THE TESTING
OF
REINFORCED CONCRETE BUILDINGS UNDER LOAD

BY

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I hereby recommend that the thesis of WILLIS APPLEFORD SLATER entitled The Testing of Reinforced Concrete Buildings Under Load be accepted as fulfilling this part of the requirements for the degree of Civil Engineer.

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Recommendation concurred in:

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THE TESTING OF REINFORCED CONCRETE BUILDINGS UNDER LOAD

I. INTRODUCTION

For several years there has been a growing demand for tests of full-sized structural members. A more recent development is the test of structures themselves and the measurement of actual stresses in the component parts.

It is believed by some engineers that a large range of small-sized tests will give information of greater value than a few very large tests. It manifestly would be unwise to begin the testing of structural materials by the loading of a completed structure, or by tests of very large individual structural members. In entering on any such investigation the information first needed can probably best be obtained by a large range of small tests. However, when as in the case of reinforced concrete, a sufficient number of tests of isolated members has been made to establish a somewhat definite theory of its action under known conditions of loading, tests made on completed structures may then be expected to give valuable information of a different nature. Such tests of reinforced concrete structures should be expected to give more or less exact information as to the continuity of beam action in a monolithic structure, conditions in actual work as regards quality of concrete, accuracy of placing the steel and other features of importance to the designing and constructing engineer.

Load tests have been required by city building departments as a condition of acceptance of reinforced concrete buildings and have been used by construction companies and engineers
to demonstrate the adequacy of various designs. Such load tests are never continued to destruction, the applied load being generally twice the design live load, and emphasis is placed upon measurement of deflection and recovery. No measurements of stresses are made in such tests and under these conditions the safe load can not be fixed upon as a definite ratio of the ultimate load. The deflections observed in such tests constitute a very inadequate and actually misleading measure of the stresses. Slight deflections have been taken to indicate low stresses in steel and in concrete, but recent tests in which deformations were measured have shown that even with slight deflections large stresses are developed in concrete even when the steel stresses were low. The tendency of building codes was to disregard continuity of action in beams in reinforced concrete buildings and to specify the design as of simple beams, but even in such cases a small amount of steel was placed across the support to prevent the opening of large cracks. This steel and the tensile strength of the concrete have been sufficient to develop a large stress in the concrete at the support which may not have been specifically provided for. Thus the so-called conservative attitude of not allowing anything for continuity of beams at the support may prove a source of weakness. The measurements of deformations in building structures confirms the truth of this statement.

In a recent number of the ENGINEERING NEWS a contributed article decries the high steel unit-stress allowed in designs of reinforced concrete buildings. It says that the increase in strength with age so much advertised by salesmen fails to materialize because the steel strength is the critical

*Jan. 4, 1912 "Reinforced Concrete Stresses" by Ernest McCullough
feature of most designs, and to utilize an increased strength of concrete requires an increase in steel strength almost as great. It is probably true that the increase in strength of a building with the increase in age above sixty days is very slight, but for a reason different from that assigned. The measurement of concrete deformations in building floors under load seems to be bringing out the fact that the critical stresses are in the concrete rather than in the steel.

As the number of tests available becomes large enough to cover some variation in design and the inevitable inaccuracies of measurement, an analysis may be expected to result showing in general terms the relations between parts of the structure. Without reference to an analysis of the general case a greatly abridged test of the above type has been used to investigate certain features of design. The tests of the Carleton and Ford-Motor buildings mentioned later are examples of this kind of test.

The reports which have been made of all such tests deal in the main with the behavior of the structure and record the results, and are not primarily concerned with the working of the instruments or with the methods of making the tests. To conduct a successful building test is difficult, however, and this thesis is written in order to present information as to methods of testing gained by experience and to point out certain respects in which such tests may be conducted more satisfactorily than those which have already been made. The following general order of presenting the material in hand will be observed: (1) enumeration of tests, (2) the planning and
preparation for a test, (3) the instruments; their construction and use, and, the methods of making observations, (4) the methods of making calculations (5) the cost of a test, and (6) the subjects of investigation.

The following is a list of tests of building floors in which the methods described herein of measuring deformation were used. Figure 1 shows the range in size of these test areas.

Test No. 1. Deere and Webber building, Minneapolis, Minnesota, October and November, 1910; flat slab floor with four-way reinforcement; built by Leonard Construction Company of Chicago, and tested by them with the cooperation of the Engineering Experiment Station of the University of Illinois.

Test No. 2. Wenalden building, Chicago, Illinois, June and July, 1911. Beam and girder building constructed by Ferro-Concrete Construction Company of Cincinnati, and tests made by cooperation between The National Association of Cement Users, the construction company, and the Engineering Experiment Station of the University of Illinois.

Test No. 3. The Powers building, Minneapolis, Minnesota, July and August, 1911; flat slab floor with two-way reinforcement; built and tested by Corrugated Bar Company of St. Louis.

Test No. 4. Franks building, Chicago, Illinois, August, 1911; flat slab floor with four-way reinforcement; built and tested by Leonard Construction Company of Chicago.
Figure 1

Tested areas shown shaded

Franks Building

Powers Building

Barr Panel

Wenalden Building

Carleton Building

Turner-Carter Building

Deere and Webber Building
Test No. 5. Turner-Carter building, Brooklyn, New York, September, 1911; beam and girder floor; built by Turner Construction Company of New York; test made by cooperation between National Association of Cement Users, the construction company, and the Engineering Experiment Station of the University of Illinois.

Test No. 6. Carleton Building, St. Louis, Missouri. October, 1911; flat slab floor with two-way reinforcement; built and tested by Corrugated Bar Company.

Test No. 7. Barr building, St. Louis, Missouri, December, 1911; full size test panel (25 ft. x 26 ft. 9 in.). Terra-cotta tile used to lighten construction: gives two-way T-beams with web between tile on tension side and concrete flange above the tile; two-way reinforcement. Panel built to demonstrate efficiency of design proposed for Barr building in St. Louis; test made by Corrugated Bar Company.

Test No. 8. Ford Motor building, Detroit, Michigan, February and March, 1912; flat slab floor; built and tested by the Corrugated Bar Company.

These seem to be the only full-sized reinforced concrete floor tests on record in which deformations in steel and concrete have been measured. The writer was in immediate
charge of No. 2 and No. 5 and had an important part in the con-
duct of all the others except No. 6 and No. 8. The methods of
testing presented in this thesis were developed by the writer
as a result of his connection with the tests. These methods
were designed to increase the accuracy of results, to avoid
accidental errors and to correct for systematic errors. Methods
of attack of certain lines of investigation also are outlined.

Much credit for the initiative in this type of test is
due Mr. A. R. Lord, formerly research fellow at the University
of Illinois, who was largely instrumental in bringing about the
test of the Deere and Webber building, the first in the series
named. After the presentation of Mr. Lord's paper on the test of
the Deere and Webber building, The National Association of Ce-
ment Users decided to continue the investigation, and placed
Professor Talbot in charge of the conduct of further tests. All
of the tests given in the above list were conducted on the same
general lines as that of the Deere and Webber building. Only
the tests of the Wenalden building and the Turner-Carter build-
ing were in the series authorized by the National Association of
Cement Users, but the results of the tests made by the Corru-
gated Bar Company on the Powers building and on the Barr build-
ing test panel have been placed at the disposal of the Associa-
tion. The Franks building test, made by the Leonard Construction
Company, was an investigation planned to give data for an intelligent modification of the Chicago Building Code. The other two tests, those of the Carleton building and the Ford Motor building, were in the nature of investigation of special features of design. The methods used in all of these tests are essentially the same and have been developed at the University of Illinois Engineering Experiment Station.

Reports of results of some of these tests are available as follows:

1. Deere and Webber building test.


3. Powers building and Barr building test panel.


4. Franks building.


   (b) Trade publication on cantilever slabs, published by Concrete Steel Products Company. McCormick Building, Chicago, Illinois.
II. CONDUCT OF TESTS.

Definitions.

In the following descriptions of tests, many terms will be used for which somewhat arbitrary definitions will need to be made. These definitions are given here:

**Gauge Hole**: A small hole (.055 in. is here recommended) drilled into the steel bar or into the plug inserted in the concrete has been termed a gauge hole. It is for the admission of the point of a leg of the extensometer.

**Gauge Line**: The gauged length connecting a pair of gauge holes is termed a gauge line.

**Reading**: A reading is a single observation on any gauge line.

**Observation**: An observation as here used is the average of a number of readings.

**Zero Length of Instrument**: The length of the instrument at the time of taking the first observation on the standard bar will be known as the zero length of the instrument. This first observation on the standard bar is not the zero length, but a comparison of a subsequent observation with it shows any change from the zero length.

**Correction**: A correction is the amount which if added algebraically to the observation will give the observation which would have been obtained if the instrument had not changed from its zero length.
Series of Observations: The observations taken consecutively at a given load without repetitions on any gauge line is defined as a series of observations.

Interval: An interval as used here is the time elapsing between consecutive observations, and all intervals in any series are (for lack of more exact information) assumed to be equal. For this purpose the average of the consecutive observations on two standard bars is considered a single observation.

Standard Gauge Line: This is a gauge line used usually to determine changes of length of instrument, of reinforcement or of concrete due to other causes than the applied load. Its purpose usually is to determine the temperature effect on the instrument, but it may be used to detect accidental changes of the instrument or temperature stresses in the steel or the concrete. Originally this gauge line was placed on a steel bar separate from the structure, and this gave rise to the term standard bar. In several of the later tests, however, the standards have consisted of gauge lines placed in the steel and concrete of the structure away from the area affected by the load. Standard gauge line is adopted, therefore, as the more general term and any reference to standard bar may be understood to signify the standard gauge line on a bar separate from the structure.
General Outline of Method of Testing

After determining what measurements will best give the information desired from the test, the gauge lines are laid off on the surface of the concrete and small holes are cut or drilled at a predetermined distance apart, in order to expose the steel or allow a metal plug to be inserted, according as the measurement is of steel deformation or concrete deformation. The metal plugs used are securely held in place by imbedment in plaster of Paris. The gauge holes having been carefully prepared, a set of zero readings is taken on all gauge lines, an increment of the loading material is then added and a second series of observations on the gauge lines taken. The difference between the two readings on the same gauge line represents the deformation in that gauge line. It is possible that this apparent deformation may be due partly to temperature changes in the instrument instead of stress changes of the material by reason of applied load. For this reason reference measurements are made on standard unstressed bars made of Invar steel which has a very low coefficient of expansion and whose change in length due to temperature changes would therefore be very slight. From these readings on the standard bar, temperature corrections are computed as described in a later paragraph and applied to the observations in order to determine the actual change in length of the gauge line. Another increment of load is then applied and another series of observations taken.
Floor deflections also have been measured in all of these tests, but they have been considered as of secondary importance. They have been used to throw light on the correctness or incorrectness of the deformation readings and to gain some idea of the general distribution of stresses throughout a floor. They can apparently be depended upon to show with considerable accuracy the proportional rate of increase of stress, but deflection formulas are so imperfect that measurement of deflections can not be depended upon to give the actual values of stresses.

Measurements of dimensions such as span, depth of beams, location of observation points, weight of loading material, location of cracks, and any other measurements which were considered of value in working up results have been carefully taken.

The measurements taken are usually distributed over and under the surface of the floor tested in order to gain an idea of the changes occurring in different parts of the structure. The above statement gives in general terms the features of any one of the tests dealt with in this paper. There are many difficulties to be overcome and many chances for error. What follows is concerned mainly with the method of overcoming these difficulties and avoiding these errors. Most of the statements made represent the results of experience on previous building tests. Some merely give ideas which it is believed if put into operation would be advantageous.
The Planning of a Test.

In the planning of a building test the first consideration will probably be the choosing of the area to be tested, both as to the height above the ground and as to the position of the test area on the floor chosen.

Choosing of Test Story. - A number of considerations are likely to affect the choice of floor, among them may be mentioned the following:

(a) The floor tested should be at such an elevation as at least would give representative if not the most severe conditions. For example, the columns in the upper stories of the building are smaller than those in the lower stories, and a given load on an upper floor would be a more severe test of the columns than on a lower floor, especially in the columns where there is eccentricity of loading.

(b) The floor tested should not be one on which a large force of men is at work continuously, as apparatus used for testing is likely to be disturbed. In the test of the Turner-Carter building, the mill work was done on the floor where deflections were measured, and the movements of the men apparently resulted in numerous disturbances of the frame supporting the apparatus for measuring deflection. This is mentioned as an illustration of the point raised.
(c) The floor chosen should be as low as is consistent with other conditions in order to avoid unnecessary hoisting of loading material.

Location of Test Area.—Some of the conditions affecting the location of the test area on the floor chosen are as follows:

(a) The test area should be so located as to be free from irregularities of construction, such as deep or shallow beams, openings in the floor, pipe shafts, etc.

(b) The test area should probably be near the center of the building so as not to be affected by the proximity of walls or their equivalents, unless a part of the purpose of the test is to show the difference in action between interior panels and wall panels.

(c) A place accessible from all sides for the purpose of rapid loading and unloading should be chosen if possible, for the test.

The above conditions are ideal, that is, they are the conditions which would be chosen if always available. In most cases some limitation is found on part or all of them. For example, in the test of the Wenalden building it was impossible to find an area entirely free from irregularities of construction. An industrial track crossed one of the panels chosen, and the floor was thicker immediately under this track than at other places. On the edge of one or two of the panels tested, beams about an inch deeper than the regular beams were located. However, none of the measurements assumed to give typical results were taken in these panels, and it is believed that the stresses in the
other panels were not affected appreciably by these irregularities. Again, in the test of the Franks building it was not possible to choose a lower floor convenient to the loading material. An upper floor was used in order, during the course of construction, to make preparation for the test, thus avoiding digging in the concrete. However, this choice of floor fulfilled one of the conditions mentioned, in that it gave a much more severe test of the columns than a test on a lower floor would have done. Also, in the test of the Carleton Building at St. Louis the area to be tested was specified by the city building department, and there was no choice as to location on the part of those making the test.

Measurements.— The number of measurements to be taken will depend upon the nature of the test, the number of observers, and the number of laborers. If the test is a part of a series by which it is expected to gain scientific information with regard to the principles involved and on methods of design, it is likely that it will be deliberate enough that a large number of measurements may be taken. Such tests were especially those of the Wenalden building, the Franks building, the Turner-Carter building, and the Barr test panel. If, on the other hand, the test has more of a commercial nature or is a utilization of the opportunity offered by the acceptance test to take some measurements which will show actual stresses, or if for any other reason the test is hurried, the number of measurements will necessarily be rather small. Of this class, the tests of the Carleton building in St. Louis and of the Ford Motor building in Detroit, Michigan, are good examples. Notice was given the engineers only
about one day in advance that a test would be made on the Carleton building. Permission was obtained from the contractor to expose bars for measurement in various points and to erect the necessary scaffolding. The measurements were made more for the purpose of checking the analysis upon which the design was based than to form in itself a basis of design. Therefore comparatively few observation points were used. It is believed that this test is representative of the type of test which is practicable on a commercial basis, hence (by courtesy of the Corrugated Bar Company) a plan is given in Figure 2 showing the points where measurements were taken.

The number of measurements also will depend upon the number of observers and the number of laborers to be used in making the test. It is desirable that the time required to take a full set of observations should be as short as possible, say an hour, as it seems that there are unaccounted-for changes in deformation when a structure stands under constant load, usually in the nature of fatigue, but sometimes in the nature of recovery. For this reason if the number of observers is small, the number of observation points should also be comparatively small. It is probable that under ordinary conditions with experienced observers as many as 40 observations per hour can be made, provided there is a recorder for each observer.

If the number of laborers used is large, it will be necessary to make the time of observation as short as possible so that there will not be a large waste of laborers' time during the readings. Therefore, under these circumstances either the number of measurements taken should be small or the number of
observers should be comparatively large.

The arrangement of observation points will depend on the principal subjects for investigation in the test. Whatever the subject of study may be, the observation points should be arranged in such a way that a curve of deformations may be plotted against distance, showing a gradual progression from the condition at one part of the structure to the condition at another, for it is found that there are even under the most careful work, inconsistencies which will make the results look doubtful if standing by themselves. The points so arranged should be numerous near the place where the measurements of greatest importance are to be taken, so that the results will not depend upon measurements at a single point, or upon the average at portions of the structure supposed to be similarly situated but in different parts of the building where unknown conditions may actually cause a large variation in the phenomena of the test. If on a number of points close together or related to each other by some progressive variation in position, such as horizontal or vertical distance, measurements are taken so that the deformations may be plotted against loads and also against distance, a double check will be obtained on the results. It will not be possible to carry out this plan for all subjects of investigation, as the number of observations required would usually be impracticably large. Such provisions may be made to cover the main lines of investigation, and isolated observation points may be used to gain information as to tendencies of other portions of the structure, but of course, less reliance must be placed on the results of the latter measurements than where the larger number of observations is made. It would
be advantageous, as was done in the Powers building test and also
in the Barr test panel, for two observers to check measurements
on the same points. One or both of these checks is very val-
uable in establishing the correctness of observations. Figures
No. 3, 4, 5 and 6 give curves illustrating the former method.
Figure 3 gives the load deformation diagrams on several gauge
lines in the test of the Powers building. Figure 4 shows the
same data plotted as deformation against distance from the col-
umn instead of against load. It may be seen that the correct-
ness of the load deformation curve for one of these points, if
standing by itself, might be doubted because of the complete
change in the character of the curve at a load of 200 pounds
per square foot. But when these deformations are plotted
against distance, the results look so consistent that it is
scarcely conceivable that they are seriously incorrect. In
the test of the Wenvarden building very high deformations were
observed in the concrete of the beams near the supports: so
high that the results were doubted, and as the points on the
load deformation curves were few and scattering, there was
often room for doubt. For this reason it was considered es-
pecially important that evidence which would confirm or dis-
prove this high compression in the concrete be obtained in the
test of the Turner-Carter Building; accordingly the method of
placing observation points at frequent and regular intervals
along the ends of the beams was used. The deformations measured
are plotted in Figure 5 against the load, and in Figure 6
against the distance from the supporting girder, and the re-
sults not only tend to show the correctness of these measure-
ments, but also to indicate that the high stresses observed in the beams of the Wenalden building were actually present.

**Laborers.**— The number of laborers which can be used advantageously will depend on the distance from which the loading material is to be transferred, on the size and accessibility of the tested area, on the amount of work which can be done by them during the intervals between increments of loading while observations are being taken, and on the number of gauge lines assigned to each observer. The handling of the labor should, if possible, not be left to the one in charge of the test, as proper attention to the conduct of the test demands all of his time. In the tests included in this paper the number of laborers has varied between wide limits; from 5 or 6 in the Powers test to about 40 in the Deere and Webber test.

**Loading.**— In the tests which have already been made, the following loading materials have been used; brick, cement in bags, loose sand in small boxes, sand in sacks, and pig-iron. The material used will almost always be that which is most easily available, because the transporting of loading material from any distance adds very greatly to the cost of the test. Leaving consideration of cost out of the question for the present, sand in sacks seems to be the most satisfactory of the materials above mentioned for loading purposes. Some of the qualities of the materials mentioned are as follows:

(a) Brick: Brick spalls and chips in handling, covering the floor with dust and jagged particles which cause discomfort to the observer in kneeling to take observations. It is important to avoid this because discomfort necessarily decreases
the accuracy of his observations. This might be avoided by sweeping, but in sweeping it is difficult to avoid getting dirt into holes where observations are to be taken, and this is just as troublesome as having the dirt on the floor. Figure 7, a photograph of the Wenalden test, shows the use of both brick and cement in the same test. Attention is called to the proximity of the cement sacks to the beams and girders of the floor above. In some cases the intensity of the load would be limited by the height of the ceiling if cement and brick are used.

(b) Cement: Cement sifts through the sacks and the sacks become untied, scattering cement on the floor, filling observation holes and causing much dust in sweeping or cleaning up. The dust is injurious to delicate instruments and annoying to observers and recorders.

(c) Loose Sand in Small Boxes: As sand is usually damp, it does not have the fault of causing dust, and consequently is more easily cleaned up than the other materials mentioned. There are, however, other objections. In filling boxes it is difficult to avoid spilling the sand around and between the boxes, and consequently filling the observation holes. On account of the great difficulty in removing loose sand without spilling a great deal of it, it is impracticable to take observations as
the load is being removed, therefore, it is necessary to remove in one increment the whole load from a given panel. Figure 8 is a photograph of the Turner-Carter test and shows this method of loading.

(a) Sand in Sacks: Sand in sacks constitutes a very satisfactory loading material, as is shown in Figure 9 a photograph of the test of the Barr building test panel. It was piled up to a height of about nine or ten feet, and very little inconvenience was caused by the sacks becoming untied or by spilling the sand. The worst difficulty encountered, and this exists with all materials handled in sacks, is that of the sliding of sacks on themselves when the load is piled high. It can be seen in Figure 9, above referred to, that bracing was necessary to prevent the sand from sliding together and filling up the aisles. It is a source of danger to those taking observations as, if a slide should occur, it would probably give very little warning and might catch the observer while in such a position that he could not escape. However, this objection would be likely to occur with any material which is piled as high as was that in this test. Under any circumstances it is necessary that care be taken and undue risks avoided.

(e) Pig Iron: Pig-iron was used as loading material in the test of the Franks building. From the standpoint of the making of the test, the worst
objection to it is that, as with the brick, small particles break off and cause annoyance to observers. This is less noticeable than with brick and in other ways pig-iron is clean. It possesses the great advantage that with its use a very heavy load can be applied without piling the load extremely high. (See Figure 10)

Tin plate in boxes two feet square, each weighing 200 pounds, was to have been the loading material used in a building test. A more nearly ideal loading material would probably be hard to find, but unfortunately this test could not be carried out.

The intensity of the loading will depend mainly on the load for which the building was designed. It will not be possible to make the load absolutely uniform, as aisles will be necessary for the purposes of (a) convenience in placing the load, (b) access to gauge lines for the taking of observations, and (c) prevention of arching in the loading materials. It has been found that it is difficult to cover more than about 75 per cent of the actual area of the floor, and in many cases less than this will actually be covered. Hence in computing the probable height of the load, this fact must be taken into consideration.

Aisles should be so placed that the load, even though partly carried by arching of the material, will cause stresses in the floor which are approximately equal to and always as severe as those caused by an actual uniform load. Figure 11 shows the moment and shear diagrams which would be obtained by loading a simple beam with a total load W distributed over the span in three different ways, as follows:
Figure 11
(a) Solid Black Line: Uniform load \( W \), over full span.

(b) Broken Black Line: Same load \( W \) distributed over one-half of span, giving aisles of equal width at center and support.

(c) Heavy Dotted Line: Same load \( W \) distributed over one-half of span, half of load being carried by arch action to ends of boxes (shown here as concentrated loads \( \frac{W}{8} \)), and the other half being uniformly distributed over the half span.

It will be possible in almost any test to arrange boxes or piers of loading material in such a way as to come within the limits outlined by the three assumed distributions of load in the preceding illustration, and it is seen that if this is done, the presence of the aisles or of arching to the sides of the boxes or piers, while not affecting the amount of maximum moment and maximum shear, would tend to cause them to exist over greater portions of the span. In this figure aisles equal to one-quarter of the span have been assumed. In no case would they be as large as this, and, therefore, the moment and shear diagrams should actually conform even more nearly to those for uniform load than is shown in the figure.

Arrangement should be made, if possible, to store the loading material near the test area to hasten the work of applying load after the test begins. The general rule has been to allow loading material to be stored as close as one full panel length from test area, but the intensity of the storage
load has been kept down as much as possible.

Figure 12
Preparation for the Test

**Digging and Drilling of Holes.**—In all of these tests it is necessary to cut holes in the concrete in order to expose the steel. Figure 12 shows a hole cut in the concrete of the Turner-Carter building where measurements were taken at the end of the beam. This cutting has been best accomplished by the use of a cold chisel with a very gradually tapering point. This is a task for common laborers and a long one for inexperienced men, but it has been found that a great deal of speed can be developed by practice, hence the importance of completing this part of the work with a single set of workmen.

A saving in mutilation of floors can often be effected by planning the test ahead of time and inserting plugs in the concrete during construction in the proper position for the gauge lines. Removal of the plugs after the concrete has set exposes the steel without the use of a cold chisel. Likewise metal plugs may be set in the concrete at the proper positions for the measurement of concrete stresses and thus save digging into the concrete to place compression plugs. The point has been raised that by preparation of this kind a chance is given to the contractor to know what panels are to be tested and thus to make the construction of that panel better than others. For this reason there is room for question as to the advisability of using this method. In most tests under consideration this point has been taken care of by the fact that it was not known until shortly before the test what area was to be loaded. It is believed that the saving thus effected is not generally
sufficient to justify prejudicing the test by use of this method.

Drilling of the holes will be discussed under the subject of "Instruments and Observations" and need not be described here.

**Scaffolding.** A platform supported on some kind of scaffold is necessary which will enable the observer to get close enough to the floor above to take observations of deflection and deformation. This should be at such a height that when the observer stands upon it the points where measurements of deformation are to be taken will be about one inch above his head. For flat slab construction this condition is easily obtained, but with beam and girder construction where there are measurements on beams, girders, and the floor slab, the heights of different gauge lines are so different that arrangement will need to be made for building certain parts of the platform higher than others (see Figs. 13 & 14). It is important that the elevation of the platform should be such that the observer can stand erect while taking the readings, and yet such that the instrument will not be too high for convenient and accurate observation.

Another framework for the purpose of supporting deflection apparatus under the points where measurements of deflection are to be taken is also necessary. In order that the movements of the observers upon the observation platform may not jar the deflection apparatus, the two frameworks must be built independently of each other. In all the tests which have been made, up to the present date, these deflection frames
have stood on the floor and have been braced from one to the other in order to make a comparatively rigid framework. Figure 14 shows scaffolding and deflection frames for the Turner-Carter test. An objection to this method of measuring deflections is that changes of humidity are likely to change the length of the wooden posts used, and it is quite probable that an improvement could be made in the form of this frame. An arrangement which has been suggested consists of steel I-beams supported directly by the columns and carrying other steel framework on which can be placed the deflection apparatus. This would give more nearly a self-contained construction, and the changes of humidity and temperature would not change the deflections, except as the length of column between the platform thus built up and the floor above is changed.

**Equipment.**—The equipment will necessarily consist of the following: cutting and drilling tools, portable lights for throwing light into observation holes, note books and facilities for doing drafting and for reducing data.

The cutting and drilling tools are sufficiently described in other paragraphs.

Some kind of a portable light is a necessity as gauge lines are often located in dark corners and as observations may be taken at any hour of the day or night. The light shown in the photograph of Figure 15 is a hunter's acetylene light and is quite satisfactory. The light is attached to the forehead and may be thrown in various directions according to the setting of the clamp attachment. The acetylene tank may be attached to the bolt or carried in the pocket.
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Figure 16.
A loose leaf note book should be provided in which the sheets are as large as is convenient, and which has been ruled according to the form in Figure 16. These forms are very conveniently ruled in hectograph ink and copied by means of a hectograph. Printed forms might be used, but so many differences in detail are made to correspond with the particular test in question that this would not be advisable as too few sheets of a single form would be required to justify the expense of having them printed. It would be well if in addition to the equipment listed above, a hectograph be added, for in working up results of the tests it is desirable that several copies of summary sheets and of the various sketches be made, and this is very satisfactorily and quickly done by means of a hectograph.

For the most efficient work in computing results and making sketches for records, it is important that an adequate place be provided where some privacy may be had, where benches and drafting tables may be used and where instruments and other equipment may be kept. The photograph of Figure 17 shows the temporary office which was provided in the Turner-Carter building test. This was one of the portable office shanties which the Company transports to places where work is being done. The Figure shows the interior of the office with the observers and recorders at work reducing the data of the test. This added equipment will add only slightly to the cost.
of the test and very greatly to the efficiency of the work. Special attention is called to it because there is a tendency to neglect this part and to think of it as only a secondary matter, whereas it should be considered as one of the most important pieces of equipment. In case the weather is cold, there should be provided in this office some means of heating it, as physical comfort is another of the requisites to accurate work on the part of both observers and recorders. This can not be obtained in taking the actual observations in an exposed test, but if access can be had to a warm place between series of observations, it will in a large measure help to make up for lack of it during the course of taking the observations.

Summary of Test Data.— A summary of the main features of the building tests discussed in this thesis is presented in Table I, as it is believed that the information given there will be of assistance in the efficient planning of and preparation for such a test. The following notes are in explanation of data given in this table:

The column giving area of test shows the total area of the floor covered and does not count any area twice even though loaded twice during the course of the test as was done in the Wenalden building test. It does include area of separate single panel tests such as occurred in the Wenalden and Franks tests. The column giving the number of observers gives only those reading deformations. In the Wenalden and Powers tests another observer took deflection readings. In the Powers test and the Barr tests, almost all the deformation readings were taken by each of two observers, giving a larger
number of gauge lines per observer than in the other tests.

The column giving the amount of load handled includes the rehandling due to change of position of loads. The proportionate parts of the loads rehandled in this way were Wenalden 40 per cent, Powers 50 per cent, Franks 80 per cent. In all the other tests no load was rehandled.

The maximum test load in lb. per sq. ft. is given in the column under that caption. In some cases this was over only a part of the test area. The per cents of the test area having the maximum load applied were as follows: Wenalden 80 per cent, Powers 50 per cent, Franks 40 per cent, all others 100 per cent.
Table I. Summary of Building Test Data.

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<tr>
<th>Building</th>
<th>Type</th>
<th>Test Area Sq. Ft.</th>
<th>% of Total Area</th>
<th>Material Used</th>
<th>Load Lb. per sq. ft. Design Test</th>
<th>Amount Handled (tons)</th>
<th>Number of Gauge Lines</th>
<th>Number of Observers</th>
<th>Days Required for Preparation</th>
<th>Days Required for Test</th>
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<td>Deere and Webber</td>
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III. INSTRUMENTS AND OBSERVATIONS

Instruments.

Extensometers.— The great obstacle to the measurement of deformations has been the difficulty of attaching the measuring instruments to either steel or concrete on the flat surface of a floor. This has been particularly true with regard to the attaching of instruments to the steel, and recent tests show the necessity of making measurements of steel deformation directly on the steel. A satisfactory method of accomplishing this has been provided by the introduction of the extensometer invented by Professor H. C. Berry of the University of Pennsylvania. This instrument is similar in some respects to the strain gauge designed and used as long ago as 1888 by James E. Howard, Engineer Physicist of the Bureau of Standards, and until recently Engineer of Tests at Watertown Arsenal.

The great value of this instrument in building tests lies in the following facts: (a) Its use makes it possible to make measurements directly upon the steel and concrete. (b) With its use there is no apparatus left in place to be damaged or disturbed during loading. (c) Due to the fact that it is portable, measurements may be taken in a large number of places with a single instrument. Measurements have been taken at as many as 120 points in a single test. This would call for an outlay of from $1200.00 to $2500.00 for instruments if fixed instruments were used.
Figure 18 shows the Illinois extensometer in the form in which it is used at present. Any movement of the point B due to a change in the length of the gauge line is transmitted to the Ames gauge through vertical movement of point C, by means of the leg BD and the arm DC pivoted at D. The Ames gauge is sensitive to a movement at C of .0001 inch. The ratio of the length CD to the length BD is approximately five and the Ames gauge is thus sensitive to a movement at B of .00002 inch (.0001 inch / 5). However, this must not be taken to mean that the extensometer possesses this degree of accuracy in measuring stresses since some movement of the point of the leg at B is certain to result from variation in the handling of the instrument.

To obtain the exact ratio between movements at points B and C the instrument is calibrated by means of a Brown and Sharpe screw micrometer. For known movements of the point B readings of the Ames gauge are taken and a calibration curve plotted for the entire range of the instrument.
The first instrument of this type built by the Engineering Experiment Station of the University of Illinois was made by permission of Professor Berry for the Deere and Webber test. It was designed by Professor H. F. Moore and Mr. A. R. Lord, and was like the instrument in use at present except that it had a 15 in. gauge length and was made entirely of steel. Later on in making the instrument for general use aluminum was substituted for steel in order to reduce its weight. The gauge length was made variable from 6 in. to 11 in., and a screw micrometer head with electric contact was tried instead of the Ames gauge head shown in outline in the drawing of Figure 18. In a short time, however, the Ames gauge head was shown to be superior for accuracy of results and speed of observation and since then has been used exclusively in the instruments made at the University of Illinois. Since then several minor changes have been made. The legs have been made stiffer in order to reduce the error due to unconsciously applied longitudinal thrust; the points have been made sharper in order to reduce the pressure required in seating the instruments. As shown later under the discussion of accuracy, these improvements have reduced the probable error considerably.

The extensometer put out by Professor Berry is shown in Figure 19. It is not different in principle from the one just described. It is different in the following details:

(a) Instead of having a uniformly variable gauge length ranging from 6 in. to 11 in. it has two fixed gauge lengths of 2 in. and 8 in. respectively. (b) In order to obtain a multiplication ratio of five between leg and arm, it is necessary to use
Figure 18

Figure 19
a leg which is only one inch long. With this arrangement the instrument can not usually be used for measuring deformations in reinforcing bars, owing to their depth of imbedment and with longer legs a smaller ratio of multiplication is obtained.

(c) This instrument is put out with framework of Invar steel or aluminum. While Invar steel makes the weight somewhat greater than that of the aluminum instruments, it has the great advantage of avoiding so much dependence on an Invar steel standard bar and allows with great ease the study of the temperature changes in the steel and concrete of the structure.

Mr. F. J. Trelease of the Corrugated Bar Company has designed an instrument of the Berry type and has used it in at least one test. This instrument shown in Figure 20 also has as

![Figure 20](image)

its main feature a multiplying lever which actuates the plunger of an Ames gauge head. The principle difference between this instrument and the one shown in Figure 18 is that the multiplying lever is vertical instead of horizontal. Results have been obtained with it which do not differ much as to accuracy with those of the Illinois type of instrument.
Use of Berry Extensometer. - In obtaining good results with this extensometer, a great deal depends upon careful manipulation of it. The two things which in the opinion of the writer are of the most importance in this respect are (a) the preparation of the gauge holes, and (b) care and experience in the use of the instrument.

The proper gauge length is best secured by the use of some kind of gauge marker such, for instance, as is shown in the photograph of Figure 21 used for marking points where gauge holes are to be drilled. In the work of the Illinois Engineering Experiment Station the holes are drilled with a No. 54 drill (.065 in. in diameter). At the beginning of the use of the Berry extensometer a number E counter sink drill (approximately 3/32 in. in diameter) was used, but a smaller one seems to be better, mainly because it is easier to get the properly finished hole, and a slight eccentricity on a small rod is not quite so serious with a small drill as with a larger one. In the case of measurements on small rods also, the 3/32 in. drill cuts away a large percentage of the steel in the rods. Up to the present time, for drilling these gauge holes a breast drill has been used which is geared so that one revolution of the crank gives about 4 1/4 revolutions of the drill. In the hands of a skilled workman very satisfactory work can be done in this way, but where, as
quite frequently will be the case, the drilling has to be done by persons not familiar with this kind of work something better is needed. A drill driven by a flexible cable attached to a small electric motor giving a speed of rotation of 400 r. p. m. and upwards probably would be much better. Where high carbon steel has been encountered many drills have been broken and even when a hole was drilled a poor job has often been the result. After drilling the holes, the edges should be finished to remove the burr and to round off the sharp corners. The tool shown in Figure 21 is designed to accomplish this purpose. Such a tool should not be a cutting tool but rather a wearing or polishing tool. A pointed magnet to remove steel dust and small fragments of steel torn off in drilling would be of use. It is hard to place too much emphasis on the proper preparation of gauge holes.

Standard Gauge Line.—While the careful preparation of gauge holes is important, not less so is the use of a standard gauge line. The necessity for it was first found in the test of the Deere and Webber building. Variation in temperature was sufficient to cause a change in the length of the instrument as great as that in the reinforcing steel due to the applied load. Hence it was found necessary to make observations on an unstressed standard bar showing any temperature changes in the length of the instrument. In this test a bar of about 5/8 inch steel was used as a standard. It was protected from rapid temperature changes by imbedment in plaster of Paris, but kept on the floor where the test was being made. In this way it was expected to make the change in the length of the standard bar due to temperature
variations about equal to the change in length of the reinforcing steel due to the same cause. To some extent this purpose was accomplished, but as the plaster covering was thin and not very dry the change in the standard bar must have been much more rapid than that in the reinforcing steel. In the test of the Wenalden building precautions were taken to imbed the standard bar in concrete. This practice has been kept up in tests made since then, and in addition standard gauge lines have been established in parts of the floor not affected by the load. These latter have been placed both on the reinforcing steel and in the concrete. Figure 15 shows the taking of an observation on a standard gauge line in the Turner-Carter test. It can be seen that it is located in a part of the floor entirely away from the loaded area. The greatest development in the use of the standard has been in the frequency of reference to it and in the development of an exact system for the calculation of temperature corrections. It was previously noted that a steel instrument was used in the Deer and Webber test but that in the subsequent tests an aluminum instrument was used. Since the coefficient of expansion for aluminum is almost twice that for steel, it is apparent that dependence on the standard gauge line must have been of still greater importance in the later tests. Difficulty was found in interpreting the notes taken on the Wenalden test, but the greater dependence on the standard gauge line and the more systematic use of it observed since then has very largely overcome this difficulty. Subsequent to the completion of the last building test participated in by the writer, standard bars of Invar steel have been secured. Invar steel has a coefficient
of expansion only about one-sixth that of ordinary steel and its use as a standard bar makes it possible to eliminate from the results almost all the effects of temperature variation. If it is desired to determine how great are the temperature effects, a standard gauge line can be placed in the floor as before in such a position as not to be affected by the floor load.

It has been the practice in the more recent building tests for each observer to make observations regularly on two standard gauge lines. This is done so that one may form a check on the other. If only one were used, a large accidental change in the readings due for instance to sand in the gauge holes might be mistaken for a temperature effect. If two standards are used, any such accidental change as the above would seldom be the same in both, and the error would be detected. An accident to the instrument would probably cause the same change on both standard gauge lines and the use of the two standards would not help to detect this kind of an error. However, such errors are usually so large as to be apparent in any standard reading and are infrequent as compared with errors due to filling of the gauge holes.

Howard Strain Gauge.—The description of the Berry extensometer, given on page 39 does not apply in full to the strain gauge used in building tests by J. E. Howard. The distinctive difference between it and the other instruments referred to is that there is no multiplying lever. The pointed legs are present as in the Berry extensometer, but the movable leg instead of being pivoted is attached to a shaft which slides in a hollow cylinder connected with the other leg, the
amount of movement being measured directly by a screw micrometer which is sensitive to a movement of one ten-thousandth inch. Thus it is seen that while the Berry strain gauge is sensitive to a movement of one fifty-thousandth inch, the Howard strain gauge is sensitive only to one ten-thousandth inch. This does not necessarily mean an accuracy of one-fifth that of the Berry instrument. The relative accuracy can be determined only by continued use of the two instruments under similar circumstances. This matter is taken up under the subject of accuracy of observations.

Deflection Instruments. - In the building tests described in this thesis deflection instruments of two types have been used, one being that used by the Illinois Engineering Experiment Station and the other that used by the Corrugated Bar Company. The former, shown in Figure 22, consists of a screw micrometer head of one in. travel, connected in tandem with an Ames gauge head micrometer of 1/2 in. travel. The screw micrometer is designed to cover large variations in deflections, and the Ames gauge head, small ones. Figure 22 shows also the method of using this deflectometer. A plate having 1/2 in. steel ball attached is plastered to the surface, deflections of which are to be measured. A 5/8 in. bolt, which has a steel ball inserted into its upper end, is set into a wooden block (part of the deflection framework) in such a way that its elevation can be adjusted to give any desired zero reading of the extensometer. The drawing shows the method of using the instrument. Thus at the beginning of a test all the zero deflection readings can be determined so that for a con-
siderable length of time all the change in deflection will be shown on the Ames gauge without any change of the screw micrometer. As larger changes take place, a second setting of the screw micrometer will probably be necessary. The great advantage of this instrument is the rapidity with which it can be used. It has been found to work very satisfactorily in most respects. A shortcoming, however, has been the lack of a revolution counter on the Ames gauge so that in case of large changes of deflection it is possible to make an error of as much as 0.1 in. in interpreting the readings, though this is very unlikely. Since the last of these building tests have been made, an Ames gauge head, which has a revolution counter, has been provided for this instrument, so that the difficulty here mentioned is not likely to occur in the future.

The deflectometer used by the Corrugated Bar Company is shown in Figure 23 and consists of a screw micrometer depth
gauge by means of which distances for varying loads are measured between the stationary frame and a point on the beam or floor slab. It has the advantage over the one previously described that actual distances are measured instead of changes in distance, so that if the complete reading is taken each time, there is no possible way of misinterpreting results. It has also the advantage of a much larger range of measurement. In the Barr panel test a gross deflection of more than 3 inches took place. As the Illinois type of deflectometer has a range of only 1 1/2 inches, it could not have been used in this test. This, however, is more than would often if ever occur in the test of a building. Its disadvantage is that it requires a longer time to make an observation than does the deflectometer previously described.
Observations.

Observers.— Observers should be experienced in the use of the Berry extensometer before undertaking work on a field test. The chances of error in the manipulation of the instrument are large, and as a rule the deformations measured are small, so that the error is likely to be quite a large proportion of the total measurement; hence it is important to reduce errors to the lowest possible limit.

Extensometer Observations.— If the observations at zero are equally as good as other observations, a curve may be drawn through all the points of any load-deformation diagram after the test is completed, weighting the zero observations equally with the others and the zero point shown by the most probable curve should be used as the origin. This method involves waiting until the completion of the test to draw these curves. It would be better to spend much more time on the zero observations, in order to make them reliable, than is paid to any other series. By this means a check can be had upon the action of the structure as the test progresses and the construction of the most probable curve will be made more simple. To do this it is essential that several complete series of zero observations should be taken with no load on the floor, and it would be well to repeat this through considerable range of temperature to study temperature effect on the steel and on the concrete. This study was attempted in the Deere and Webber test, but the changes both in instruments and in reinforcement were included in the measurements and could not be separated, so no definite conclusions could be drawn. However, with an Invar steel standard bar or with an instrument
made of Invar steel these two sorts of changes can be separated and to some extent at least the effect of temperature determined.

In taking an ordinary observation about five readings should be averaged. In all of the building tests which have been made, individual extensometer readings were recorded, but in laboratory tests the practice of averaging the results mentally has been adopted. This gives very satisfactory results for laboratory tests and saves a great deal of time. It is possible that this practice could be adopted safely for field tests also. It would save a great deal of time on a test and with a good recorder the calculations could be kept up with the observations. In the more recent building tests the practice followed in obtaining readings for any observation has been to reject all readings until 5 consecutive ones have been obtained which agree within 0.0004 inch. These five consecutive readings then are averaged to form an observation.

Deflectometer observations have been sufficiently discussed in the description of the deflectometer and will not be taken up again here.

Observations of Cracks.- Up to very recently the observation of cracks has been considered one of the most important features of a test, and if carefully done it may yet add considerable to the confidence in the results. These observations should be made and recorded for zero load and at each increment of load. This is one of the most tedious parts of the test, and to carry it out faithfully
requires a great deal of patience. The examination should be minute and very thorough. One who is not familiar with this kind of work will be likely to miss important indications and careful supervision should be maintained over this part of the investigation.

Special attention has been called to observation of cracks because of incorrect ideas which apparently prevail with regard to them. It seems to be the idea of some engineers that the type of construction advocated by themselves is immune from cracks. When it is remembered that plain concrete fails in tension at a unit-deformation of about .0001, it is apparent that cracks must form when the stress in the steel is such as to correspond with this deformation, or at about 3000 lb. per sq. in. At this stage the cracks are often too small for detection with the naked eye, but almost always very fine cracks are found at stresses ranging between 3000 and 10,000 lb. per sq. in. Thus to report for a floor loaded to twice the design load that no cracks were observed is to admit one of three things, namely, that an excess of steel was used, sufficient care in taking observations was lacking, or that not all the facts of the case were reported. It should be borne in mind that the cracks referred to in this thesis are often extremely minute and usually are not visible to a casual observer. Frequently cracks have been traced with a lead pencil to make them distinct for the purpose of sketching, and it seems apparent that some persons visiting the test have mistaken these pencil marks for large cracks. At any rate reports have been circulated as to the
existence of large cracks in a test where to the writer's personal knowledge there were none.

Figure 24
Accuracy of Deformation Measurements.

Probable Error.- The ratio of multiplication in these extensometers is not exactly equal to the ratio of the length of the arm to the length of the leg, the error being due to the fact that the plunger of the Ames gauge head does not always travel in a line perpendicular to the multiplying lever. However, calculations show that this approximation results in an error in the measurement of steel stresses equal to only about one-quarter of one per cent for an extreme case. It will be later seen that errors of observation are large enough in proportion that this error can be neglected.

In forming a basis for a conclusion as to the accuracy of the figures given out as results of tests, use has been made of the check readings taken by two observers on the same gauge lines and of calculated probable error of the mean of five readings. While it is possible to calculate with some accuracy the probable error of replacing the instrument on the same gauge line time after time at one sitting, it is very difficult to determine the error caused by gradually cramping the quarters of the observer as the loading material piles up. A determination of errors based on independent checking by a second observer should be expected to eliminate to a large extent errors of all kinds and the greatest dependence should be placed on this kind of results.

In the test of the Powers building most of the observations taken were checked by a second observer and some
of the results are shown in the load stress curves of Fig. 24. The values shown in solid circles were observed by Mr. F. J. Trelease and those in open circles, by the writer. The zero reading for the latter is in all cases at a load of 50 lb. per sq. ft., and in order to make a direct comparison of results, all these curves must be set over so that their zeros coincide with the stress values at 50 lb. per sq. ft. of Mr. Trelease's curves. Having made this correction the average variation between all the comparable points is about 670 lb. per sq. in. (.0000223 unit deformation), which amounts to a probable error of approximately ±340 lb. per sq. in. (±.000011 unit deformation.)

Figure 25 shows the results of a series of measurements taken in the same way on the upper and lower surfaces of a 4 in. by 4 in. timber beam loaded with sacks of sand on a 12-foot span. The points in open circles represent measurements on the top surface and those in crosses on the bottom surface. Determined in the same way, these measurements show an average probable error of approximately ±.000017 unit deformation. As previously stated, these check measurements must be taken to give results more applicable than calculations.
of probable error of the mean of a group of readings. However, it may be expected that where an increase in accuracy of setting the instrument is found, a decrease in error due to cramped quarters, etc. will be found. In Figure 26 is given a curve which shows for each of four building tests the probable error of the average of five readings. Each plotted point is the average of the probable errors calculated for six different gauge lines at a given load. What this diagram may be expected to show is the improvement in results with increased experience rather than the actual value of the probable error. The marked improvement in results shown here is due in part to increased skill in the observer and in part to improvement in the instrument itself. Figure 27 gives a curve showing deformations in steel in the bottom bar of the sketch. The points shown as open circles are for a load of 590 lb. per sq. ft. and solid circles are for a load of 615 lb. per sq. ft. This is the best curve the writer has been able to obtain on any building test, and it can not be taken as representative, but rather to il-
lustrate what may be obtained under the best conditions. The regularly varying differences for a small difference of loads indicate that the stresses must have been determined correctly within a very small range.

It has been stated that the probable error calculated from the readings obtained in replacing an instrument a number of times on the same gauge line cannot be taken as showing quantitatively the probable error of the results found in a test. Neither is it likely that a comparison of instruments made in this way will be entirely fair, unless the observer is equally familiar with all the instruments compared. However, the extensometers described in this thesis are enough alike that experience in the use of any one of them will very greatly aid in the use of the others. As the writer knows of no person skilled in the use of all the types here described, he has based a comparison of three types of instrument on results of his own observations with these instruments. These results are shown in Table II. They show comparisons of the accuracy of results obtained with (a) the Illinois type of Berry extensometer equipped with 60° and 45° points respectively, (b) the Howard strain gauge in gauge holes prepared as described on Page 45 and as prepared by the makers of the strain gauge, and (c) the Illinois type of Berry extensometer, the extensometer put out by Professor Berry and the Howard Strain Gauge, all three in the hands of the same observer. The results are decidedly in favor of the sharper pointed legs of the Illinois instrument and the holes with rounded edge rather than the deeply countersunk holes. The comparison of instruments shows up in the
TABLE II. PROBABLE ERROR CALCULATED FROM READINGS ON STANDARD BAR

<table>
<thead>
<tr>
<th>Position of Instrument</th>
<th>Illinois 60° Points</th>
<th>Berry 45° Points</th>
<th>Howard 60° Points</th>
<th>Deeply Countersunk Holes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upright</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>.00000504</td>
<td>.00000270</td>
<td>.00001750</td>
<td>.00001650</td>
</tr>
<tr>
<td>2</td>
<td>.00002880</td>
<td>.00000000</td>
<td>.00000269</td>
<td>.00001650</td>
</tr>
<tr>
<td>3</td>
<td>.00005550</td>
<td>.00000000</td>
<td>.00000548</td>
<td>.00000000</td>
</tr>
<tr>
<td>4</td>
<td>.00002840</td>
<td>.00000270</td>
<td>.00000369</td>
<td>.00000000</td>
</tr>
<tr>
<td>5</td>
<td>.00004360</td>
<td>.00000000</td>
<td>.00001160</td>
<td>.00001340</td>
</tr>
<tr>
<td>6</td>
<td>.00002950</td>
<td>.00000270</td>
<td>.00001315</td>
<td>.00000000</td>
</tr>
<tr>
<td>Av.</td>
<td>.000040</td>
<td>.000002</td>
<td>.000013</td>
<td>.000000</td>
</tr>
<tr>
<td>Inverted</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>.00000351</td>
<td>.00000000</td>
<td>.00001040</td>
<td>.00003440</td>
</tr>
<tr>
<td>2</td>
<td>.00000808</td>
<td>.0000031</td>
<td>.00000504</td>
<td>.00003310</td>
</tr>
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<td>3</td>
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<td>.0000031</td>
<td>.00000269</td>
<td>.00002700</td>
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<tr>
<td>4</td>
<td>.00001280</td>
<td>.00000738</td>
<td>.00000540</td>
<td>.00002530</td>
</tr>
<tr>
<td>5</td>
<td>.00000990</td>
<td>.00000504</td>
<td>.00000331</td>
<td>.00003310</td>
</tr>
<tr>
<td>6</td>
<td>.00001360</td>
<td>.00000787</td>
<td>.00000662</td>
<td>.00001350</td>
</tr>
<tr>
<td>Av.</td>
<td>.000015</td>
<td>.000005</td>
<td>.000007</td>
<td>.000033</td>
</tr>
</tbody>
</table>

The following order of accuracy: (1) Illinois instrument, (2) Professor Berry’s instrument, (3) Howard instrument. However, more experience with all three of the instruments might change this order.

A study of probable error was made in the Turner-Carter test by the use of a series of 100 observations taken by each of the two observers on two gauge lines selected as likely to give the most and the least accurate results. The results of this study are given in Table III.
<table>
<thead>
<tr>
<th></th>
<th>Observer</th>
<th>Gauge Line</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Unit deformation</td>
<td>H. F. Moore</td>
<td>.00000687</td>
</tr>
<tr>
<td></td>
<td>W. A. Slater</td>
<td>.00000435</td>
</tr>
<tr>
<td>Stress in steel in lb. per sq. in.</td>
<td>H. F. Moore</td>
<td>206</td>
</tr>
<tr>
<td></td>
<td>W. A. Slater</td>
<td>130</td>
</tr>
</tbody>
</table>

While these measurements were not all on steel, the probable error has been reduced to terms of stress in steel for convenience of interpretation. It is very interesting to note that the average probable error of \( \pm 282 \text{ lb. per sq. in.} \) agrees very well with that for the Turner-Carter test as shown in the curve of Figure 26. The same observer took the data in both cases, but the data for the value shown in Figure 26 are taken directly from the records of the test and represent the conditions on six typical gauge lines. The method of obtaining the values given in Table III is explained at the beginning of this paragraph.

From the data in hand it seems safe to conclude that for ordinary conditions stresses in steel can be measured to the nearest 1000 lb. per sq. in., though in the past there have been some glaring failures to obtain as great a degree of
accuracy as this. The advantage of further increase in accuracy of results lies in the determination of the relation of parts of the structure. In the investigation to detect arch action described in a later paragraph, it will be of the greatest importance that all measurements of deformation should be very accurately made in order to determine how far the stresses are carried out laterally.

**Effect of Temperature on Instruments.**

Changes of temperature will give measurable changes of length in reinforcing steel, in concrete, and in instruments made of ordinary materials. In most of the building tests, corrections have been made for the changes in instrument due to changes in temperature by means of observations on standard unstressed gauge lines chosen to represent as nearly as possible the conditions of the steel and the concrete in the part of the structure tested. The method of calculating this correction will be described in a later paragraph. It is there mentioned that in distributing the corrections found by reference to the standard bar, a linear variation from the time of one standard observation to the time of the next standard observation was assumed. Some observations have been made to determine the correctness of this assumption.

To determine the amount of change in length of an aluminum extensometer covered and uncovered, a test was made in which the two instruments were suddenly exposed to a change of temperature of 60 degrees F. A covering which consisted of a double layer of rather heavy felt protected one of the instruments from too sudden change in temperature. The other
instrument was entirely uninsulated. The results of this test are shown in Figure 28 with the change of length of the instrument plotted as ordinates against time as abscissas. For these measurements a standard bar of Invar steel was used. The coefficient of expansion of this being very small, the change of length measured must have been almost entirely that in the instrument. The curve shows that for an instrument not insulated from temperature changes only about five minutes is required for the instrument to come to the temperature of the air. For the insulated instrument about 20 minutes was required. This may be interpreted to mean that if an unprotected instrument is used, readings on the standard bar should not be more than five minutes apart. With an instrument protected as was this one, intervals of 20 minutes would not be too much. The amount of change for the case shown here is extreme as the instrument was suddenly exposed to a change of temperature of about 60 degrees F. This range would seldom be found, and the length of time required to make the change for a smaller difference of temperature may be less but probably would not vary much with other ranges of temperature. It may be concluded that the method used for distributing the correction is justifiable, since the instrument was protected from sudden change of temperature and the observations
on standard bars were usually at intervals not greater than 20 minutes.

**Temperature Effect on Reinforcement.** - The above test shows the effect on the instrument of change in temperature. Another test was made to determine the effect of change in temperature on steel imbedded in concrete and on steel exposed to the air. A 3/8-inch square bar of steel entirely unprotected from temperature changes and a 3/8-inch round bar imbedded in 1 inch of concrete were exposed to a sudden change of temperature of about 43°F. Measurements were taken on a six-inch gauge length of each bar at very short intervals of time. The results are shown in Figure 29. The results of this single test must be used with caution as the total measurements were very small and a small error would show up very plainly. However, the curve for the imbedded bar agrees in general characteristics with some of the results obtained by Professor Woolson on "Effect of Heat on Concrete" reported in the 1907 Proceedings of the American Society for Testing Materials. The test indicates that for this range of temperature rather rapid changes may be found in the steel, corresponding with stresses of about 9000 lb. per sq. in. and 3000 lb. per sq. in. respectively for exposed steel and steel protected as was done in this case. The range of temperature is extreme and the size of bars smaller than often found in floor construction.
therefore, the results found in tests would probably be less extreme. However, this indicates the necessity of attempting to eliminate from the results of the test the effect of temperature changes, especially if the stresses measured are small.
IV. RECORDS AND CALCULATIONS

Since the beginning of the use of the Berry extensometer for testing purposes, as much development has been made in the keeping of notes as in the use of the instrument. Because of a lack of completeness of notes the advantages of the use of the standard bar were not fully realized for a long time. Only after the method of keeping notes had been highly systematized was it possible to properly make the corrections which observations on the standard bars indicated should be made. During the time of placing an increment of load the recorder will have considerable time in which to be working up results of the series of observations taken at the previous increment of load, and as the method of making these calculations is quite intricate, a man is required for this work who has ability to do more than merely record. It is important that calculations should be kept up as the work progresses, because it can be done with less labor then than at any other time and because it will be of value to know as the test progresses what results are being secured.

Records.

It is very important on account of the great number of observations taken (about 12,000 in the Turner-Carter test) that all records be arranged systematically. The following points are mentioned as being important in this connection: (1) In the field tests individual readings should be recorded and their average used as a single observation. The proposed
The exact sequence of observations should be maintained in the records as the calculation of corrections depends largely on this.
Calculations.

The results should be calculated according to an exact system. The following is given as one which, with modifications, has worked very satisfactorily for both field and laboratory tests:

(1) Corrections.

(a) Assume the zero length of the instrument (see definition) to be correct, and assume that all subsequent changes from zero length as determined by readings on standard bar are actual changes in the length of the instrument and not errors of observations. This is not absolutely true, but as a basis on which to work it seems to be satisfactory.

(b) Subtract all subsequent standard bar readings from the zero length, recording the algebraic sign of the differences. This gives the correction at the time of observation on the standard bar.

(c) To determine the corrections to be used at any other time, assume a linear variation in length of instrument, interpolating between the readings on the standard bar, according to the number of intervals which have elapsed.

(2) Corrected Average. According to the definition of a correction, the corrected average is the sum of an observation and the corresponding correction. In other words, it is the observation which would have been obtained if the instrument
had not changed from its zero length. The corrected average is obtained for the no-load readings on all gauge points, and all further observations are referred to this as the base.

(3) Uncorrected Differences. The uncorrected differences are obtained by subtracting algebraically any uncorrected observation from the corrected no-load observation on the same gauge line. Strictly speaking, this is not an uncorrected, but a partially corrected difference, since there has been applied to it the correction which accumulated between the zero length and the no-load observation on the gauge line in question. The reason for using this partially corrected difference instead of the uncorrected difference is that by so doing one computation for each observation after the no-load observation is avoided.

(4) Corrected Differences. The corrected difference is obtained by subtracting algebraically the correction from the uncorrected difference. That this is true may be shown by the following equations:

Let \( A_x \) = corrected zero average on gauge line \( x \).
\( a_x \) = Corrected load average on gauge line \( x \).
\( r_x \) = Uncorrected load average on gauge line \( x \).
\( c_x \) = Correction for gauge line \( x \).
\( d_x \) = Corrected difference for gauge line \( x \).

\[
\begin{align*}
A_x &= A_x - a_x \\
&= (r_x + c_x) - (r_x + c_x) = (A_x - r_x) - c_x.
\end{align*}
\]

A form showing the method of procedure in calculating the results is given in Table IV.
<table>
<thead>
<tr>
<th>Load</th>
<th>Interval</th>
<th>Gaugeline</th>
<th>Standards</th>
<th>Arbitrary numbering of gauge-lines</th>
<th>Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$a$</td>
<td>$b$</td>
<td>$c_i$</td>
<td>$c_2$</td>
</tr>
<tr>
<td>Uncorr. Av.</td>
<td>$S_a$</td>
<td>$S_b$</td>
<td>$R_1$</td>
<td>$R_2$</td>
<td>$R_{n-2}$</td>
</tr>
<tr>
<td>Correction</td>
<td>0</td>
<td>0</td>
<td>$\frac{1}{n} \frac{C_a''+C_b''}{2}$</td>
<td>$\frac{2}{n} \frac{C_a''+C_b''}{2}$</td>
<td>$\frac{n-2}{n} \frac{C_a''+C_b''}{2}$</td>
</tr>
<tr>
<td>Zero Av.</td>
<td>$R_1+G_1$</td>
<td>$A_i$</td>
<td>$R_2+G_2$</td>
<td>$A_2$</td>
<td>$R_{n-2}+G_{n-2}$</td>
</tr>
<tr>
<td>Uncorr. Av.</td>
<td>$s_a$</td>
<td>$s_b$</td>
<td>$r_1$</td>
<td>$r_2$</td>
<td>$r_{n-2}$</td>
</tr>
<tr>
<td>Uncorr. Diff.</td>
<td>$a_i-r_i$</td>
<td>$A_i-r_i$</td>
<td>$a_i-r_i$</td>
<td>$A_i-r_i$</td>
<td>$A_{n-2}-r_{n-2}$</td>
</tr>
<tr>
<td>Correction</td>
<td>$S_a'-S_a''$</td>
<td>$S_b'-S_b''$</td>
<td>$c_{ab}+\frac{1}{n}c_{ab}$</td>
<td>$c_{ab}+\frac{1}{n}c_{ab}$</td>
<td>$c_{ab}+\frac{n-2}{n}c_{ab}$</td>
</tr>
<tr>
<td>Corr. Diff.</td>
<td>$d_{n-2}-c_{n-2}$</td>
<td>$d_{n-1}-c_{n-1}$</td>
<td>$d_{n-2}-c_{n-2}$</td>
<td>$d_{n-1}-c_{n-1}$</td>
<td>$d_{n-2}-c_{n-2}$</td>
</tr>
<tr>
<td>Put $C_a''+C_b''=c_{ab}$</td>
<td>$d_{n-2}+c_{n-2}=e_{n-2}$</td>
<td>$d_{n-1}+c_{n-1}=e_{n-1}$</td>
<td>$d_{n-2}+c_{n-2}=e_{n-2}$</td>
<td>$d_{n-1}+c_{n-1}=e_{n-1}$</td>
<td>Put $C_a''+C_b''=c_{ab}$</td>
</tr>
</tbody>
</table>
V. COST OF BUILDING TESTS

Statements of costs incurred in several of these tests have been obtained and are here given in the same form as they were received.

Turner-Carter Test

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lumber</td>
<td>$179.85</td>
</tr>
<tr>
<td>Less for lumber afterwards used in building or returned to dealer</td>
<td>142.36</td>
</tr>
<tr>
<td>Photographs taken of test</td>
<td>32.00</td>
</tr>
<tr>
<td>Hotel expenses of Professor Talbot's assistants, Mr. Slater and Mr. Moore</td>
<td>60.94</td>
</tr>
<tr>
<td>Drilling holes in steel in beams, etc., for measuring instruments</td>
<td>7.20</td>
</tr>
<tr>
<td>Miscellaneous material</td>
<td>7.20</td>
</tr>
<tr>
<td>Tools</td>
<td>3.24</td>
</tr>
<tr>
<td>Blue prints</td>
<td>2.57</td>
</tr>
<tr>
<td>Telegram</td>
<td>.50</td>
</tr>
<tr>
<td>Expressage</td>
<td>1.38</td>
</tr>
<tr>
<td>Freight on material</td>
<td>7.06</td>
</tr>
<tr>
<td>Forms for test pieces</td>
<td>3.70</td>
</tr>
<tr>
<td>Rental of scow for sand used as load for floors</td>
<td>36.00</td>
</tr>
<tr>
<td>Labor placing and removing loads on floors, cutting and repairing concrete, etc.</td>
<td>382.35</td>
</tr>
<tr>
<td>Liability insurance on labor</td>
<td>14.16</td>
</tr>
</tbody>
</table>

Total $595.59
Franks Test

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preliminary services and traveling expenses on planning test</td>
<td>$121.77</td>
</tr>
<tr>
<td>Cost of inserts and cost of placing same</td>
<td>18.00</td>
</tr>
<tr>
<td>Test plans and blue prints</td>
<td>16.00</td>
</tr>
<tr>
<td>Services, supervision and observation</td>
<td>757.35</td>
</tr>
<tr>
<td>Supplies required for preparation</td>
<td>18.55</td>
</tr>
<tr>
<td>Pig-iron and charge for hauling same (241 tons)</td>
<td>471.69</td>
</tr>
<tr>
<td>Services of workmen at time of test</td>
<td>408.00</td>
</tr>
<tr>
<td>Services of workmen taking away pig-iron</td>
<td>109.39</td>
</tr>
<tr>
<td>Preliminary and trial reports</td>
<td>93.00</td>
</tr>
<tr>
<td>Working up data, drawings, etc.</td>
<td>96.25</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$2110.00</strong></td>
</tr>
</tbody>
</table>

Powers Test

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material, etc.</td>
<td>$131.00</td>
</tr>
<tr>
<td>Tools, etc.</td>
<td>31.21</td>
</tr>
<tr>
<td>Labor</td>
<td>61.25</td>
</tr>
<tr>
<td>Traveling and hotel expenses</td>
<td>160.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$583.46</strong></td>
</tr>
</tbody>
</table>
Carleton Test

Expenses, Labor, etc. $41.05
Tools 11.30
Total $52.35

The statement of cost for the Turner-Carter test was received from the Turner Construction Company and represents the cost to the National Association of Cement Users instead of the total actual cost of the test. The Turner Construction Company did not make any charge for services of their engineering or construction departments. The University of Illinois Engineering Experiment Station made no charge for services, and traveling expenses also have been omitted from this statement. It is estimated that the items omitted from the actual cost would be about as follows:

Turner Construction Company: services of engineers, draftsmen, superintendent, foreman, carpenters, etc. $400.00
University of Illinois Engineering Experiment Station: services for supervision, observation and working up data 350.00
Traveling expenses 200.00
Total $950.00
Adding this to the cost given in the statement would bring up the total cost to approximately $1550.00.

The statement of the cost of the Franks test appears to be complete and is much higher than the total estimated cost of the Turner Carter test. An inspection of the items shows a much larger cost for rental and hauling material than in the Turner-Carter test. It is $472.00 for 482,000 pounds of pig-iron as against $45.00 rental of scow and freight on 520,000 pounds of sand. Again, the cost of labor in placing and removing loads, cutting and repairing concrete given as $382.00 in the Turner-Carter test amounts to $535.00 in the Franks building test. In the latter test, however, about 80 per cent of the material was handled twice in the process, changing the position of the loads. This is equivalent to handling a total of 865,000 pounds as against 520,000 pounds handled in the Turner-Carter test. Assuming that one-fourth of the $535.00 cost item in the Franks test, approximately $135.00, was for cutting and repairing concrete about $400.00 would be left for the handling of 865,000 pounds of loading material. The proportional cost of handling 520,000 pounds is $240.00. Adding to this the $135.00 estimated cost of cutting and repairing concrete, brings the cost of the two items to $375.00, a reasonable comparison with the $382.00 for the corresponding items of cost in the Turner-Carter test. In order to reduce the data on cost of the two tests to a basis for comparison it is best to eliminate such variable quantities as traveling expenses and charges for rental and transportation of loading material. This
brings the costs to approximately $1300.00 and $1400.00 for the Turner-Carter and Franks tests respectively. It is probable that to reduce the two cases to a commercial basis the item added to the Turner-Carter test for the services of members of the University of Illinois Engineering Experiment Station staff should be somewhat more than $350.00. Exclusive of traveling expenses and charges for rental and transportation of loading material it is probable that the actual cost of a test of the magnitude of these will lie between $1200.00 and $1500.00.

The data on the Powers test do not give enough detail to allow of analysis. Apparently no charge is recorded for planning, superintendence and working up of data.

The cost of $52.35 for the Carleton test is of interest in showing that a test for the checking of details of design can be made at a cost slightly above the cost of the required acceptance test.
VI. SUBJECTS OF INVESTIGATION.

In the building tests which have been made deformations have been measured with a view to obtaining information on each of the following subjects:

(a) The values of the moment coefficients at the center and support of the beam or slab under investigation.

(b) Relative moments at support for various conditions of fixedity.

(c) The extent to which the floor slab acts as a compression flange of the floor beam to produce T-beam action.

(d) Bond stresses.

(e) Diagonal tension.

(f) Stresses in columns.

(g) Time effect under constant load.

(h) The lateral distribution of stress to parts of the structure entirely outside of the loaded area.

(i) The extent to which steel stresses are modified by errors in the assumption that no tension is carried by concrete.

(j) Stresses in slabs of beam and girder construction.

Other subjects of investigation have received attention but these are the most important ones. Some phenomena have been observed, offering problems of great importance, the solutions of which have not yet been accomplished. Such phenomena are the presence of so-called arch action and the fluctuation of stresses under
constant load. The former of these is the most important and is so intimately involved in the determination of moment coefficients that it is discussed under that head. The other is discussed in a later paragraph.

A matter of importance in flat slab construction and demanding further investigation is the inter-relation of stresses at the same point at right angles to each other.

**Moment Coefficients and Arch Action.** In all of the tests so far made, an attempt has been made to determine moment coefficients. These attempts have not been entirely successful due to errors of measurements and unexpected variations in similar parts of the structure remote from each other. The method has been to measure deformations on both steel and concrete at the center and support, and from these measurements to determine the total resisting moment developed. Equating this resisting moment to a constant $K \times Wl$ a solution is made for the value of $K$. The indications that arch action has been present have so complicated this that even where measurements have appeared quite satisfactory, the uncertain amount of arch action entering has rendered the value of $K$ uncertain. A proposed method of determining the amount of arch action in any case is to make a special study of the deformations in a cross-section at the center of each beam across an entire panel. In this study, deformations should be observed on the steel and at various elevations on the concrete so that the position of the neutral axis and of the center of gravity of tensile and compressive stresses respectively can be definitely located. By this means it should be possible to determine if the sum of the compressive stresses is in excess of that of the tensile
stresses. If so, the difference apparently must be the direct thrust due to arch action. The same study can be made, though not so satisfactorily, at the ends of the beams. This measurement of thrust will require observations on an extremely large number of gauge lines, and it would appear important to concentrate the greater part of the attention of the test on one panel. If the floor be considered to be made up of strip-beams of differential width capable of transmitting shear from strip to strip, it is not necessary, for perfect beam action, that the sum of the tensile and compressive stresses on a cross-section of any one strip be zero. However, beam action does require that the sum of the tensile and compressive stresses on the total cross-section of the beam should be zero, and for this reason it is important to extend the investigation sufficiently to determine if appreciable deformations are continued out into the panel adjacent to the loaded area.

**T-Beam Action.**—In the Wenalden and Turner-Carter tests measurements were taken to determine whether the compression in the floor slab in a direction parallel with the longitudinal axis of a beam grows appreciably less as the distance from the axis of the beam increases. This study was fairly successful. Figure 6,p.20 shows the results of the measurements.

**Bond Stresses.**—In four tests, namely, those of the Powers building, the Franks building, the Turner-Carter building and the Barr test panel, data has been taken which will give light on bond stresses developed. In most of them this consists of deformations obtained on a series of gauge lines along the length of a single bar. Thus the difference in stresses at
successive gauge lines divided by the product of the perimeter of the bar and the distance center to center of gauge lines, gives the average bond stress for that distance. This has shown rather high bond stresses at supports decreasing toward the center. Figure 4 shows these results. In the test of the Turner-Carter building, the information obtained is of a different nature. The measurement was designed to determine slip of the bar at the end as well as the average bond stress at that point. Figure 30 shows the arrangement of the bars for the purpose of measuring the bond stresses and slip of bars. The place selected for this study was a point where bars designed to resist negative bending moment extend slightly across the supporting girder between adjacent panels and lie side by side. Measurements of deformations were taken in each of the bars on gauge lines nearly opposite. Measurements were taken from a point of one gauge line to a point on the other bar and from points on each of the bars to a point in the concrete. The arrangement of gauge lines is shown in Figure 30. Gauge lines 312 and 314 were for the measurement of deformations in the bars respectively. Gauge line 312-14 was from a point on one bar to a point on the other bar and should show whether there was any movement of the one bar with respect to the other bar. 312e and 314e were measurements from points on the two bars respectively to points in the concrete, and should show any movement of the bars with respect to the concrete. This
feature of the test would have been of more value if $312c$ had been reversed. That is, the points on the steel bar should have been close to the end of the bar and the points in the concrete should have been opposite the other gage point of $312$. This would have shown slipping at the end of the bar where it is most likely to occur instead of at a point about 10 inches from the end of the bar where the bond stresses would naturally be much lower. The results of this test apparently showed that very little if any slipping of the bars in the concrete occurred.

**Diagonal Tension**.— As to a method of studying diagonal tension in structures, little can be said that will be general. An attempt was made to determine actual stresses in stirrups in the Turner-Carter building, but for some reason, possibly due to the presence of arch action, and partly to the fact that the stirrups sloped in the wrong direction to be effective, the stresses found in them were compressive instead of tensile. Figure 31 shows the position of gauge lines on stirrups in the Turner-Carter test. It may be seen then that stirrups at gauge lines 212 and 228 slope in the wrong direction. Even in laboratory investigations results from tests of beams reinforced with loose vertical stirrups have shown lack of uniformity and considerable inconsistency. Certainly no more can be expected from beams in a structure where the conditions of fabrication and of loading
are much less definite. It is possible that in beams where
stirrups are securely anchored to the tensile steel and have
the proper slope results which are of value may be obtained.

**Stresses in Columns.**—In the tests of the Franks
building and of the Turner-Carter building some investiga-
tion was made of stresses in columns. The former test was on
a portion of the top floor in a ten story building where col-
umns were small, and the column capitals were large, making
the floor construction stiff around the column and throwing
the most severe possible test upon the column. This test gave
positive results showing quite severe compression and consider-
able tension in the columns. The Turner-Carter building has
eight stories and the floor tested was the third where the col-
umns were heavy and the proportion of the test load to the
total load carried by these columns extremely small; hence re-
sults of any positive value could scarcely be expected and were
not obtained. It may be said that if a test is desired to show
comparative results on columns under different conditions of
loading, it should be designed much as was the Franks building
test. However, the measurements in the Turner-Carter test may
be of value in helping to define the lower limit of the field
in which live load column stresses are of importance.

Figures 32 to 35 inclusive show the arrangement of
gauge lines for the Wenalden building and Turner-Carter build-
ing. A study of them will illustrate some of the plans for
carrying out the lines of investigation described above.
Figure 32

Figure 33

Figure 35

Figure 34
Fluctuation of Stresses under Constant Load. - In most of the tests which have been made, observations have been taken to determine how much increase in stress has been caused by allowing the load to remain constant on the tested floor for a considerable length of time. The results have been rather erratic, in many cases indicating an increase in stress, while in others a decrease was shown. They have been apparently so unrelated that in most cases little could be made from the results. However, there seems to be some reason for thinking that instead of the results being in error the fluctuation in stresses actually exists, and according to some law. In the load deformation diagrams obtained from the test of the Turner-Carter building, considerable consistency was observed when only deformations were plotted which had been obtained immediately after completing the corresponding increment of load, while the deformations obtained after the load had stood for some hours often showed inconsistent changes. Previous to the test of the Barr test panel, it had been supposed that these inconsistent changes were merely errors in observation, although they were often so large that it seemed scarcely reasonable that such errors should be there. During this latter test, in which observations were taken on the same points by independent observers, a whole series of deformations obtained at 300 pounds per square foot on the gauge lines 105 to 115, when taken by observer No. 1 showed uniformly an excess of about 25 per cent over those obtained by observer No. 2 on the same points. The stresses measured by the two observers and the ratios of these stresses are plotted in Figure 36. The differences between the stresses plotted on the
two curves are so uniform that they can scarcely be considered accidental, for it seems hardly possible that a whole series of accidental errors of so great uniformity could enter unless it was due to a difference in the two instruments. Therefore, the instruments were calibrated and it was found that a difference existed between them of not more than one per cent. This could not account for the difference in stresses observed, and in order to further check the instruments against each other in actual operation a special test was devised. A 4-in. x 4-in. (nominal size) timber was supported on a 12-foot span and loaded with sacks of sand at about the third points. Measurements of deformation on the upper and lower surfaces at the center of

![Graph showing stress and ratio](image-url)
the span were taken independently by the two observers, and the results agreed almost identically with what should have been expected from the difference found in calibrating the instruments. This test, therefore, does not help to explain the variation in the stresses found in the building. The only explanation which could be given for the difference of 25 per cent in the stresses plotted in Figure 36 was that the values shown in curve b were observed about a half hour later than those shown in curve a. Since the values which observer No. 2 obtained were less rather than greater than those of No. 1, it was evidently not a case of fatigue under load, but was more in the nature of a recovery, and could be explained only by the assumption of a period of vibration. It can not be said that there is any other evidence which directly supports this theory. The most which can be said is that there has been in all the tests phenomena which are contradictory among themselves unless explained by some such theory. It would seem that an investigation of whether such a thing does exist would be very profitable.
The stage has been reached in the investigation of reinforced concrete where building tests may be expected to contribute information of great value to the designer and builder in reinforced concrete. The main feature of such tests should be the measurement of stresses but information as to the location and size of cracks will be of great value in checking the results if the examination for cracks is conducted with sufficient care and minuteness. There is need for increasing as much as possible the accuracy of deformation measurements, and experience in the use of the instrument is gradually accomplishing this. All the confirmatory evidence possible on the correctness of results should be obtained.

For a very slight additional cost, measurements of stresses in a building floor may be made at points of especial interest during the progress of the load test which is often required as a condition of acceptance.