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footing settlement were about equal to dead load moments and to wind load moments, but in the interior panel the moments due to settlement were from two to three times the dead load or wind load moments." If this is true for $1/4$ " settlements of the nature studied, even small settlements of $1/8$ " or $1/16$ " are worth considering.

A second case which was carefully studied by Walter Scholtz in 1935, is that of the upper ten stories of the classic Parcel and Maney bent, in which one of the interior columns was assumed to settle. Mr. Scholtz concludes that a settlement of $1/8$ " induces girder moments at the second floor adjacent to the settling column equal to one third of the total allowable moment for the girder.

Effects such as these are not to be lightly passed over by designing engineers. Although the labor involved in analyzing structures for footing movements is arduous, and perhaps not commercially possible at the present time, the recognition by engineers of the magnitude of the induced stresses is important. If engineers, architects, and owners can be made to realize how much information can be obtained from modern subsurface investigations and tests, another step in the direction of better structural design will have been taken.

No. F-5

SETTLEMENT OF EXHIBITS BUILDINGS AT THE TEXAS CENTENNIAL CENTRAL EXPOSITION
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During 1936 the State of Texas is celebrating the one hundredth anniversary of its independence. The major part of this celebration will be a world fair held in Dallas called the Texas Centennial Central Exposition.

The site of this exposition is a section of old river terrace formerly used as the State Fair grounds. This terrace consists of a layer of clay approximately twenty-five feet thick over a stratum of sand. Boring shows the sand to be over 40 feet thick and geological maps indicate that it is probably 60 feet thick and underlaid by a medium soft limestone known as the Austin Chalk. The water table is over 30 feet below the ground level and well below the clay. Fig. 1 gives the log of test borings.

For economic reasons, it was decided to place the foundations of the semi-permanent exhibits buildings on the brown or yellow clay. Physical tests of the clay are given in Table I. It will be noted that this clay possesses large volume changes when disturbed and that in the undisturbed condition only about one-half of the voids are filled with water. (Tests made by U. S. Bureau of Public Roads Methods.)

T A B L E I

Physical Characteristics of Soil from the Site of the
Texas Centennial Central Exposition

Lower Liquid Limit	69.49
Lower Plastic Limit	20.45
Plasticity Index	49.04
Shrinkage Limit	5.3
Shrinkage Ratio	2.065
Volume Change	141.45
Lineal Shrinkage	25.3
Absolute Specific Gravity	2.7007
Voids in Undisturbed Sample	38.48%
Initial Moisture Content of Undisturbed Sample	19.14%
Voids, Filled with Air	9.79%
Initial Void Ratio	0.6255
Voids in Sample after consolidation test	35.85%
Moisture content after consolidation test	20.25%
Voids Filled with air after Consolidation test	1.25%

Note: Total voids and voids filled with air are given in percent of voids in total volume. Moisture contents are given in weight of contained water divided by the dry weight.

The black top soil appears to be a disintegration of the yellow and brown clay. State Fair buildings placed on this black soil were virtually wrecked by its movement. It is believed that the Auditorium was built on the yellow clay but the information is indefinite. This structure is almost 15 years old and in very good condition.

In planning the foundations, a test pit was dug (See Fig. 2) and a field loading test made. Fig. 3 gives the results of this test. A maximum settlement of slightly more than one-half inch was obtained for a load of 3000 pounds per square foot.

A cubic foot undisturbed sample was cut from the bottom of another test hole, coated with paraffine, and sent to The University of Texas, Bureau of Engineering Research. A sample, $3-3/4$ inches in diameter and 3.3cm. high, was carefully cut from the center of this specimen and tested in the Terzaghi Consolidometer. The consolidation test and absolute specific gravity determination (vacuum method) were made according to "Laboratory Procedure in Testing Soils and Sediment" of the U. S. Waterways Experiment

TEXAS BUILDING FOUNDATION TEST
HOLE No. 26
LOCATION O-62, 1890

ELEVATIONS OF CHANGES IN SOIL
IN TEST PIT 70 FT. SO. OF POULTRY BUILDING

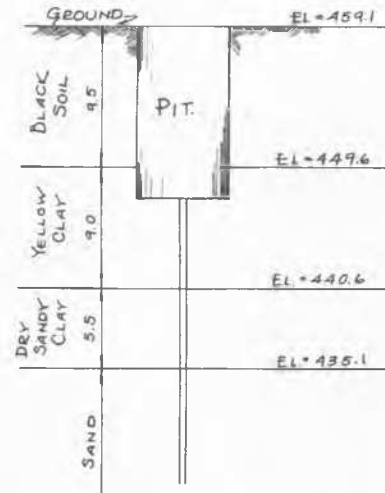
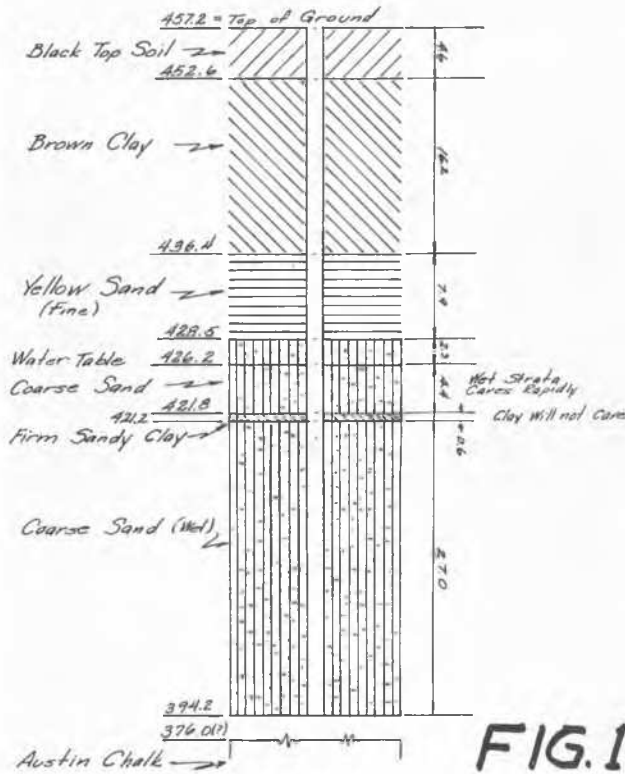


FIG. 2

FIG. 1

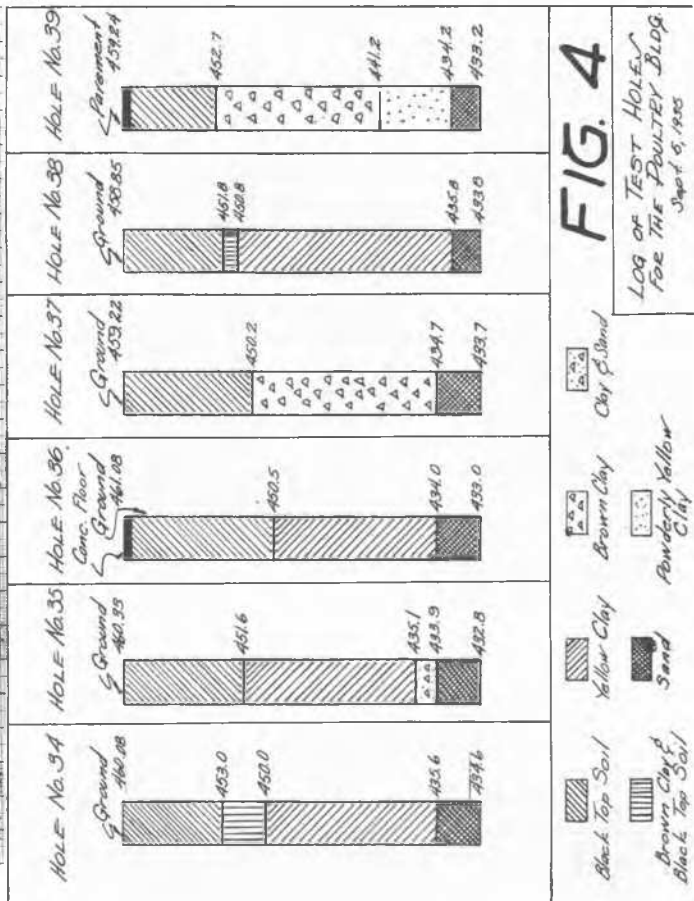
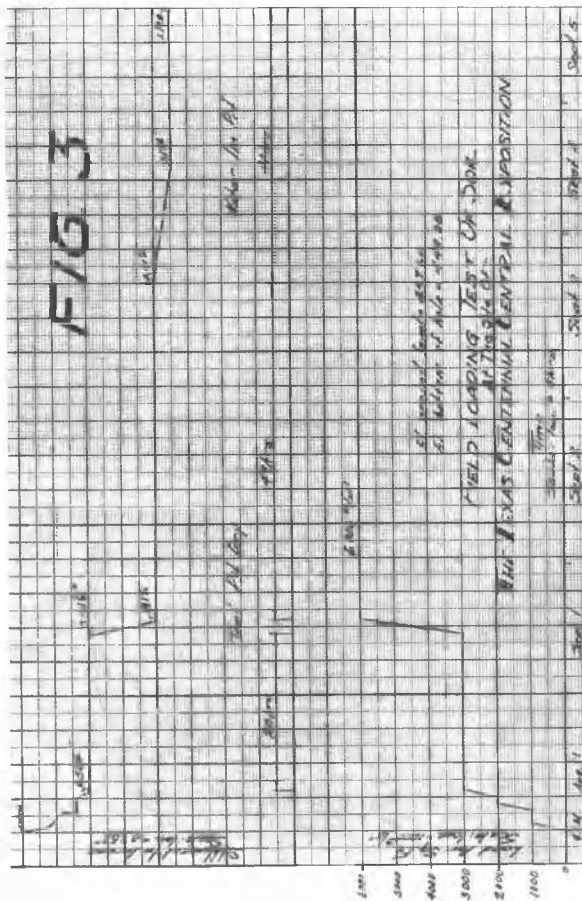
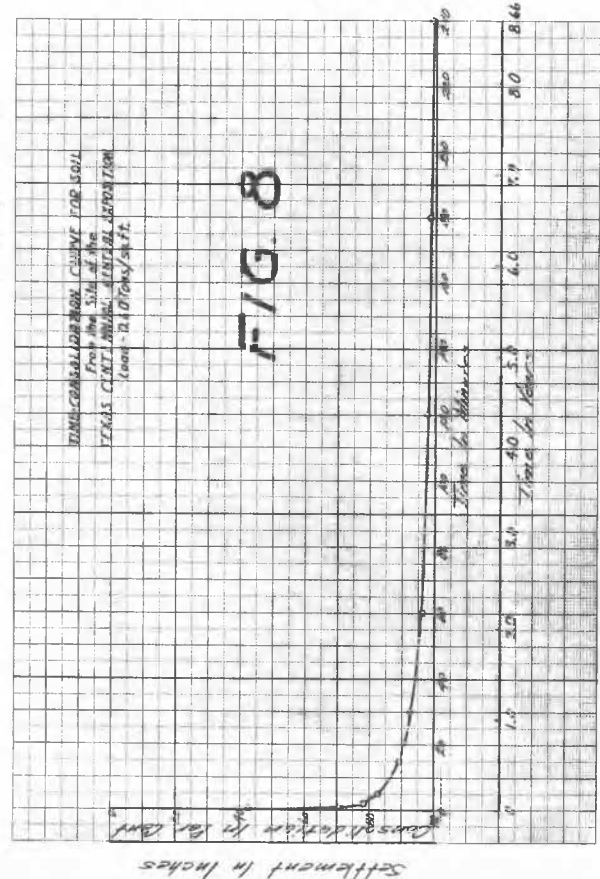
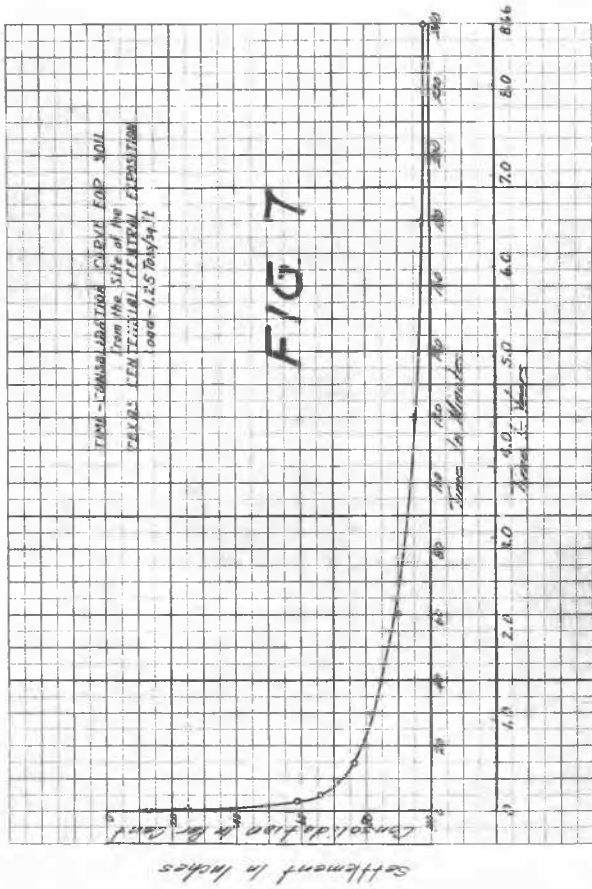
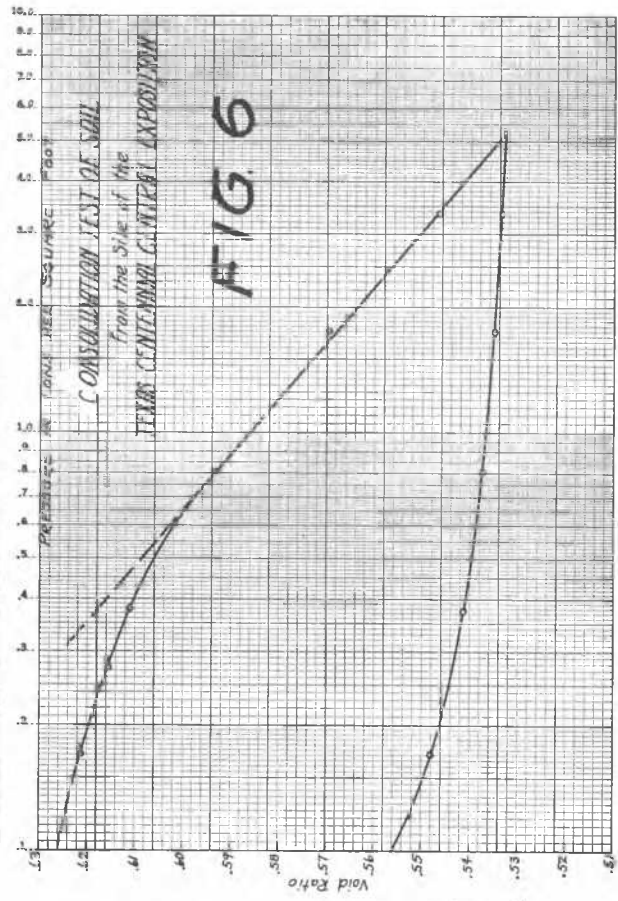
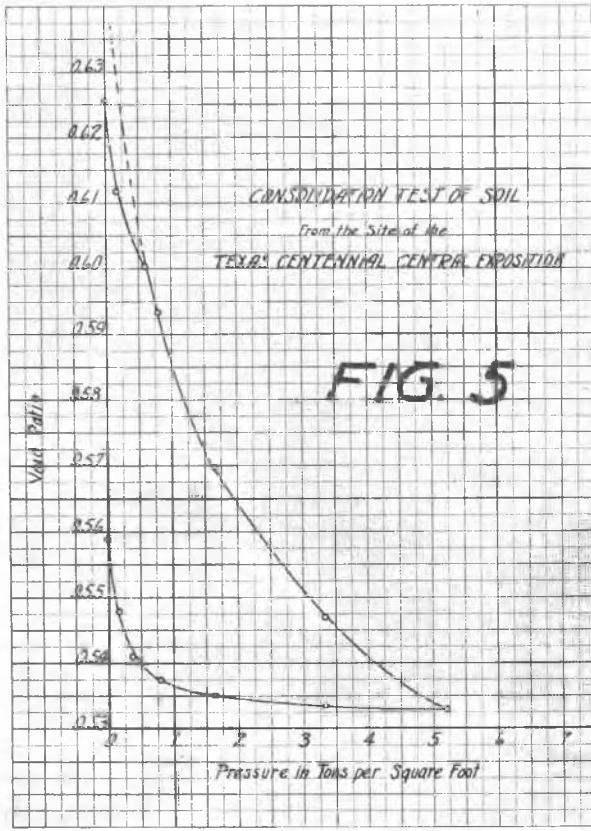
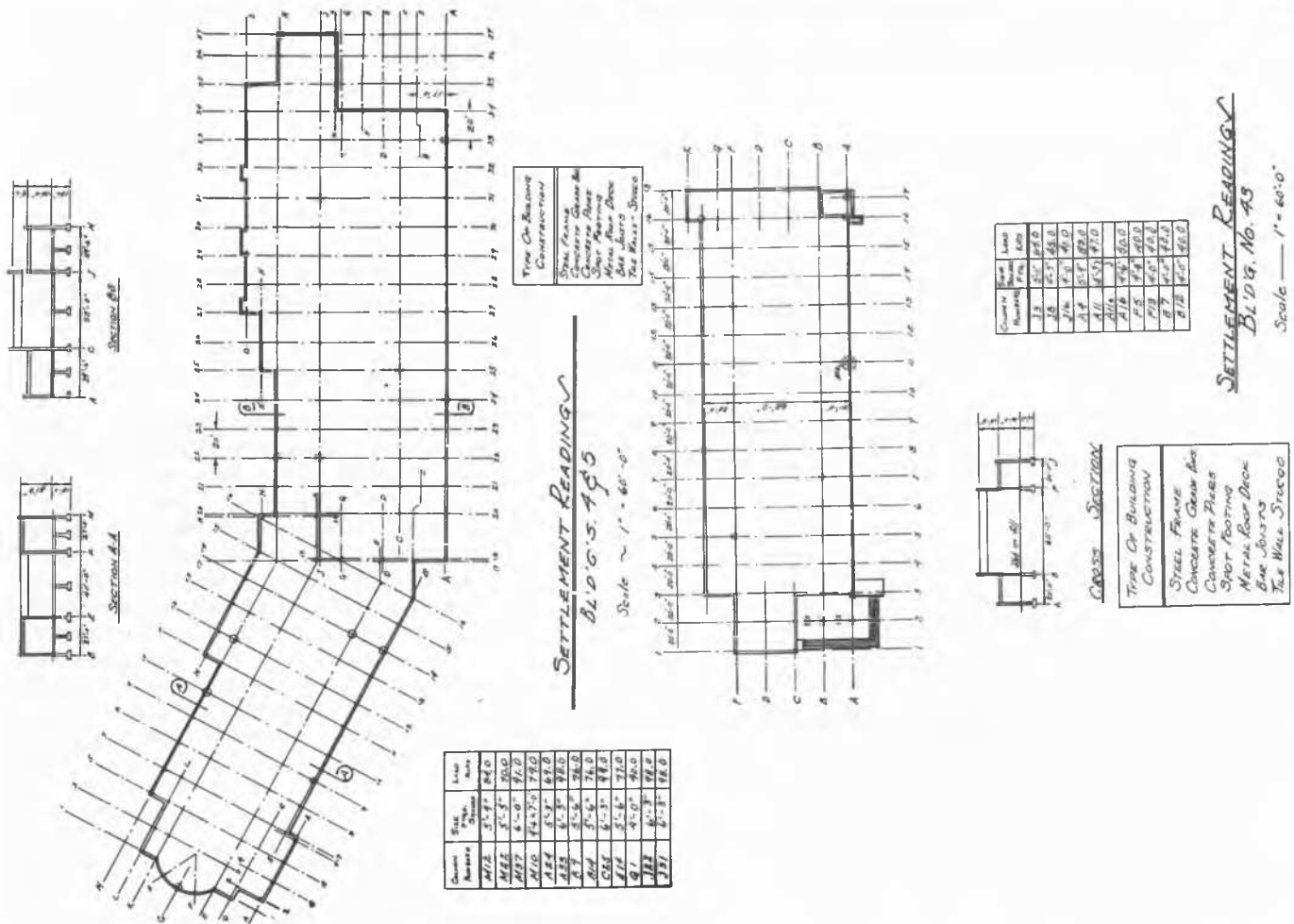


FIG. 4

LOG OF TEST HOLES
FOR THE POULTRY BLDG.
Sept. 5, 1905





Station. Fig. 5, 6, 7 and 8 give results of the consolidation test.

Following these tests the engineers decided to place the exhibits buildings on spot-footings going well down into the yellow or brown clay and use an allowable dead load of 1.25 tons per square foot. The exhibits buildings are one-story structures of the following type: steel frame; concrete grade beams; concrete piers; spot footings; metal roof deck; bar joists; tile walls-stucco. Although the exhibits buildings are of the semi-permanent type, they will not be destroyed after the Exposition but will remain as a part of the State Fair group.

Since this soil has given considerable trouble as a foundation material, and because of the wide difference in estimated settlements between the field loading and consolidation test actual settlement observations have been started on three of the buildings. However, construction on only two of them had progressed far enough at the time of the last reading to give settlements. Settlements have been observed on Buildings 4 and 5 (Foods Group) which has an area of 33,528 square feet, and Building 43 (Poultry) which has an area of 27,203 square feet. Fig. 4 gives the log of test holes under these buildings.

The average depth of the clay under these structures is 25 feet. The footings of buildings 4 and 5 are 13 feet deep leaving a 12 foot layer of clay underneath. The footings of building 43 are only 10 feet deep thus leaving a layer of clay 15 feet underneath.

Three permanent bench marks were constructed in the stadium which has been built for about 10 years, therefore has had ample time to settle. It is also near the structures under observation and still away from the actual construction. The bench marks consist of two inch pipe set in mortar deep in the sand and well below the water table. The two inch pipe is cased-off from the clay and upper sand by a four inch pipe.

Settlement observations are made by precise levels reading to one-thousandth of a foot. Foresights and backsights are measured to keep the distances equal. The first readings were taken when the concrete piers were completed, this is the zero settlement. Subsequent readings were taken after the steel was erected, after the masonry was completed and after the roof was completed. Observations are being made on 13 columns of building 4 and 5, and 11 columns of building 43.

In calculating the settlements from the consolidation test, it was felt that to consider the total load effective for the entire depth of the clay would give estimated settlements that would be too large. Results of these calculations are shown in Table II, "Estimated Total Settlement, Entire Pressure."

Typical columns were selected and pressure distributions calculated by the method proposed by Nathan M. Newmark in "Simplified Computations of Vertical Pressures in Elastic Foundations," Circular No. 24, Engineering Experiment Station, University of Illinois. The stratum of clay was divided into three-foot layers and the average pressure calculated. For the first three-foot layer the entire load of 1.25

tons per square foot was considered effective but nothing was added for pressures from adjoining columns. In all the layers below the first, pressure from adjoining columns was added. The weighted average of pressure at the center, edge and corners was purely an estimate. From these effective

average pressures and the consolidation curve, settlements were estimated for each three-foot layer. The total of these estimates for each column is given in Table II, "Estimated Total Settlement, Pressure Distributed."

From the time-consolidation curve, Fig. 7, the percent of estimated settlement was determined for a period of time equal to that of the actual settlement observations. These values are given in Table II along with the actual settlements of the columns.

While the estimated settlements from the distributed pressure and the actual settlement agree remarkably well for these first readings it is questionable whether or not future observations will check as well. In the first place the "time" in the actual settlement observation is not the time the column has carried its entire load but the time from the initial reading. Since the entire load has been on the column only a fraction of this period one might expect that ultimately the actual settlements will greatly exceed the ones estimated by distributed pressure. However, the footings carried some load during this entire period and under lighter loads the rate of settlement was greater than under the 1.25 tons per sq. ft. load. From Fig. 8, we see that under a load of 0.60 tons per sq. ft., there was a settlement of 71% in 1 minute on the sample or 13 days on the structure. Thus the settlement would be more nearly complete for the light loads and tend to offset the difference in time. Data is not available to calculate the settlement for these lighter loads.

Table III gives the maximum, minimum and average settlements for the various types of columns of the buildings. At this date there have not been sufficient observations to plot time-settlement curves for the structures.

Table Number 2		ESTIMATED AND ACTUAL SETTLEMENTS OF TYPICAL COLUMNS OF THE TEXAS CENTENNIAL CENTRAL EXPOSITION BUILDINGS									
Story	Column No.	Size of Footing	Location	Entire Pressure	Estimated Settlement	Actual Settlement	Time	Time	Time	% of Total Amount	Estimated Settlement from the Time-Consolidation Curve
4-5	F-35	6'-3" x 6'-3"	Wid. near Corner	2.78 m.	1.44 m.	0.878 in.	41 days	40 days	40	59.0	0.837 in.
"	F-28	"	interior	"	1.40 m.	0.578 in.	43	43	43	59.0	0.826 in.
"	F-22	3'-0" x 3'-0"	Wid.	"	1.33 m.	0.740 in.	42	42	42	59.0	0.787 in.
4-3	F-13	4'-4" x 4'-0"	interior	3.82 m.	1.58 m.	0.674 in.	20	20	20	50.0	0.690 in.
"	F-16	"	corner	"	1.44 m.	0.960 in.	33	33	33	62.0	0.813 in.

* From Initial Reading

T A B L E III

Actual Settlement Observations on Exhibits Buildings at the
Texas Centennial Central Exposition

Building	Type of Column	Maximum	Minimum	Average
4 and 5	Interior	0.624"	0.528"	0.585"
"	Wall	0.828"	0.432"	0.613"
"	Corner*	0.600"	0.600"	0.600"
43	Interior	0.624"	0.588"	0.606"
43	Wall	0.792"	0.276"	0.475"
43	Corner	0.960"†	0.372"	0.588"

* Only one column.

† This column is at a corner where an "L" projects from the structure. Therefore, the structure covers 270° around the column instead of 90° as in the case of the usual corner.

Since part of the voids in this clay are filled with air we can expect a much greater rate of settlement during the earlier loading periods because the air can move through the soil at a greater speed than water. Curves in Fig. 7 and 8 show this to be true. It is also interesting to note that after the consolidation test was complete there were still some voids in the soil filled with air although water was available through the lower porous disc, during the entire test and under a head of approximately 3.3cm.

The following conclusions may be drawn from these tests:

1. The field loading test on this clay gave estimated settlements lower than the actual observed settlements.
2. Pressure distributions under the footings should be calculated before estimating the amount of settlement.
3. The estimated settlement calculated from the laboratory consolidation curve and distributed pressures, checks very closely to the observed settlements. However, one may well question whether or not future observations will check as well.
4. We cannot consider that the voids in clay are entirely filled with water in all cases.
5. Although water was available during the entire consolidation and rebound test, the clay did not take up sufficient moisture to fill the voids.

No. F-4

ABSTRACT

SETTLEMENT RECORDS OF THE MISSISSIPPI RIVER BRIDGE AT NEW ORLEANS

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Prior to the erection of the Mississippi River Bridge above New Orleans two series of borings were made. The first borings were made in 1926 and used for the tentative selection of foundation types, construction methods and landing elevations. The second series was conducted in 1933 just before construction was begun. The soil stratification as determined by the borings, the location of the borings, and the profile of the bridge and the main piers are shown in Fig. 1. Undisturbed samples were obtained by means of a sampling tube illustrated in Fig. 2. Other borings than those shown were made for a distance of several thousand feet along the approaches to the bridge, but this paper confines itself to a study of the main piers.

Using the undisturbed samples obtained in the 1933 boring program estimates were made of the settlements of the nine main piers. The results of the estimates were forwarded to the engineers in charge of the work three months before the construction of the piers was begun.

Observations of settlement were taken on all the piers from the time of sealing the caissons. These observations are being continued and the records for the first six months of 1936 will be appended to this paper as they become available. A comparison between the estimated and observed settlements is shown in Table II.

The settlement estimates led to two practical results:

1. The truss bearing plates were redesigned to allow jacking the trusses back to position and the bridge seats were finished at higher elevations than called for on the plans;
2. It was agreed to land the caisson for Pier A 15 feet above the plan elevation. It was thought that this would effect a saving of over \$10,000, several times the cost of the actual settlement analysis. This caisson over-ran the new proposed landing elevation during construction, however, and was finally brought to rest at the plan elevation.

Adaptability of Conditions to Soil Studies. As shown in Fig. 1 the soil stratification lends itself rather readily to consolidation analysis. The various strata are reasonably homogeneous throughout their respective depths, and obvious drainage course are provided for the consolidation of the clay