudinal gage as a criterion of the state of stress, and consequently an indication of the destructive effect of the load.

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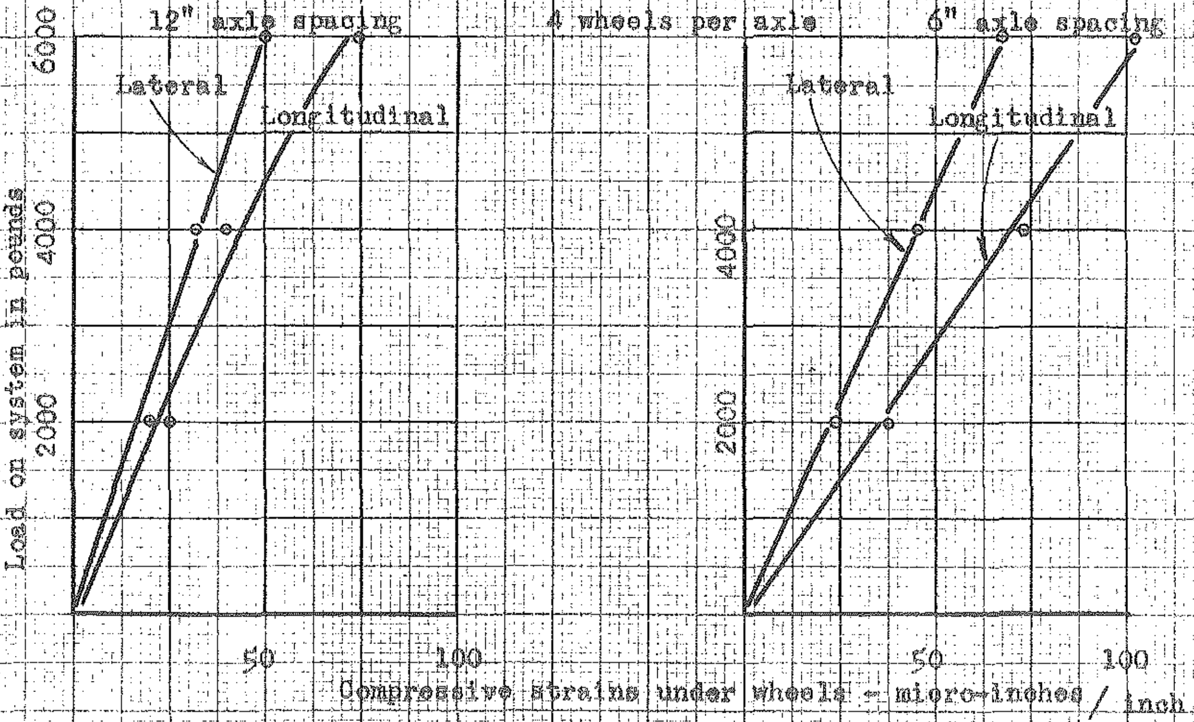
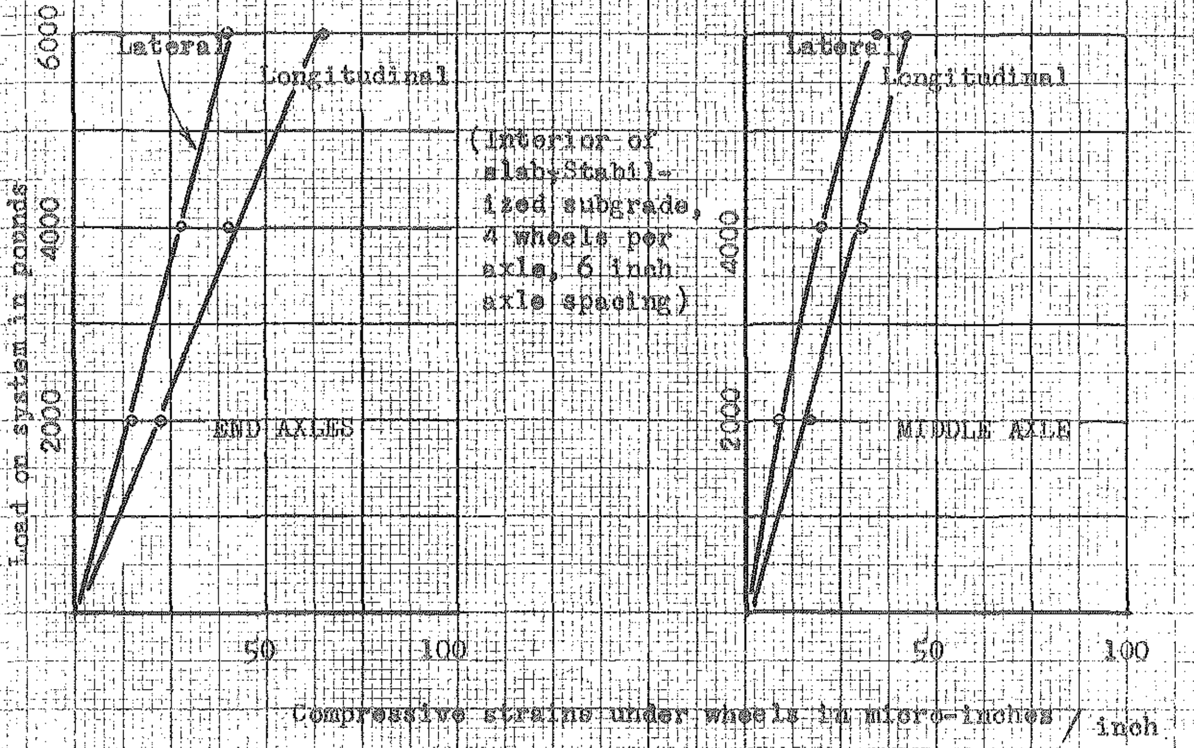
(7) Fremont, W. O. - Effect of Various Loadings on Highway Pavements, Mimeographed Report, Research Laboratory, Michigan State Highway Department, February, 1942.

(D) Relations between strain values and direction for two axles
(Interior of slab - Stabilized subgrade)



(E) Relations between strain values and direction for three axles



COMPARISON OF LATERAL AND LONGITUDINAL STRAINS FOR 2 AND 3 AXLE SYSTEMS

PLATE III

Multiple Wheels on a Single Axle

Because of the present day trend to add additional wheels to trailer axles to allow transportation of heavy loads, a study was devised to evaluate the benefits derived from this practice. Axles with 2, 4, and 6 wheels were located at the center, edge, and corner of the model. Figure 7 is typical of the arrangement for center loading.

It was found that the stress reduction due to the addition of wheels was dependent upon the subgrade. The strains caused by a load upon an axle with four wheels were 32% less than those produced by the two wheel system, and the six wheel array gave a reduction of 23% when the slab was resting on the stiff base. However, similar tests when the sand subgrade was used showed reductions for four wheels of only 3%, and an increase in strain of 6% for six wheels. Since modulus tests on the sand indicated approximately field conditions, the latter figures are more indicative of the effects experienced on the road. Graph A of Plate IV is a summary of the data from these single axle tests at the center of the slab. Graph B of Plate IV shows the relationship at the edge and Graph C is the corner condition. The differences in strains for the various wheel arrangements and the apparent inconsistencies in their order of magnitude seem to indicate that no increase in load is warranted by the addition of extra wheels to an axle.

Two Axles

The alternative method of adding wheels to support heavy loads is to add an additional axle. Glovers' (3) report indicated that there is an axle spacing above which the strains under each axle for a

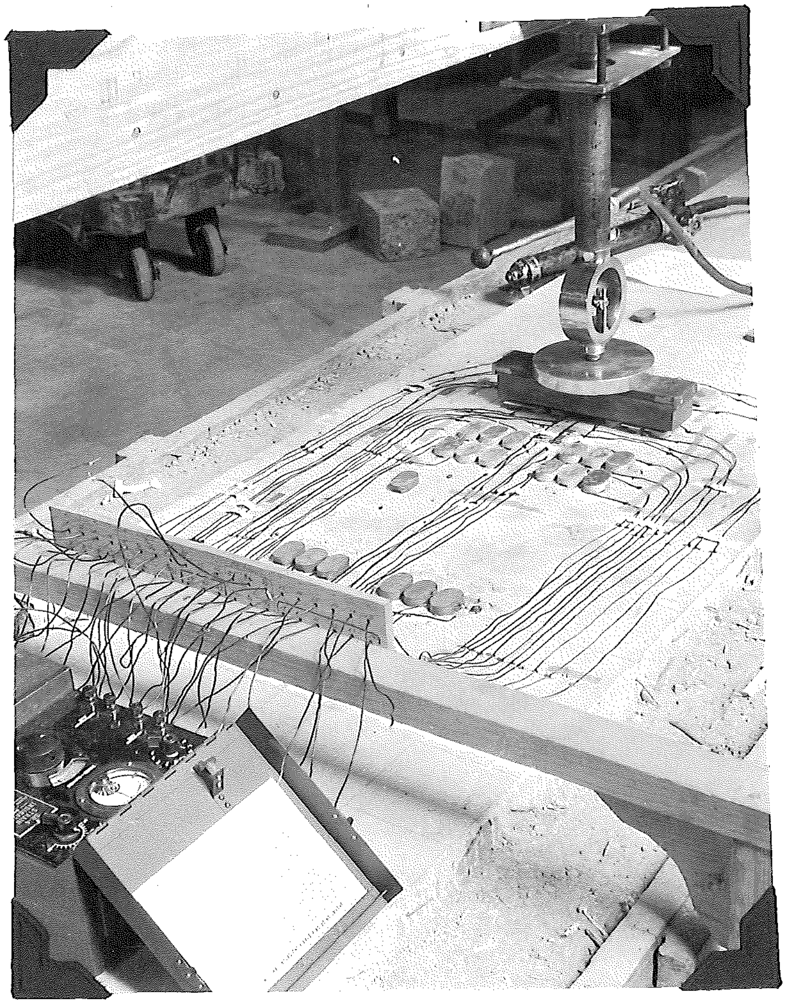
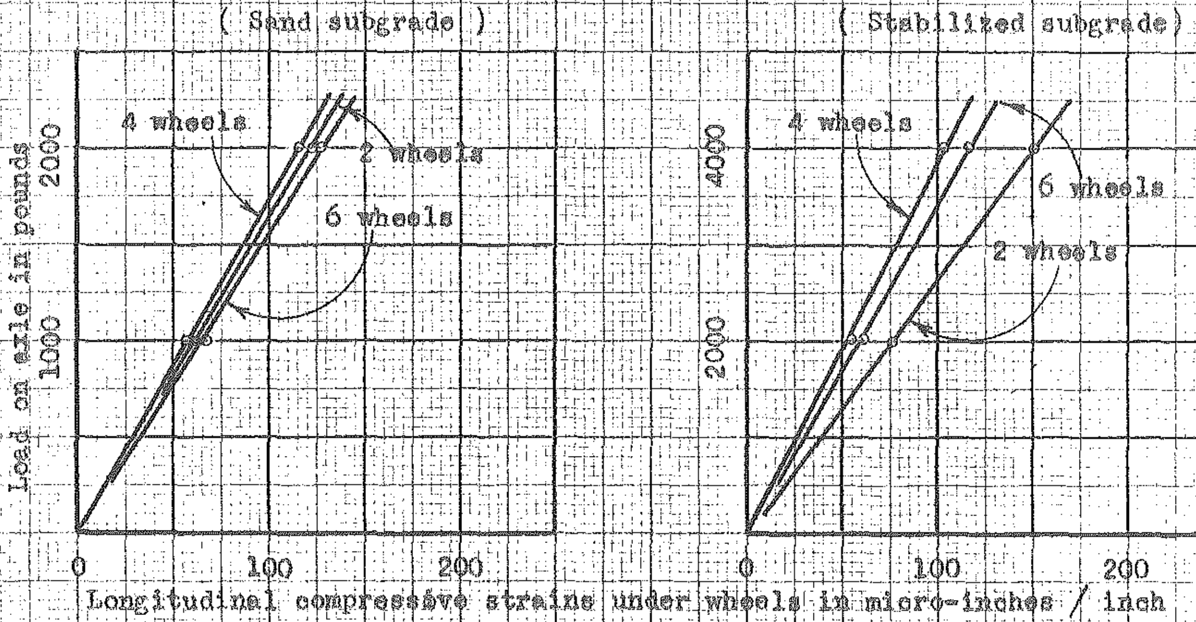


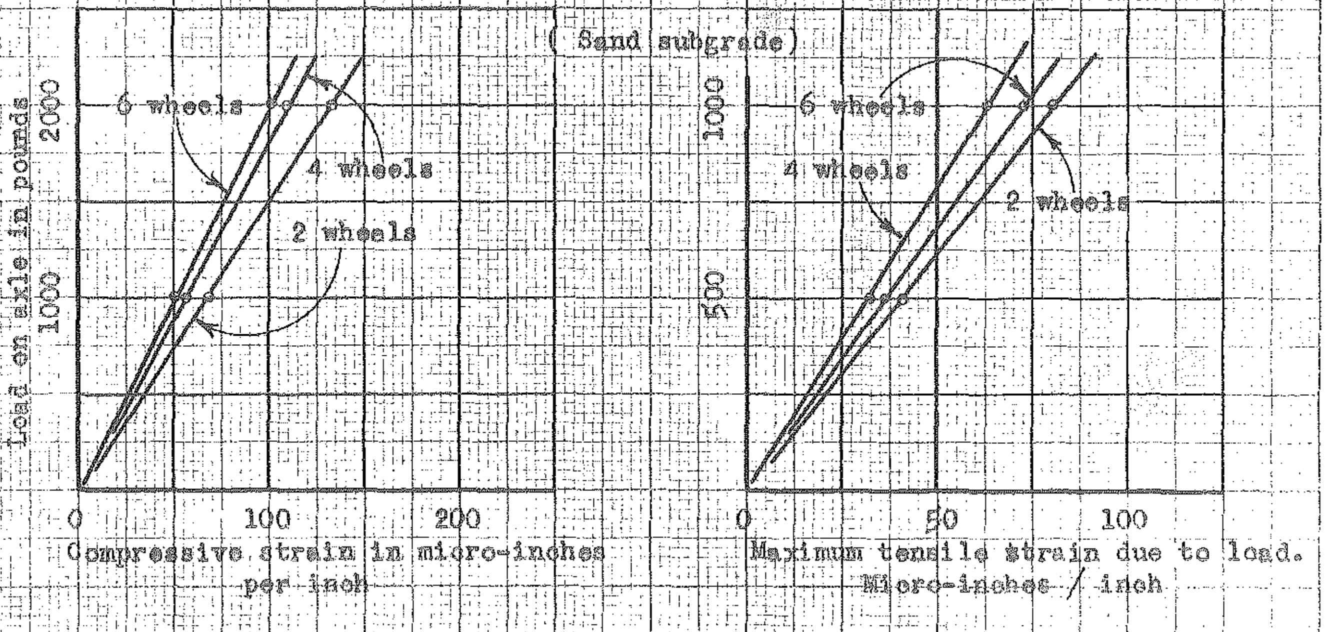
Figure 7. Details of loading method for a single axle at the slab center.

(A) Comparison of strains for single axle loading at interior of slab



(B) Effect of single axle at edge of slab

(C) Effect of single axle at corner of slab



EFFECT OF THE ADDITION OF WHEELS TO AN AXLE

PLATE IV

constant axle load are slightly lower than they are when one axle is loaded alone. This result was corroborated by the experiments on the model slab.

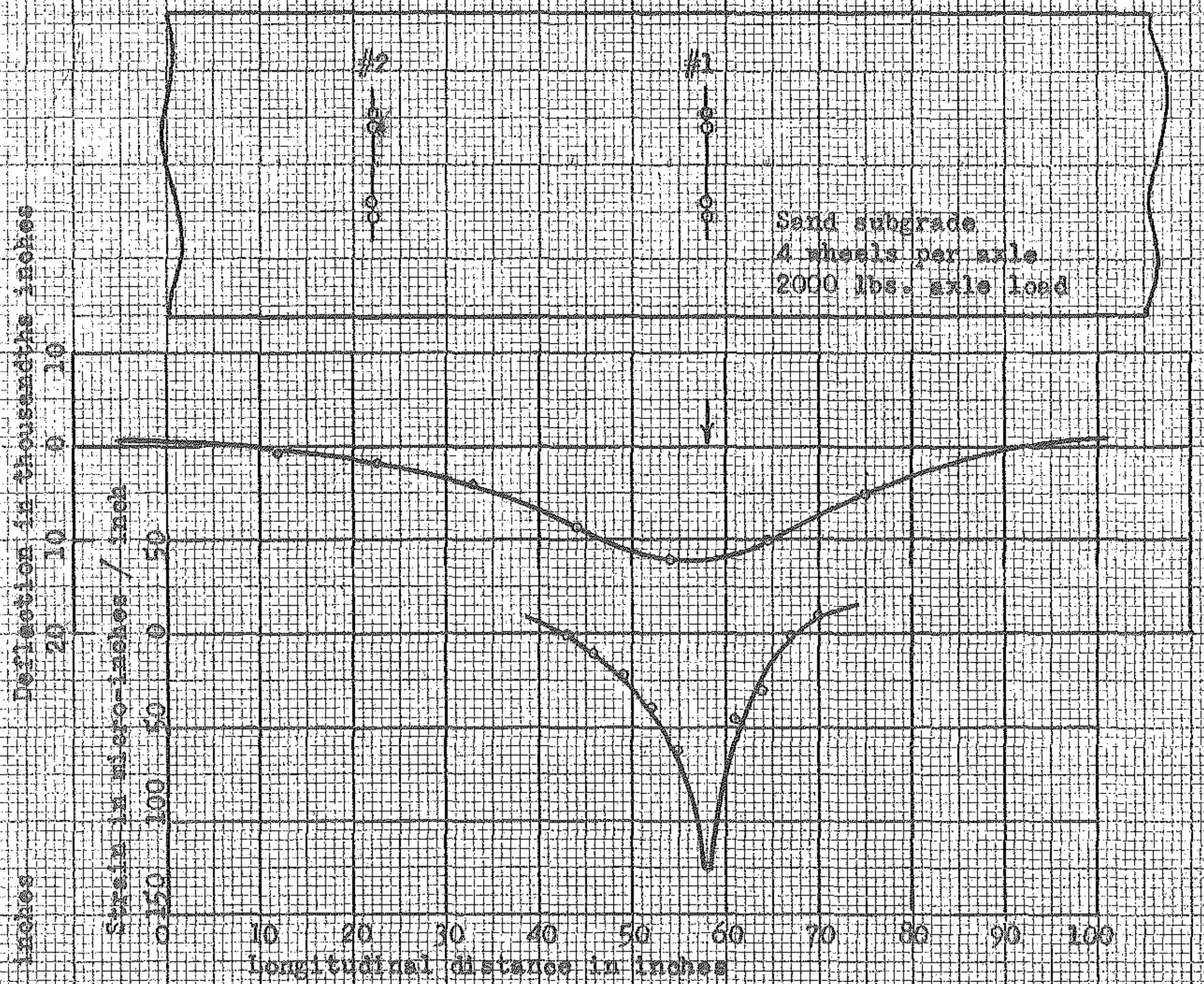
Two axles were spaced at the extreme distance of 102 inches and this space was reduced by stages until a minimum spacing of 6 inches was reached. Deflections and strains were read both for a load on the first axle alone and for equal loads on each axle. By this method the strain and deflection patterns for one axle could be readily compared with the patterns for two axles, and any increase or decrease in strain under the first axle was easily observed. Figure 6 is an example of the method used to load two axles.

Examination of Graph A of Plate V shows that the deflection curve influences a large portion of the slab. The distance between points of zero deflection measures about 8 feet. The influence of the load extends beyond this distance because of the small upward deflection outside of these zero points. However, the upward deflection is very small so that the slab is not greatly affected beyond a point four feet each side of the load.

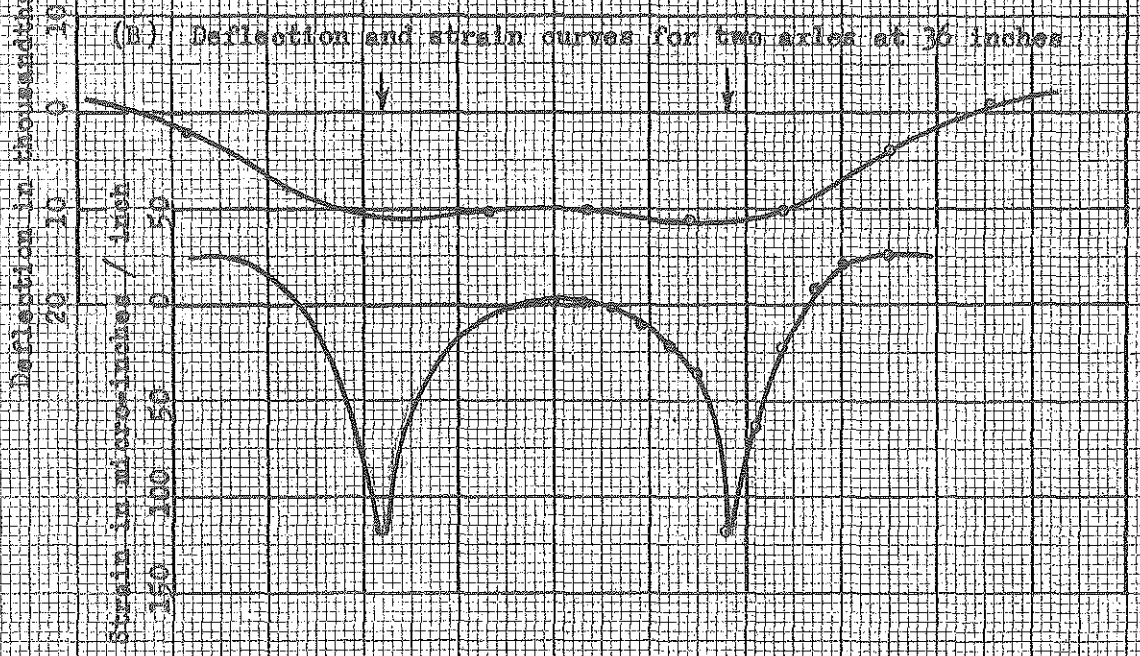
The stress curve shows that the top of the slab is in compression within a region two feet wide and in tension beyond. There were not enough gages available to chart the complete curve, but the radius of curvature of the deflection curve is large in this region of tension so it is expected that the values attained are relatively small. No measured tensile values exceed 25% of the maximum compressive strain.

An attempt was made to space two axles sufficiently far apart that one would not influence the other. Although the strains in the

(A) Deflection and strain curves for a single axle



(B) Deflection and strain curves for two axles at 36 inches



DUAL AXLE STUDY

PLATE V

first axle area were not measurably affected by the second axle load when the largest available spacing of 102 inches was used, the deflections were readable.

The curves obtained from the data on two axles at 36 inches is presented in Graph B of Plate V. At this spacing the deflection curve is practically flat at the bottom, and the strain curve shows only slight tension midway between the loads. Graph A of Plate VI shows the change in the curves produced by closer spacing. Here the axles are 15 inches apart. Although these curves were plotted from the six wheel data, they do not differ measurably from the four wheel case.

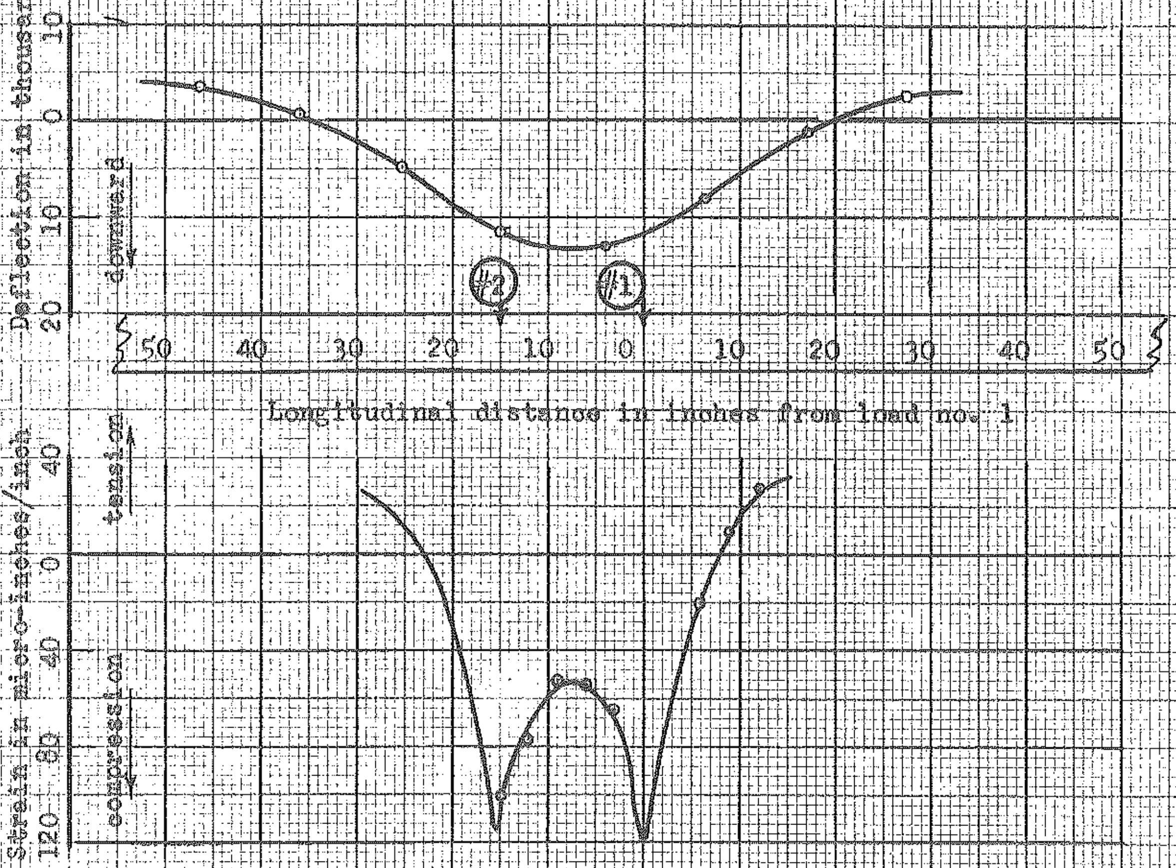
Curves (B) and (C) in Plate VI present a relation between stress change under the first load caused by the application of the second load. Graph (C) for the edge of the slab seems to be better than B, the curve for the interior. The discrepancy was probably caused by variations in subgrade modulus or subgrade bearing. The curves are a good indication that any axle spacing under 12 inches must be accompanied by a reduction in axle load if the strains are not to be increased beyond those caused by a single axle. Apparently a spacing of 25 inches will produce minimum strains. Since the axle lengths used in the project were about 12 inches, it may be roughly stated that axles must be spaced at least one axle length apart if the two axle systems are to carry twice the load of a single axle. If the spacing is twice an axle length the total load could be increased about 10%.

Three Axles

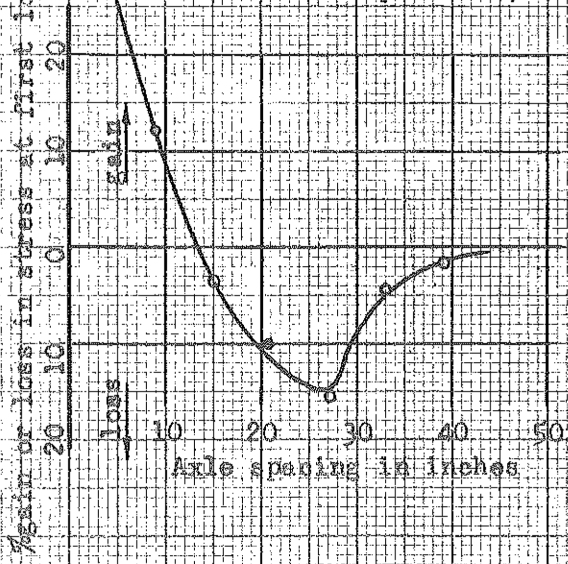
A third axle was added to the system in order to ascertain whether or not the trend found in the two axle studies continued when additional

(A) Deflection and strain curves for loads on two axles.

(15" spacing, 6 wheels per axle, 2000 lbs. per axle, sand subgrade)

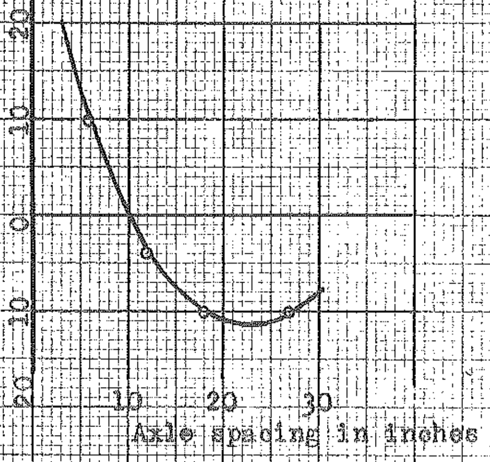


(B) Effect of 2nd load upon strain under first at interior of slab.
(6 wheels per axle)



(Sand)

(C) Effect of 2nd load upon strain under first at edge of slab.
(2 wheels per axle)



STUDY OF EFFECT OF AXLE SPACING

PLATE VI

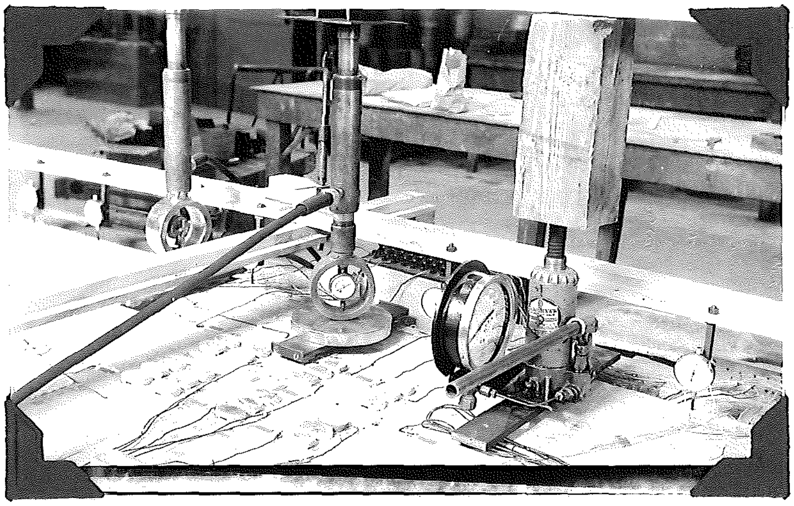


Figure 8. Three axles loaded at the edge of the slab.

axles were added. Figure 8 illustrates how 3 axle loading was accomplished. Deflection and strain curves for 32 inch and 12 inch axle spacing are drawn on Plate VII.

It is seen that the strains under the middle axles are greater than the strains under the outside axles in these two instances. There is a slight reversal in curvature in the deflection curve for the 32 inch spacing accompanied by a corresponding section of the strain curve registering tension. Closer spacing of the axles eliminates this effect.

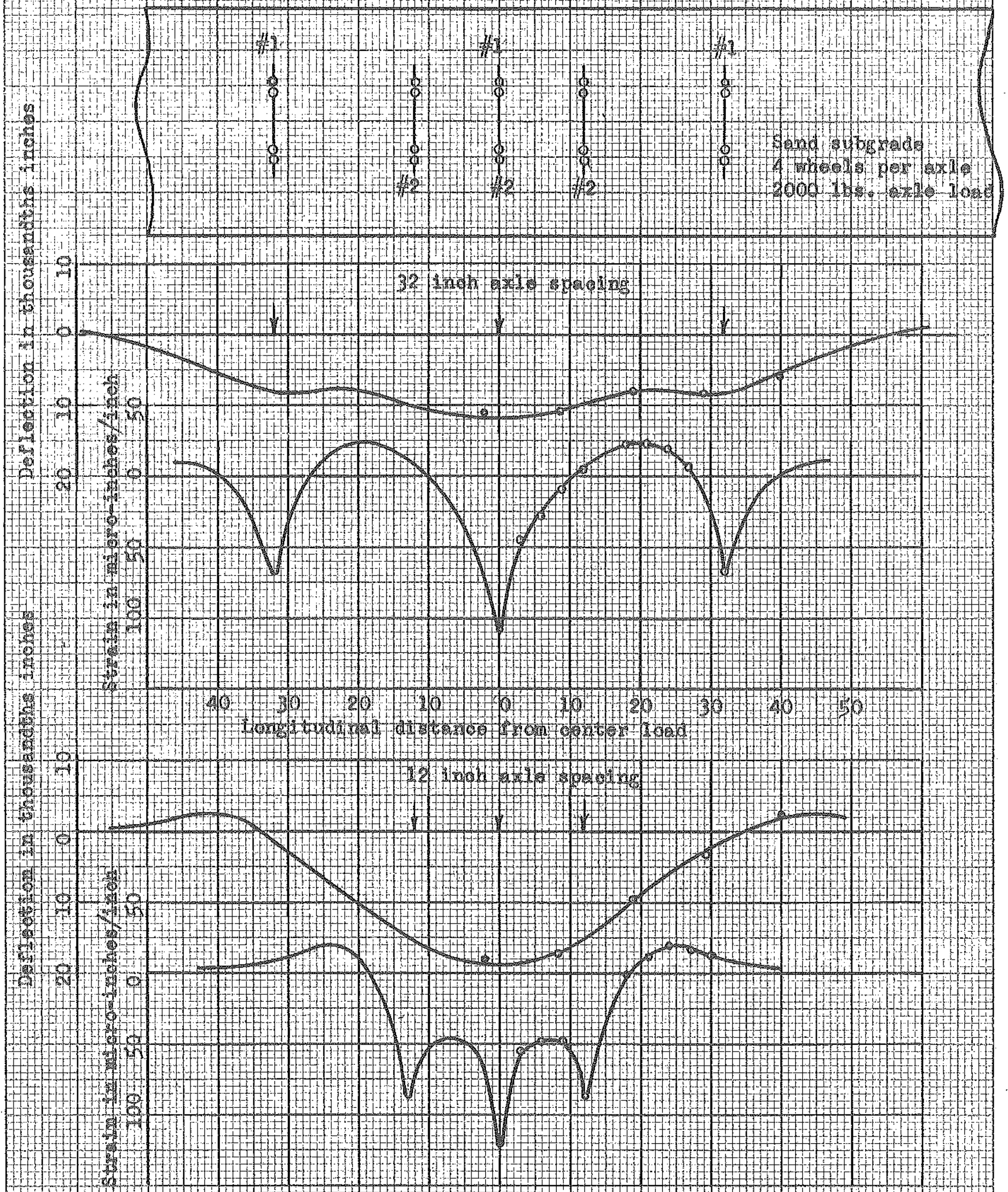
The investigation at the slab center shows that the largest strain reductions occur under the inner axle when the spacing is about 22 inches, see Plate VIII, Graph A, curve (a), and a corresponding maximum reduction is found at 23 inches for the outside axles, Graph A, curve (b). These values support the results of the two axle study in which it was shown that a spacing of about two axle lengths produced minimum strain. If no other factors are involved, curve (a) suggests that in the case of three axles spaced at 23 inches the axle load might be increased 15% over the single axle load without increasing the strain beyond that produced by one axle.

Edge Loading

Strain gages were cemented to the slab along a longitudinal edge and a deflection dial pattern was arranged to permit a study of conditions at the edge of the slab. Figure 4 is typical of the layout for edge testing.

The strain and deflection patterns for this location were similar in appearance to those found at the slab center with the qualification that the amplitudes of the curves were greater. Graph A of Plate

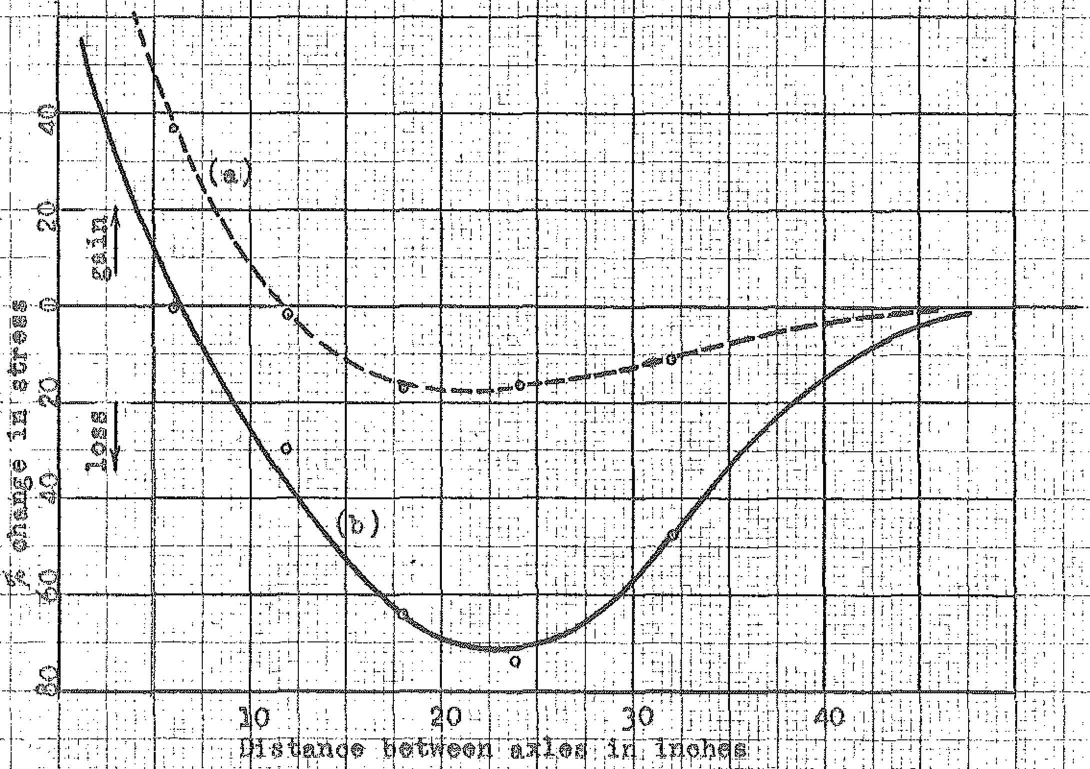
Deflection and strain curves for three axle loading



THREE AXLE STUDY

PLATE VII

(A) Percent gain or loss in stress on (a) middle axle and (b) outside axle due to proximity of the other two axles



(B) Effect of axle length on stress under outside wheel at slab edge

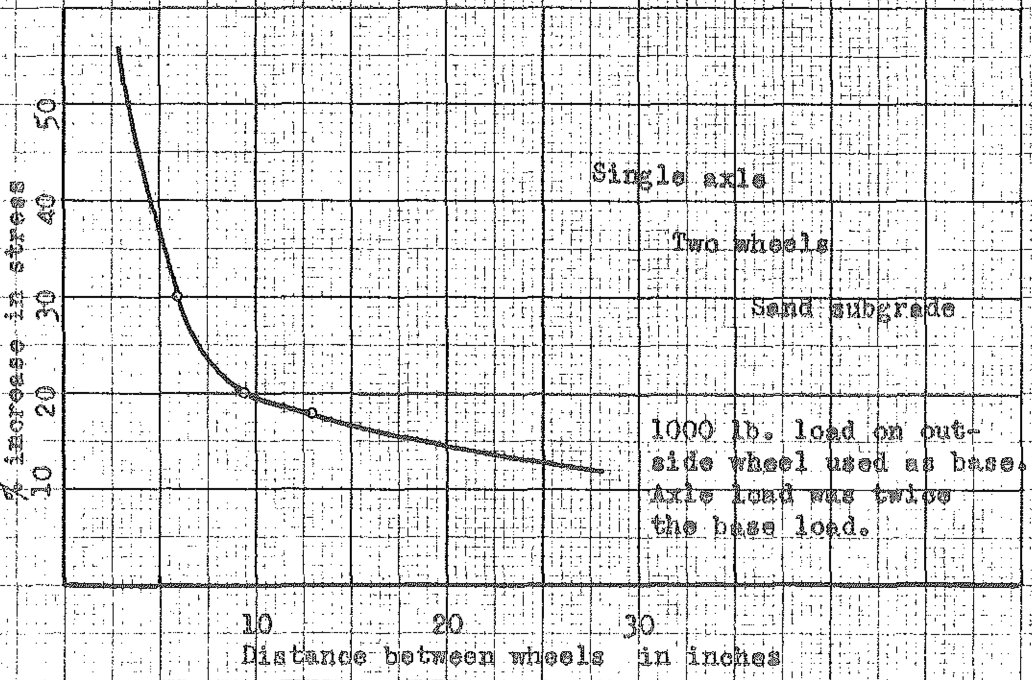


PLATE VIII

IX indicates that the strains at the edge exceed those for the center by 25 percent.

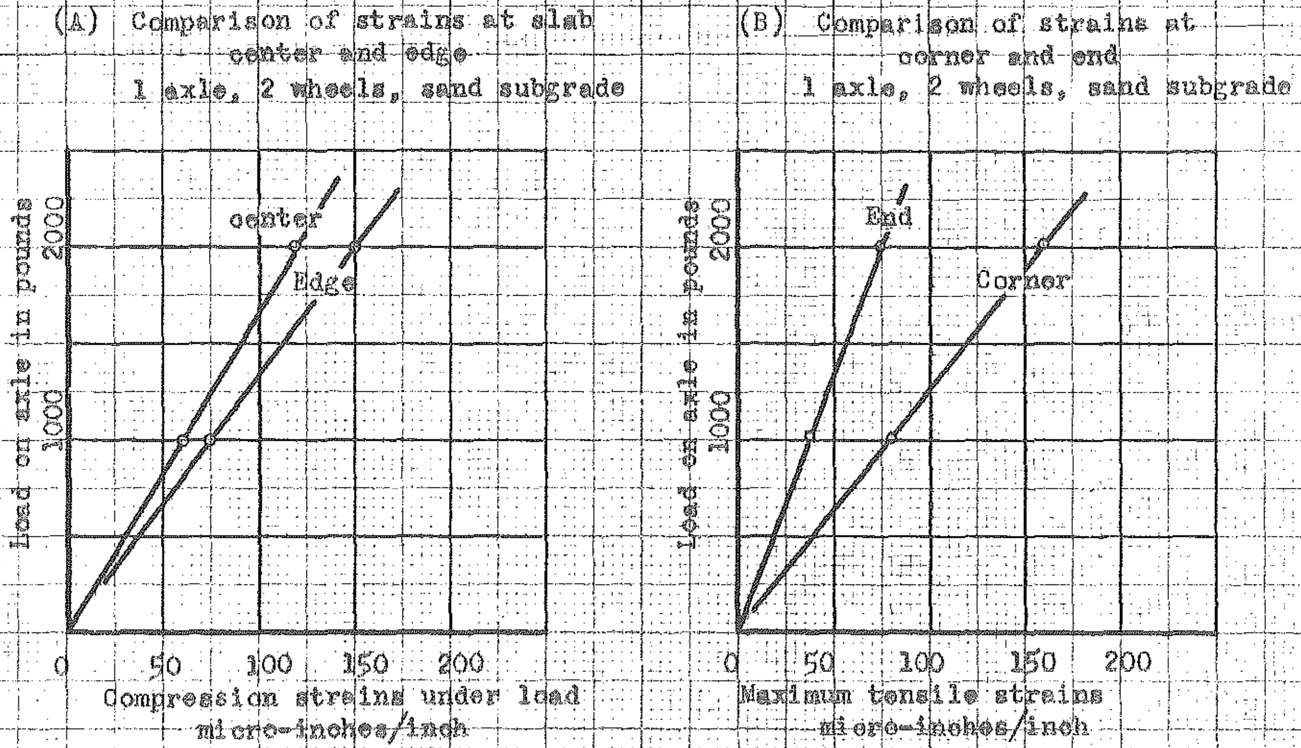
The axle spacing effect for the edge was exhibited by Plate VI, Graph C. The critical spacing is seen to be 10 inches, and the spacing for minimum stress is 23 inches. These values are in fair agreement with the results of the center study.

In order to study the effect of the inner wheel upon the strains under the wheel at the edge, the loading jacks were arranged so that each wheel could be loaded separately. The magnitude of the strain caused by loading the outer wheel alone was found. The inner wheel was then loaded an equal amount and the increases in strain noted. The size of this increase was dependent upon the distance between wheels, being about 20 percent for the regular axle length. Graph C, Plate IX compares the outer and inner strains. The effect of other axle lengths upon this strain are shown in Graph B on Plate VIII. It is seen that axle lengths under 9 inches yield rapid increases in strain under the outside wheel.

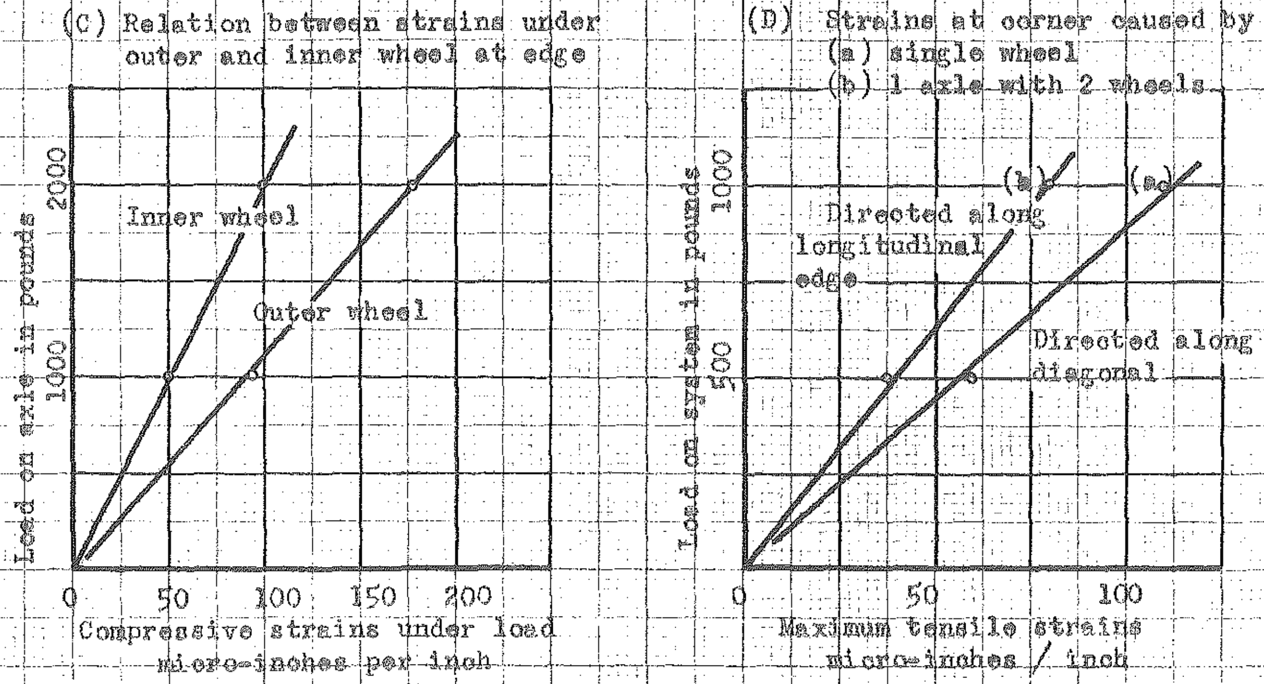
Conditions at the Slab End

Usually concrete road slabs are joined at the ends by some load transfer device such as slip dowels. However, much wartime construction has been done without this steel. The model upon which these tests have been conducted simulates such construction, since there were no supporting dowels at the end.

Loads at the end of the slab produced strains of nearly equal magnitude in two directions: (1) tensile strains along the slab center line with a maximum a few inches inward from the load, and (2) compressive


(A) Comparison of strains at slab center and edge
1 axle, 2 wheels, sand subgrade

(B) Comparison of strains at corner and end
1 axle, 2 wheels, sand subgrade


(C) Relation between strains under outer and inner wheel at edge

(D) Strains at corner caused by
(a) single wheel
(b) 1 axle with 2 wheels

COMPARISON OF STRAINS AT CENTER, EDGE, END, AND CORNER OF SLAB

PLATE IX

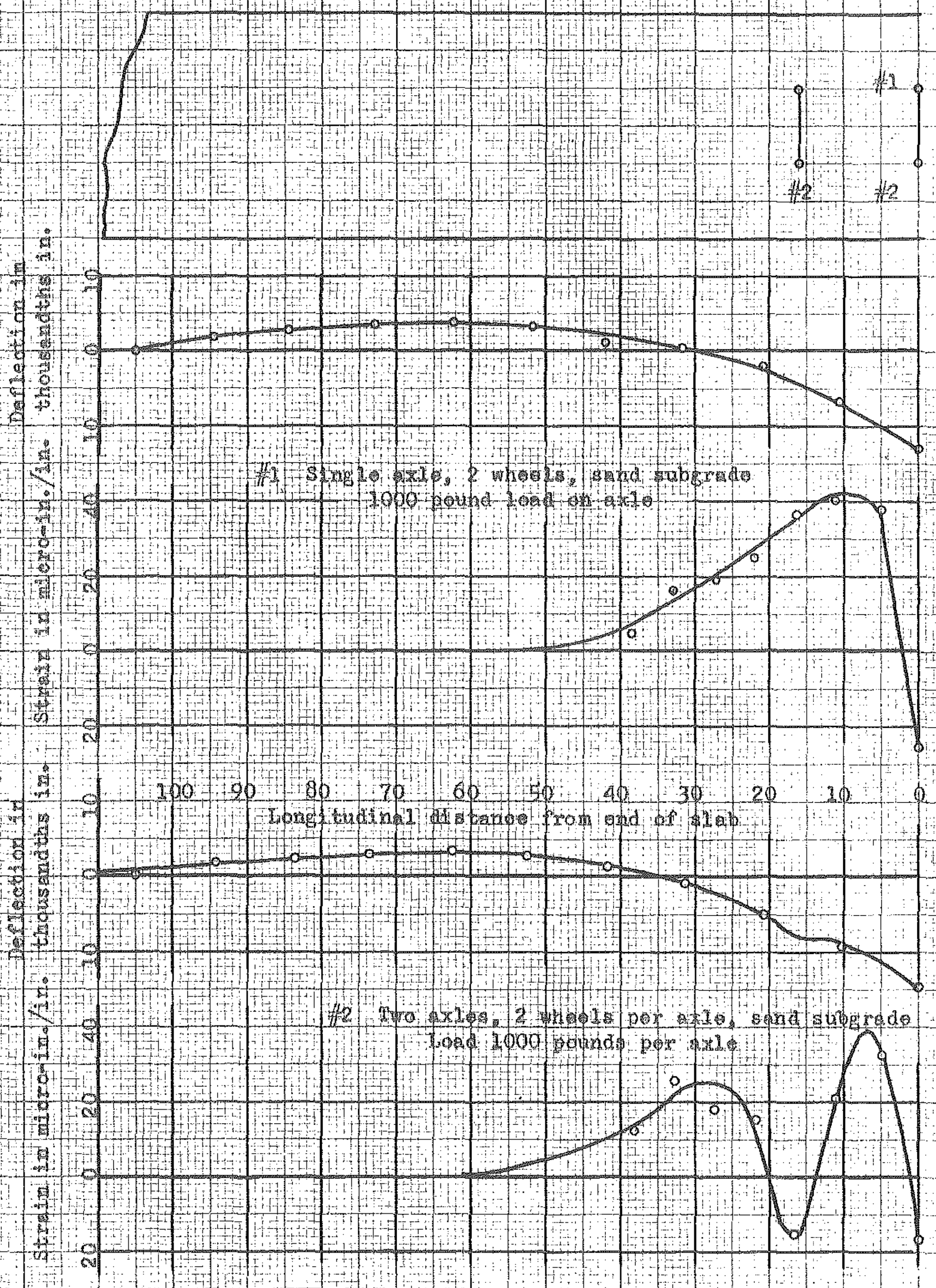
strains under the load in a lateral direction. The latter case is very similar to edge loading, but the amplitude of the strain curve was less than that for the edge because of the flat deflection pattern resulting from the narrow slab width. The longitudinal strains and deflections for a single axle and for two axles at 16 inches are exhibited on Plate X.

These graphs show that the maximum strain is somewhat reduced by the application of a second axle, while the deflections remain about the same. The amount of such stress reduction is dependent upon the axle spacing. Graph A of Plate XI shows the effect of the distance between axles. This curve reveals a critical spacing at about 9 inches and a spacing of 16 inches to produce minimum strain.

Investigation at the Corner

Figure 2 shows the gage layout and dial arrangement along the longitudinal edge for the corner loading test. In addition to the gages along the slab edges, several gages were attached in the diagonal direction. The regular wheel and axle study was repeated here, and in addition tests were made for the case of a single wheel on the corner.

The direction of maximum strain for this study was dependent upon the type of loading. A single wheel on the corner produced maximum strain along the diagonal, certain two axle systems showed greater strains along the diagonal than along the edge, while others gave larger strains at the edge. The single axle loading produced maximum strains along the longitudinal edge.



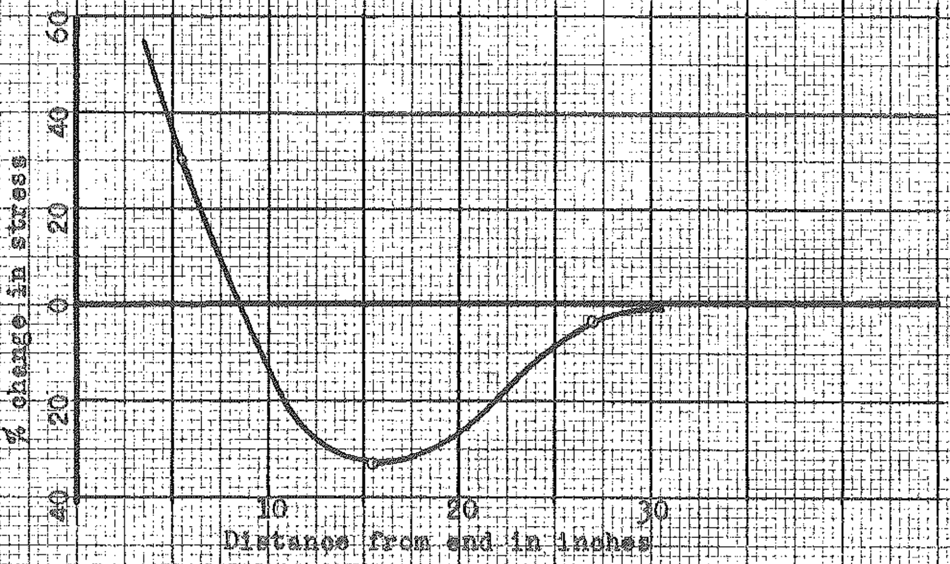
DEFLECTION AND STRAIN CURVES FOR THE END OF THE SLAB

PLATE X

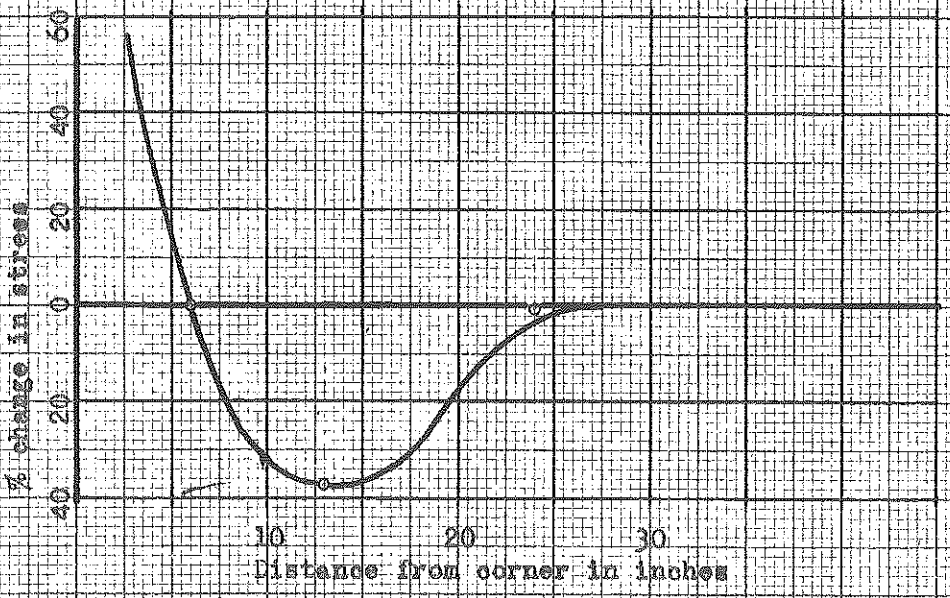
Results of the single axle study at the corner were shown on Plate IV, Graph C. Strain and deflection diagrams for the two wheel case for one axle and for two axles at 13 inches are shown on Plate XII. The stress reduction is quite noticeable for the axle spacing shown. Graph B of Plate XI shows that this value of axle spacing is the spacing which produces minimum stress. The critical spacing is 6 inches.

Stresses due to corner loading exceed those caused by any other type of loading. A study of Plate IX shows that the end stresses are less than 50 percent of the corner stresses; edge values are about 94 percent, and the center values are 75 percent of those at the corner. Graph D, Plate IX compares the effect of a single wheel load with that of a single axle and shows a strain increase of almost 45 percent over the values of axle loading.

(A) Effect of axle spacing on magnitude of maximim tensile stress along longitudinal center line at end of slab



(B) Effect of axle spacing on maximum tensile stress along longitudinal edge at corner of slab



EFFECT OF AXLE SPACING

PLATE XI

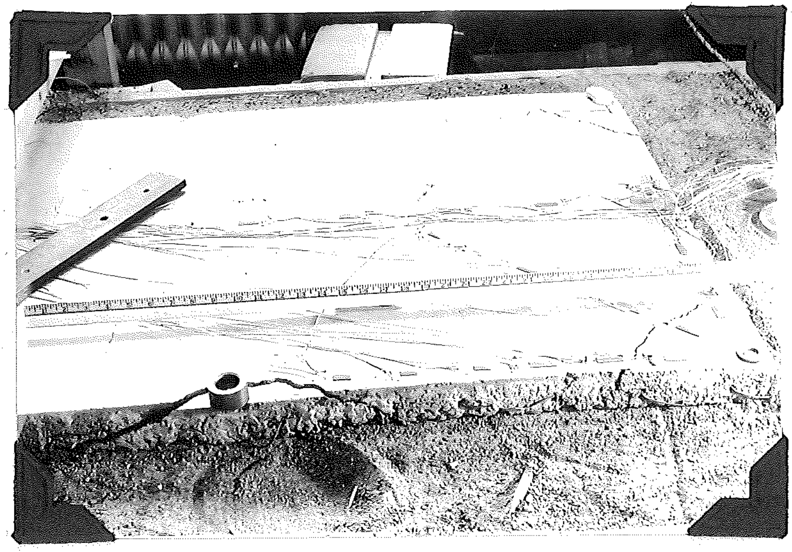


Figure 9. End of slab showing failure due to single wheel at corner in right foreground, corner break from tandem loading in right background, and edge break caused by semi-circular loading area in left foreground.

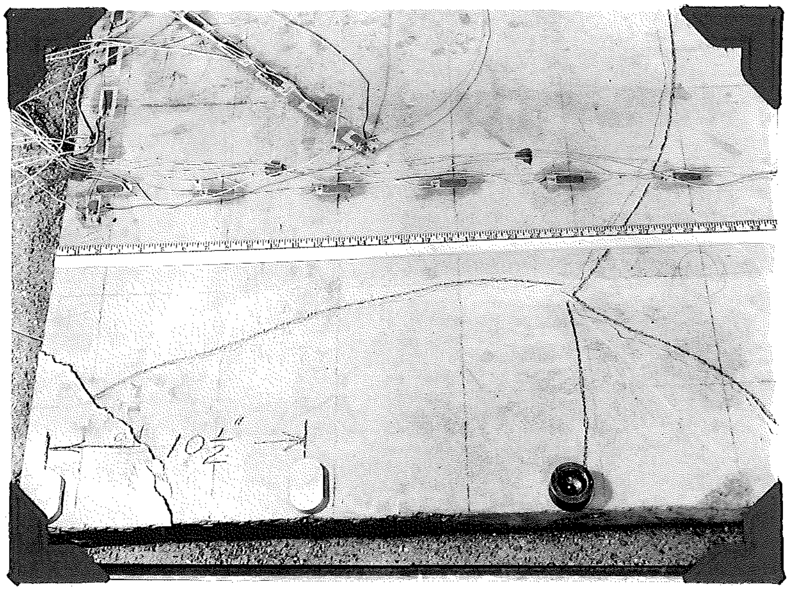


Figure 10. Left foreground: break due to tandem load. Right: cracks formed when load was applied on 1-3/4 in. circular plate at slab edge.

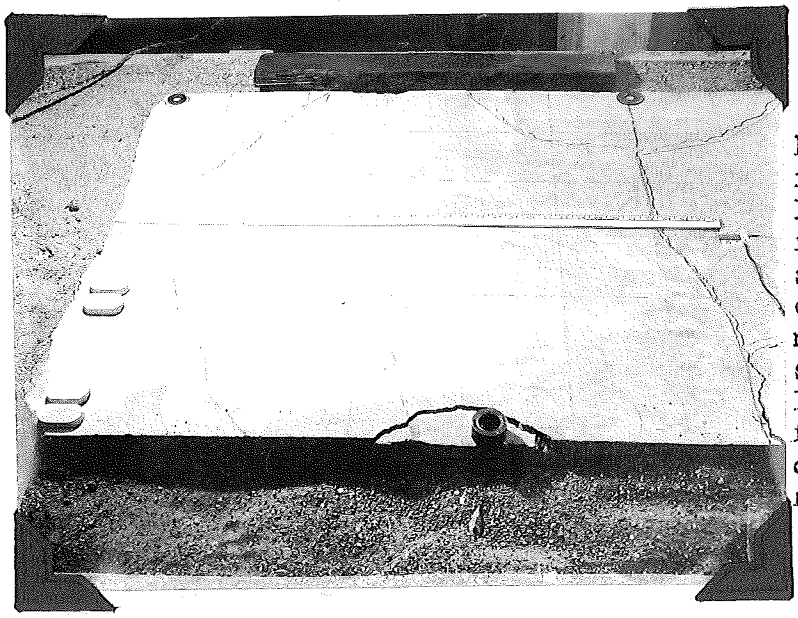


Figure 11. Corner break from axle loading in left foreground, edge failure due to load on semi-circular plate in center foreground, corner break caused by single wheel load in left background, and failure from edge load on 1-3/4 in. disc at right.

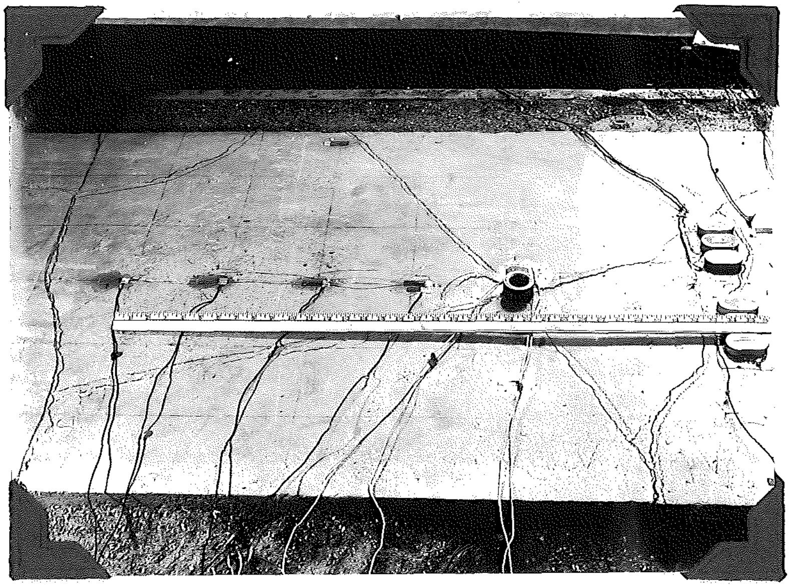


Figure 12. Radial and transverse cracks in center of slab caused by load on 1-3/4 in. plate. There was apparently some shear failure at the point of load.

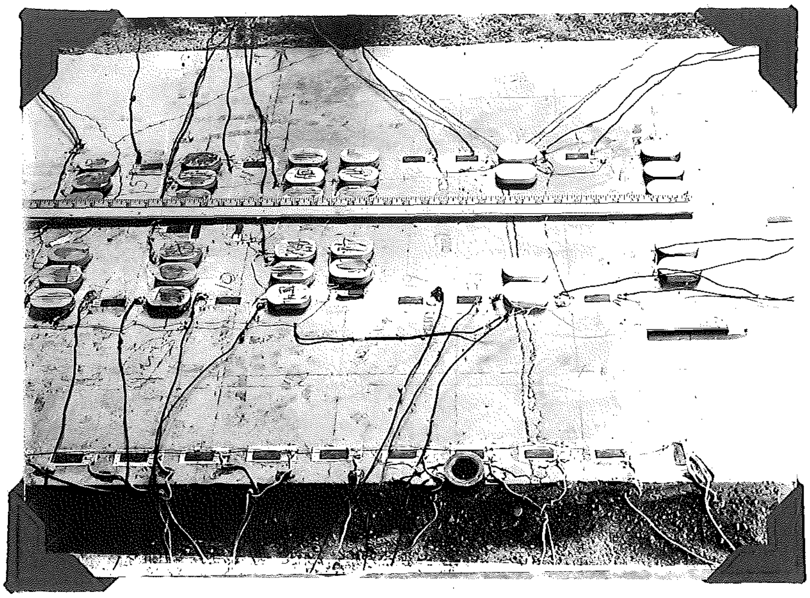
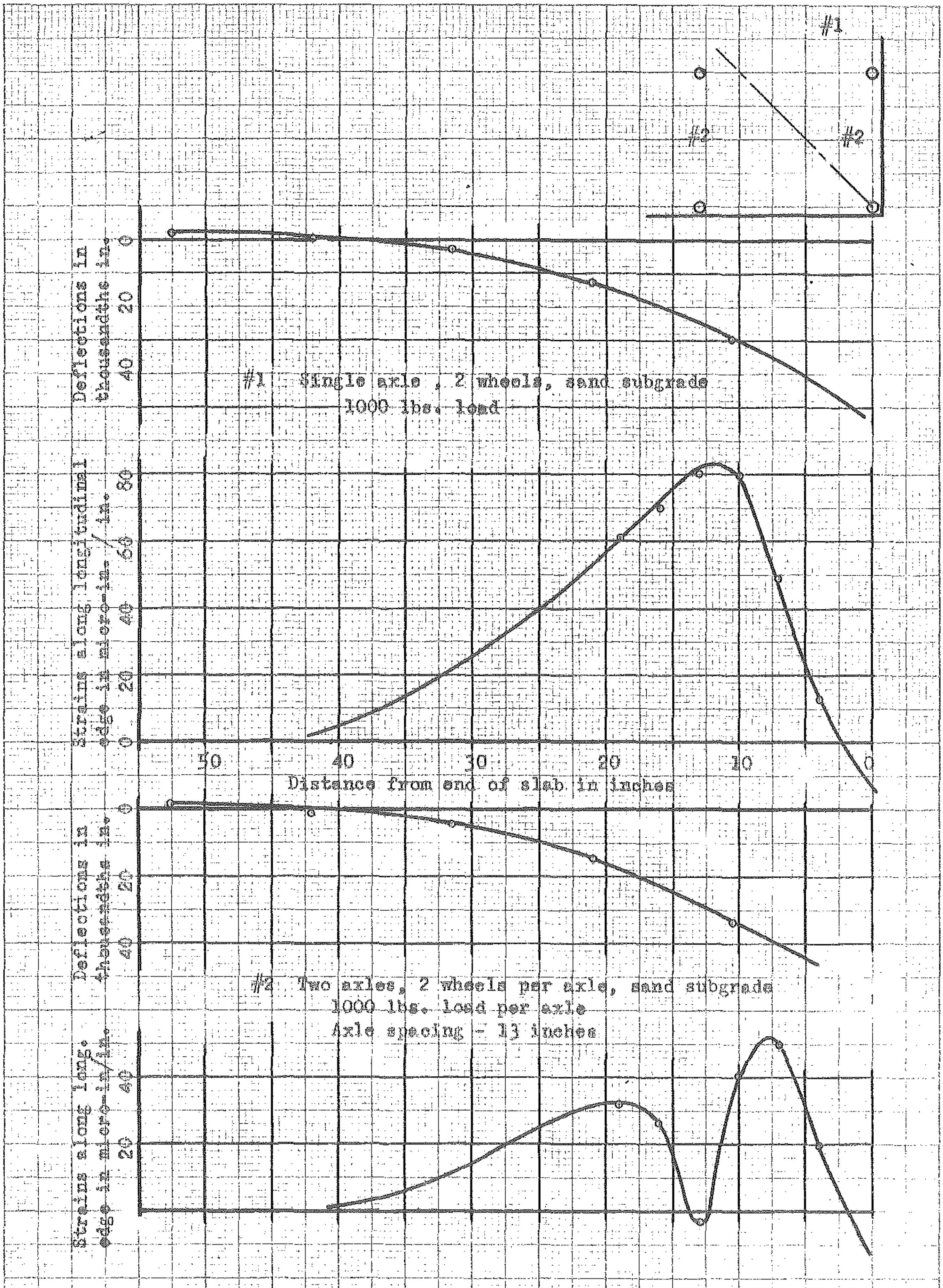


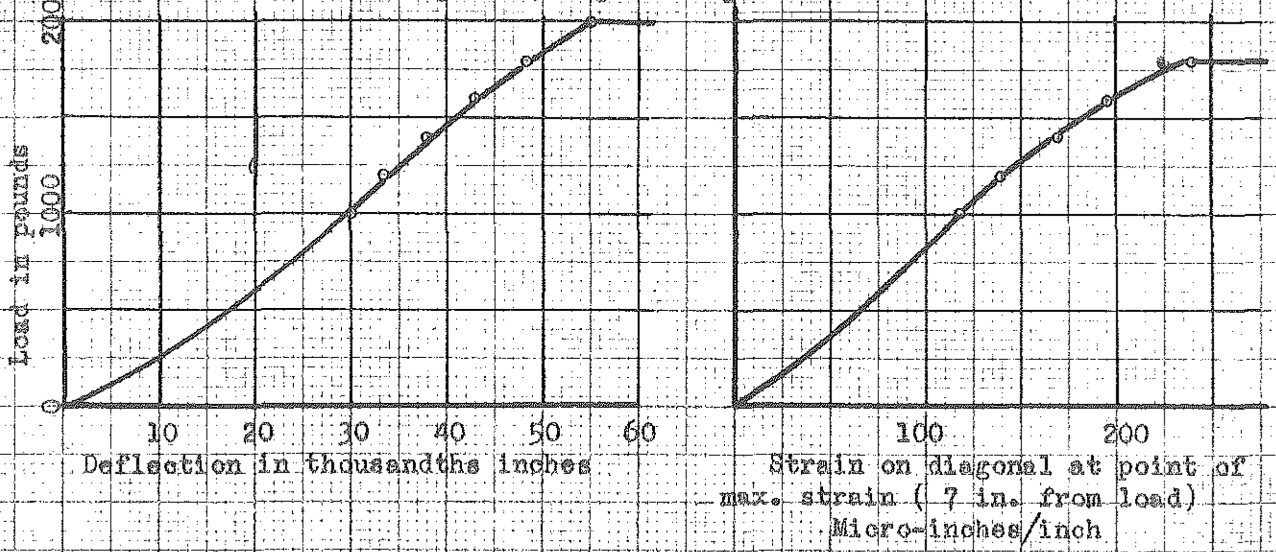
Figure 13. Foreground: failure from load on semicircular area at slab edge. Center: Cracks formed when excessive load was applied on axle with four wheels near slab center. Note some radial cracks under far wheel. Cracks at left are continuation of failures shown in Figure 12.



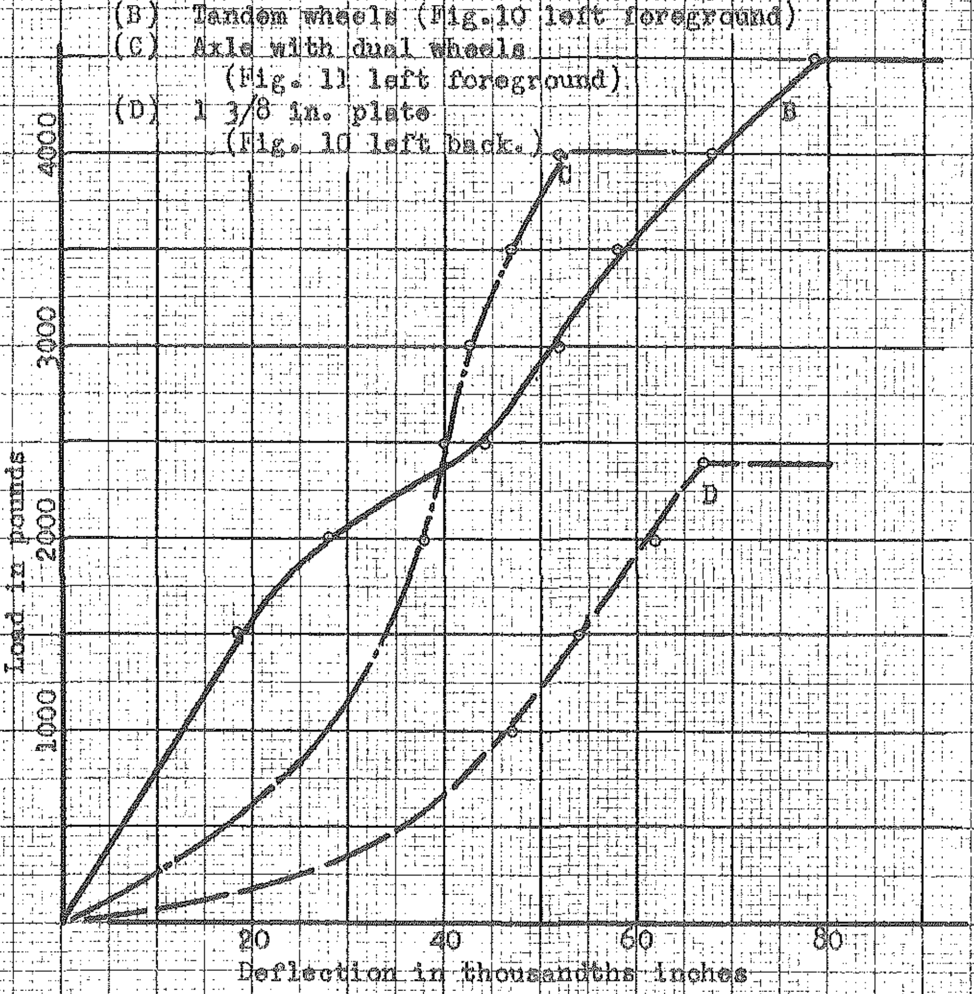
DEFLECTIONS AND STRAINS FOR AXLE LOADS ON CORNER

PLATE XII

(A) Deflection and strain curves for corner load on 1 3/8 in. disc
(See Figure 9, right foreground)

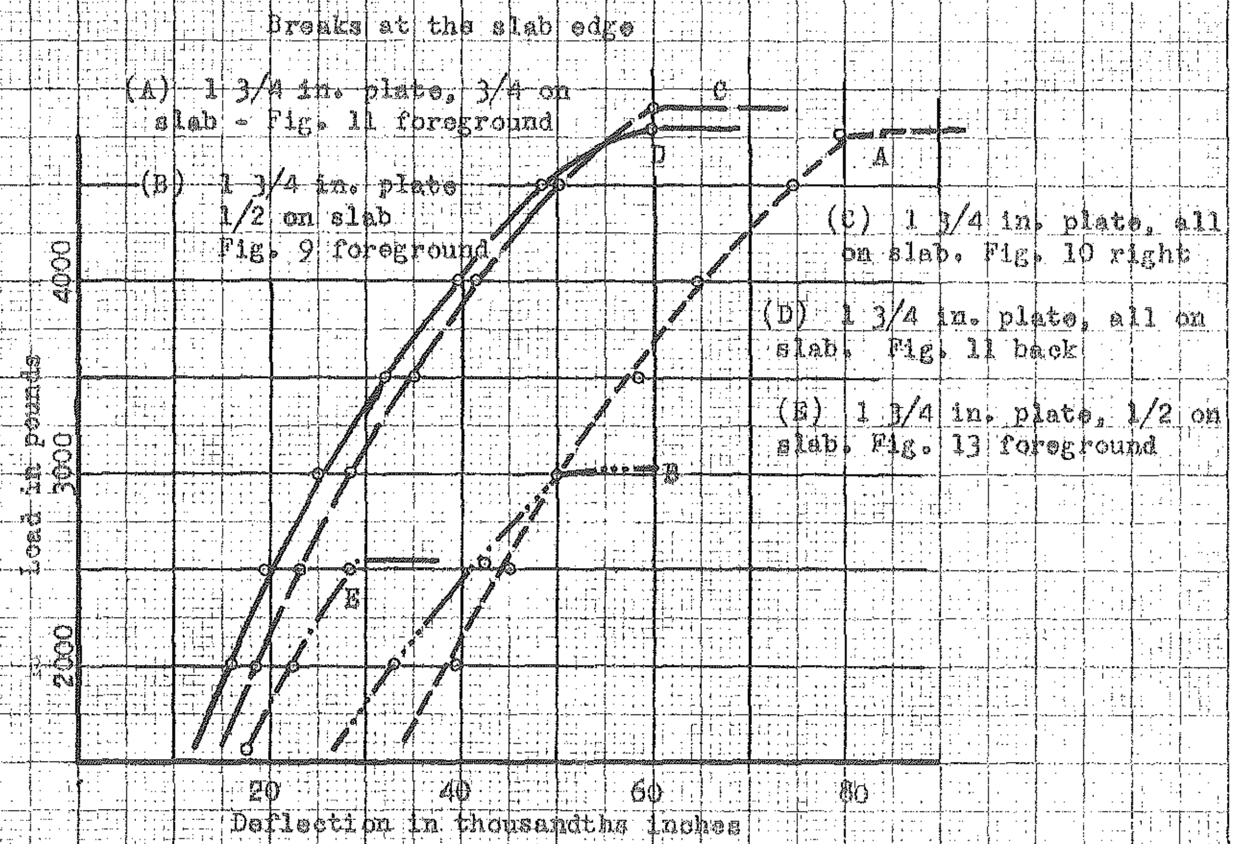


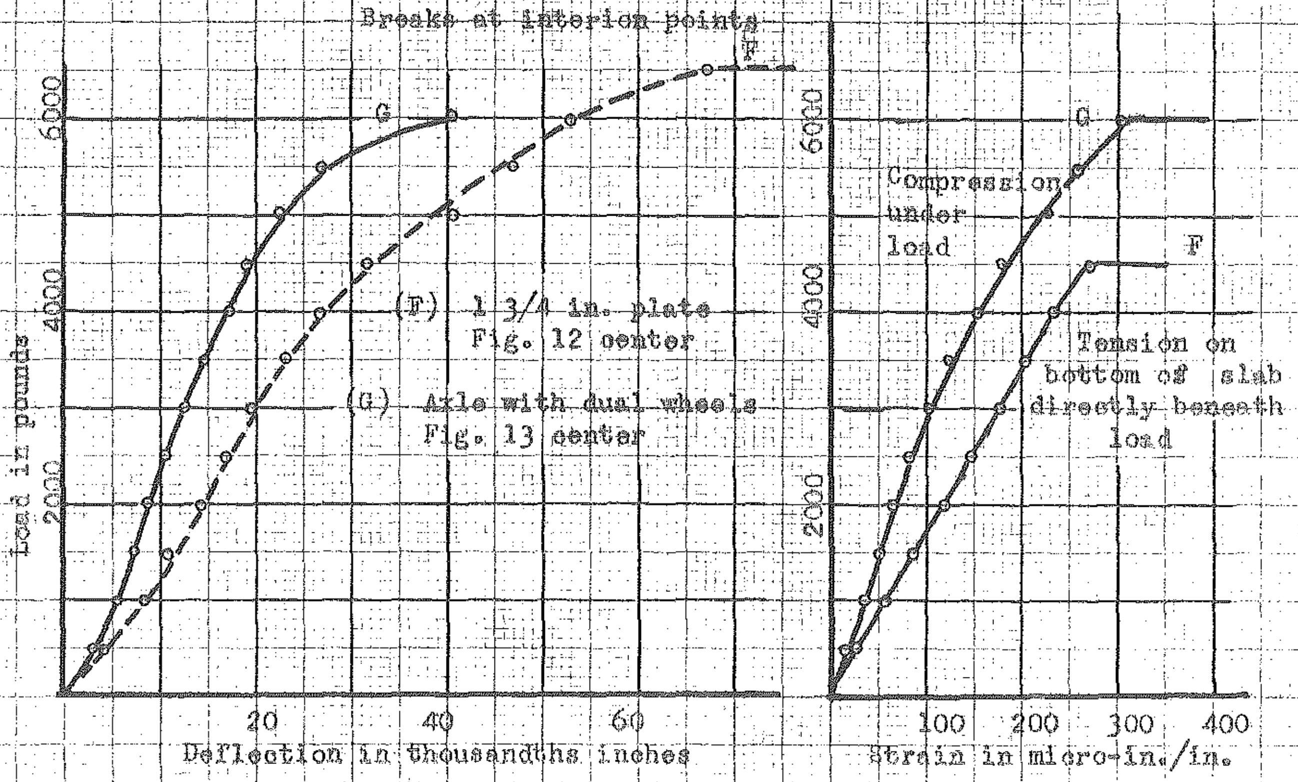
Load deflection curves for corner loading arrangements



CORNER BREAK DATA

PLATE XIII





EDGE AND CORNER BREAKS

PLATE XIV

A STUDY OF FAILURES

At the conclusion of the experiment several points were located on the slab and loads were applied through various devices at these points until the slab failed. Photographs of these breaks are shown and graphs are included for the presentation of load deflection data. Strain readings were taken at two positions.

Single wheel corner loading produced breaks across the corner perpendicular to the diagonal and a few inches inward from the load. Figures 9 and 10 show these failures. Load-deflection and strain curves are presented on Plate XIII, Graphs A and D. Loads on wheels in tandem caused a failure between the wheels, whereas dual wheels on an axle broke a large corner section. See Figures 10 and 11 for pictures of the breaks and Graphs B and C of Plate XIII for the data.

The edge breaks were of two types. The load applied to a semicircular area at the slab edge caused a local failure, but when the load was transmitted through the full area of the disc complete transverse cracks were formed. Views of these cracks are shown in Figures 10 and 11. Graphs A, B, C, D, and E of Plate XIV supply the data.

Figures 12 and 13 present views of the failures resulting from loads at the interior of the slab. Plate XIV supplies both deflection and strain data for this test. Graphs F apply to the single area case, and Graphs G apply to the case for four wheels on one axle.

An inspection of the curves on Plates XIII and XIV reveals the following: An ultimate load of 4500 pounds was required to cause failure for the single wheel at the interior of the slab. The value at the edge was the same for the full disc area, but reduced to about

50% of that value when the disc was on the extreme edge with only half the area on the slab. The load to cause failure at the corner was 40% of the value for the center break.

An axle with four wheels caused failure at the center when the load was 6000 pounds. Although the loading area was increased 300% the ultimate load was only 33% larger than the value for the single wheel. The corner failure in this case required a load of 4000 pounds. This is a reduction of 33% below the value for the interior, but is twice the value for the single wheel.

CONCLUSIONS

The data resulting from the investigation seems to support the following conclusions:

1. Loads supported by single axles cannot be increased in proportion to the number of wheels added to the axle. When the slab rested upon the sand subgrade, the modulus of stiffness of which was comparable to road conditions, the strain reduction for four wheels was only 3% below the two wheel value, and the corresponding strain for six wheels showed an increase of 6% above the two wheel strain. These small variations are negligible and certainly do not warrant an increase in the number of wheels per axle as a means of decreasing the pavement stress.
2. The load supported by two axles can be twice that carried by a single axle without increasing the strain above that recorded for one axle loading providing the two axles are properly spaced. In the case of this model, this spacing is from 13 inches to 25 inches, or approximately from one to two axle lengths. An optimum spacing of 18 inches permits a further increase of 10% of the total load.
3. A three axle system permitted loadings of three times the single axle load for axle spacings about the same as that found in the two axle case. Strains beneath the middle axle increase rapidly for axle spacings below 13 inches.

4. Maximum strains at the center and edge of the slab were beneath the load, while those at the end and corner were a short distance inward from the load. The strains due to edge loading were 12% above those caused by center loading, and the strains caused by corner loading exceeded the strains for the center position by 25%.
5. A single wheel at the corner of the slab produced maximum strains in the direction of the diagonal, but an axle at the corner caused larger strains along the longitudinal edge. The strains due to the single wheel were 50% greater than those caused by the axle.
6. Tensile strains on the underside of the slab were found to be approximately equal to the compressive strains on the upper surface.
7. Deflection and strain values are dependent upon the subgrade. These curves increased in amplitude about 60% when the slab was moved from the stabilized to the sand subgrade.
8. Failures due to edge loading produced small edge breaks only when the load was on the extreme edge. Full tire impressions on the slab at the edge caused complete transverse cracks. Tandem wheels on a corner produced a break between the wheels. Single wheel loads caused a combination of radial cracking and two transverse cracks at positions of

maximum tensile strain, the radial cracks appearing first. Axle loads at interior points caused transverse cracks beneath the load.

Future Projects

It is now proposed to continue this investigation on a full size slab upon which the loads are to be applied through actual truck and trailer wheels. This will enable analysists to evaluate constants for actual working conditions and predict the effect of many types of slab loading.

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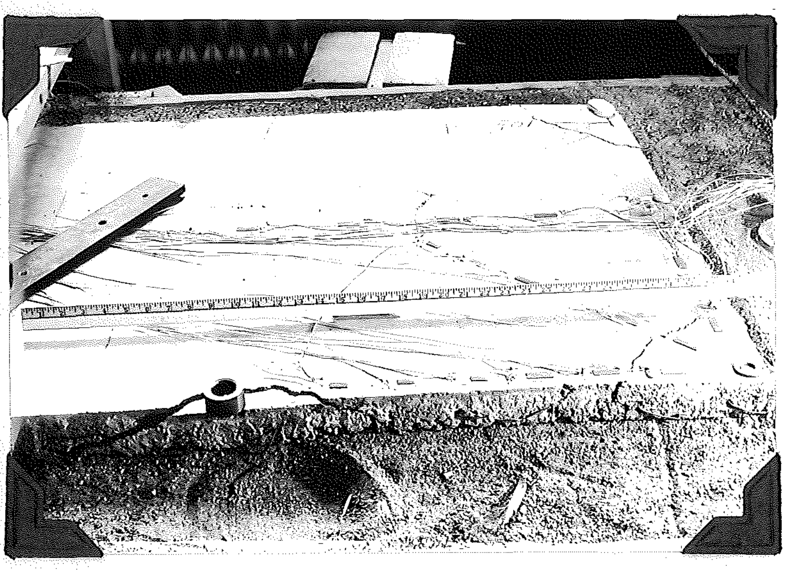

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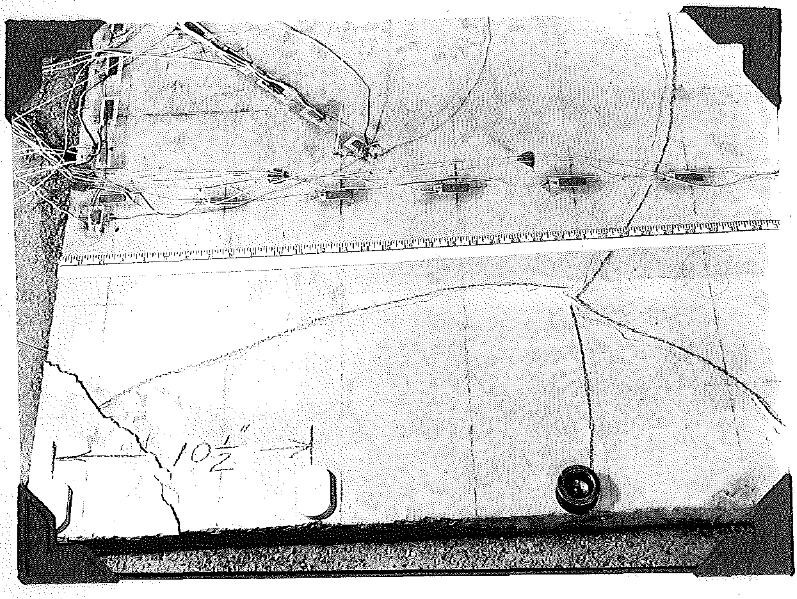
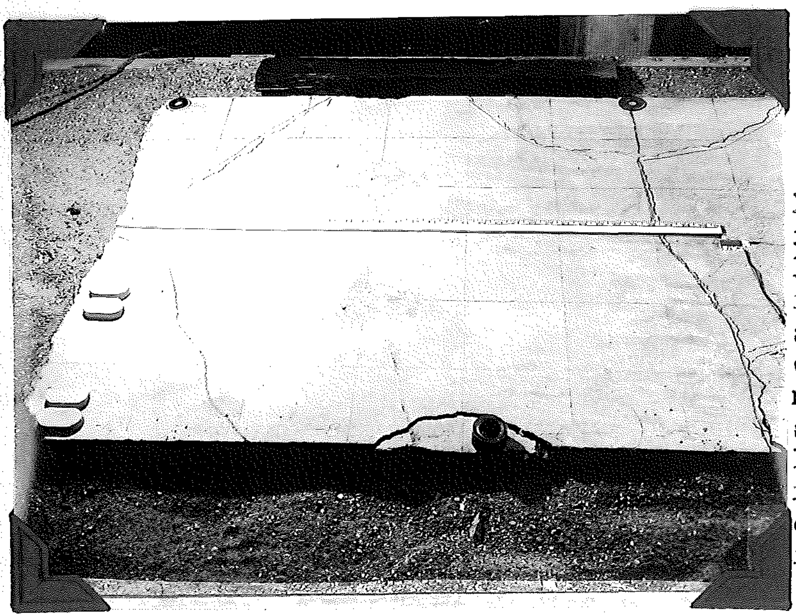


Figure 10. Left foreground: break due to tandem load. Right: cracks formed when load was applied on 1-3/4 in. circular plate at slab edge.



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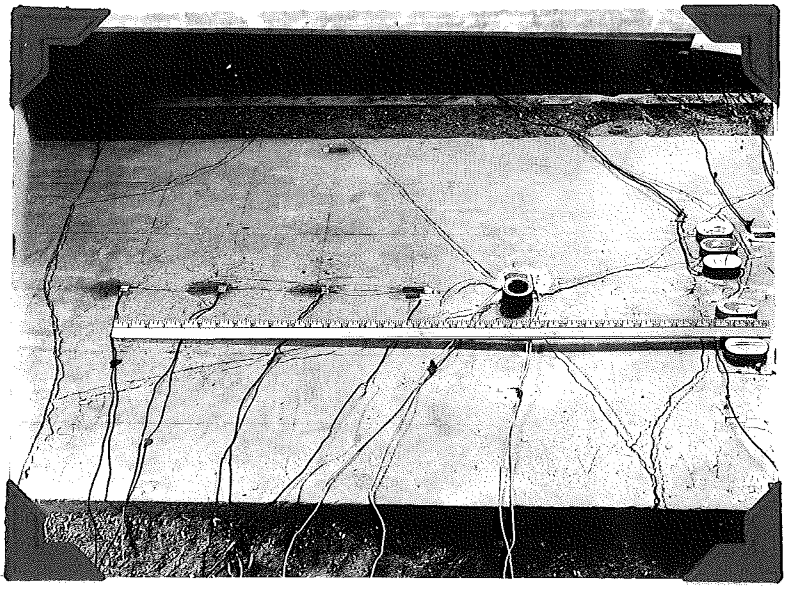

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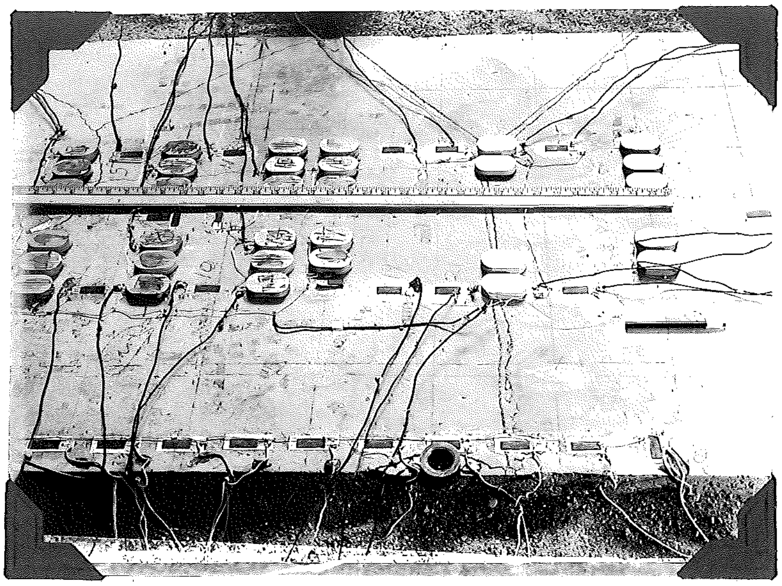

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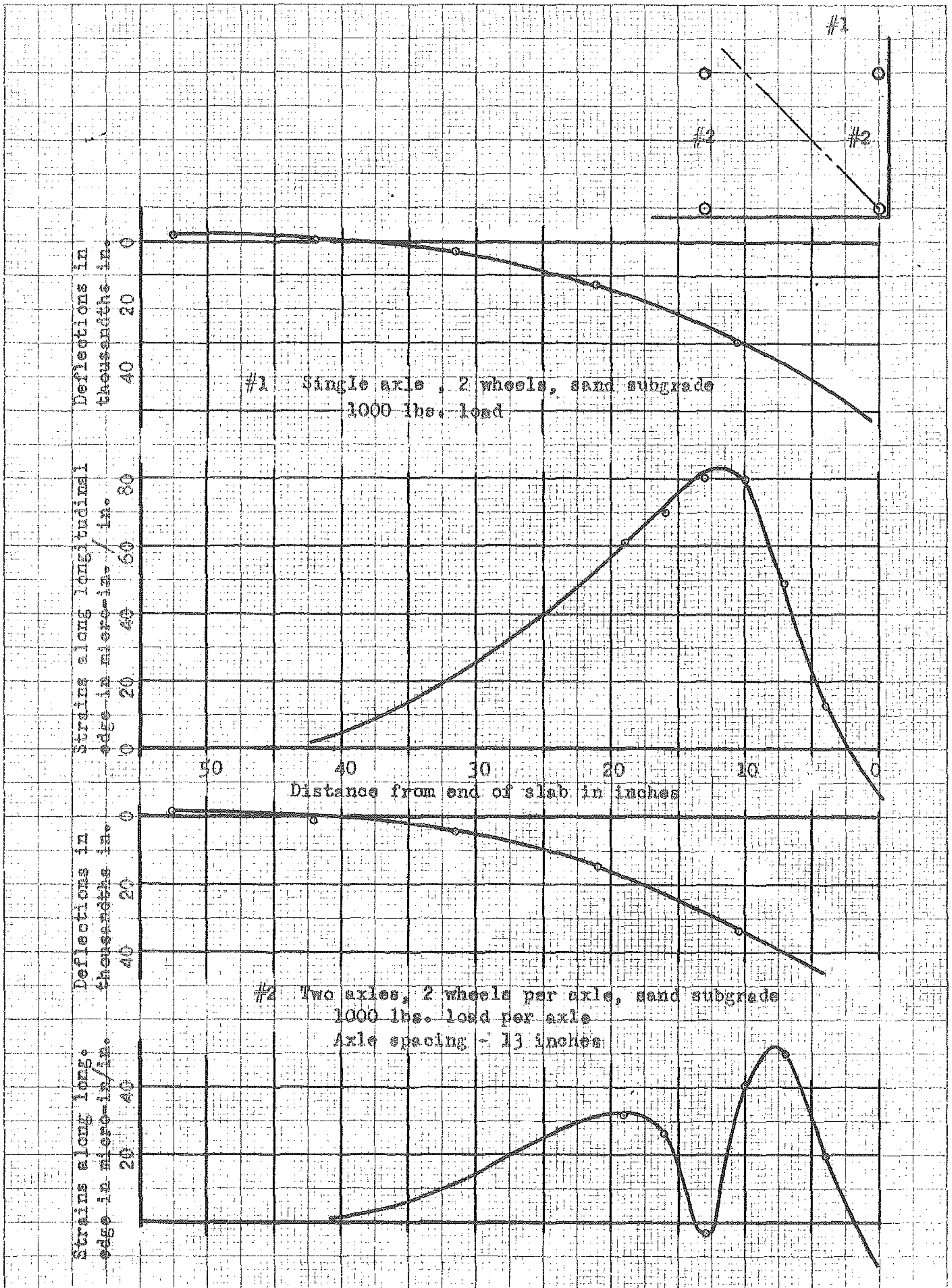
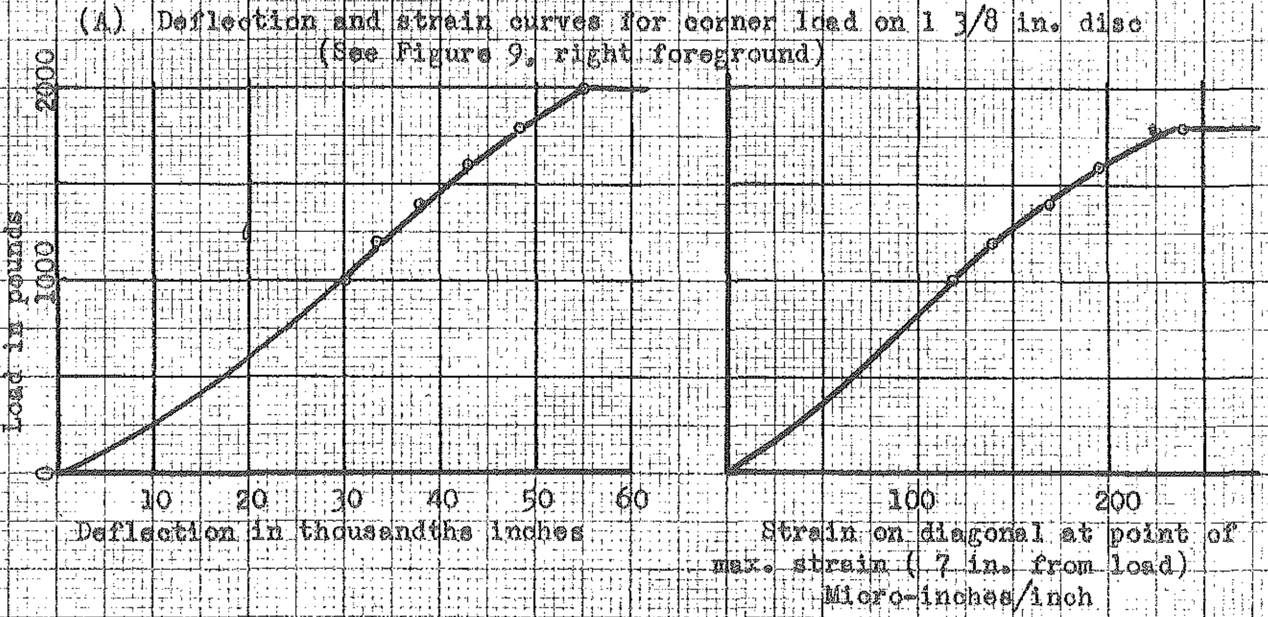


Graph 13

DEFLECTIONS AND STRAINS FOR AXLE LOADS ON CORNER

PLATE XII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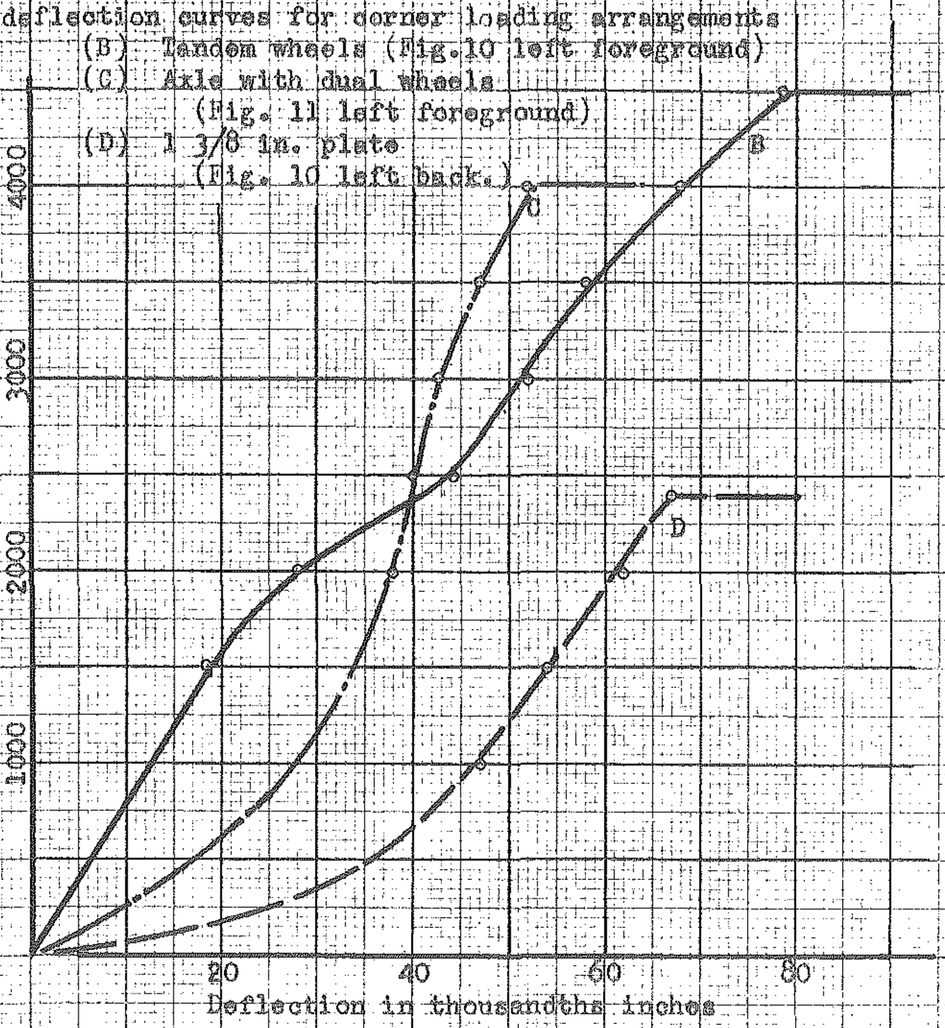
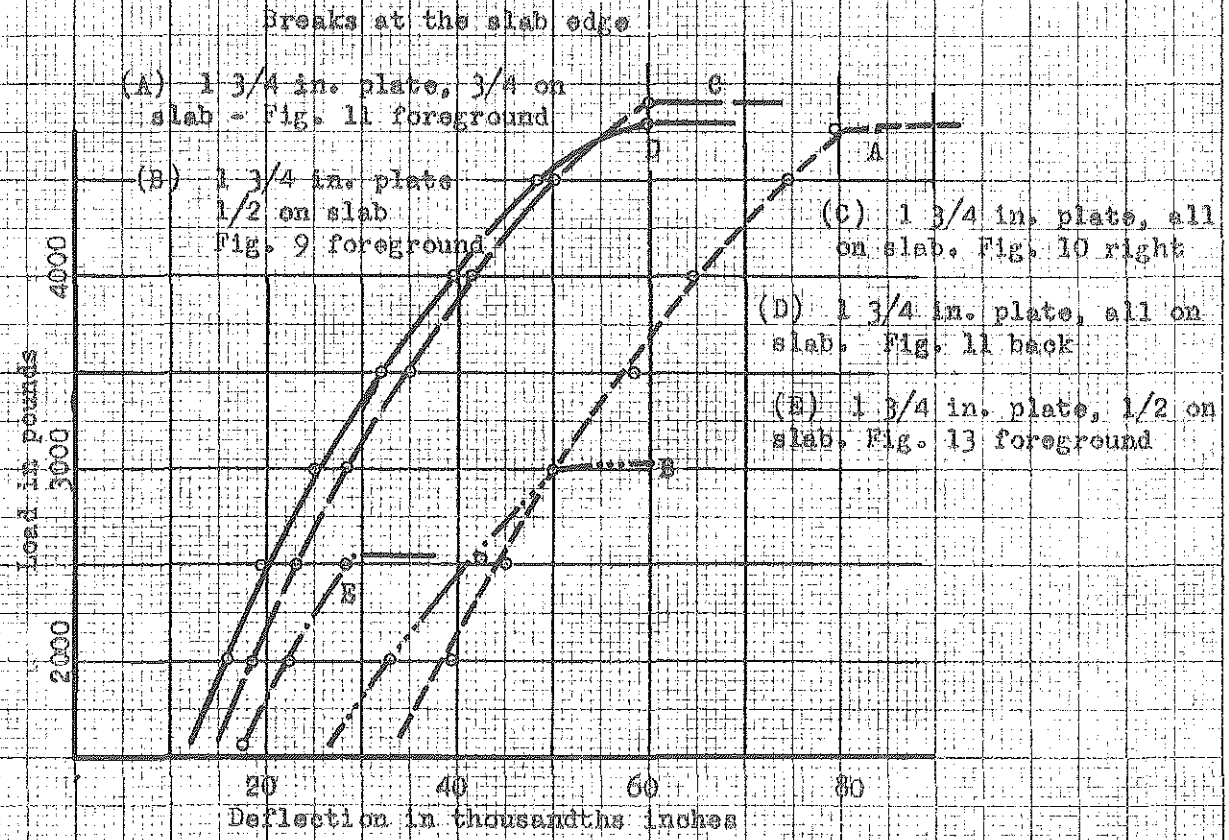
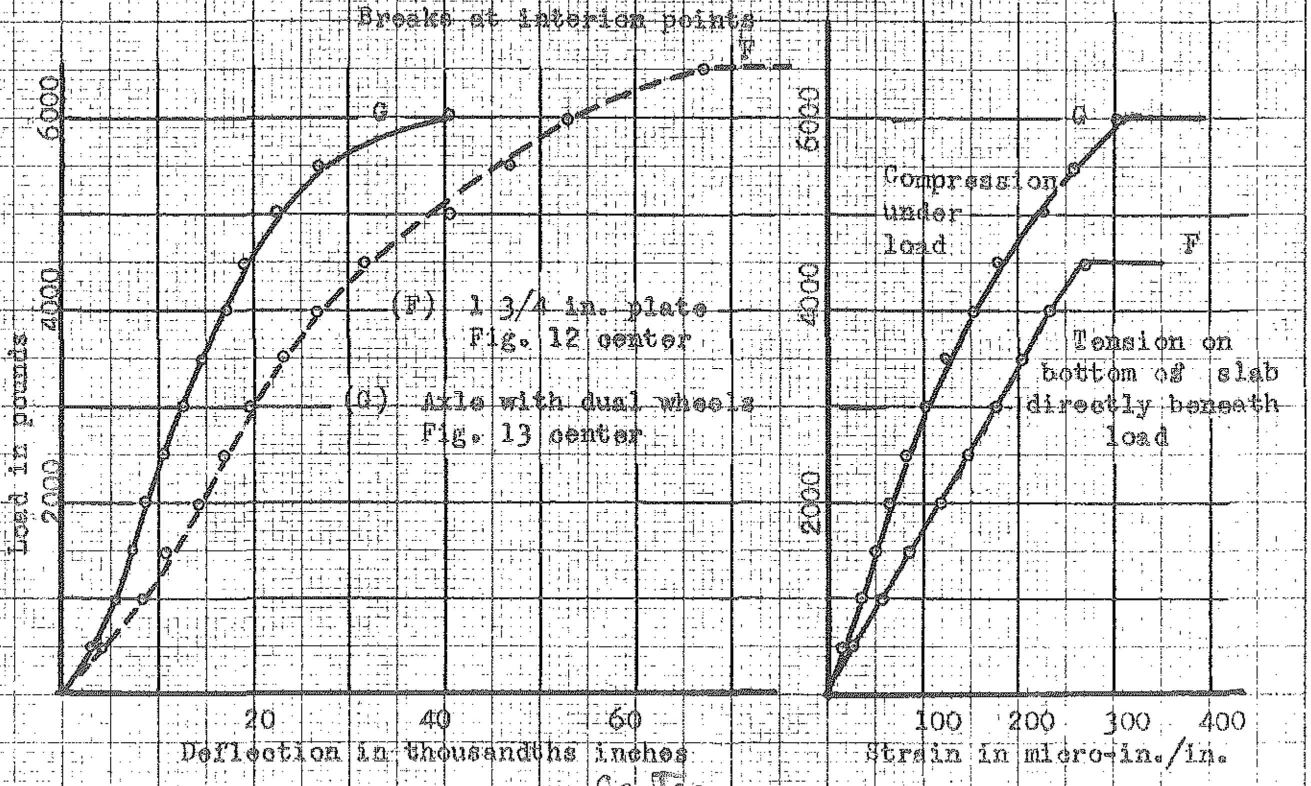

Load deflection curves for corner loading arrangements
(B) Tandem wheels (Fig.10 left foreground)
(C) Axle with dual wheels
(Fig. 11 left foreground)
(D) 1 3/8 in. plate
(Fig. 10 left back.)

CORNER BREAK DATA

PLATE XIII

graph 14





EDGE AND ~~CORNER~~ Center BREAKS

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