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ELECTRICAL RESISTANCE STRAIN GAUGES FOR DETERMINING THE TRANSFER OF LOAD FROM DRIVEN PILING TO SOIL

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SUMMARY

This paper discusses the results of recent full-scale experiments with electrical resistance strain gauges of two types to determine the transfer of load from driven piling to the supporting soil on two separate projects. For one project, the strain gauge measurements were made for only a relatively short period of time in conjunction with the performance of static load tests on three piles; for the other project, strain gauges were installed in one pile of a large group for the purpose of obtaining long-time measurements.

Because of a number of defects in the apparatus and techniques which could be developed in the limited time available, the results of the tests performed in conjunction with the static load tests were qualitative rather than quantitative. However, sufficient information was obtained to determine the probable behavior of the piling and also to suggest improvements in apparatus and technique so as to assure more complete results in subsequent tests.

Since the second project is still under construction and only a fraction of the ultimate foundation load has been applied, no significant results are now available. It is hoped that some data may be obtained in time to be presented at the Conference.

INTRODUCTION.

The evaluation of the manner in which a pile transfers applied structural loads to the supporting soil mass has long been a perplexing and difficult problem. While a number of investigators have attempted solutions by means of models, such studies are made under extremely artificial conditions and are subject to undertainties when the data are extrapolated to conform with actual conditions. To secure information regarding actual conditions, electrical resistance strain gauges were employed for measuring the transfer of load from driven piling to the soil mass on two recent projects.

The first project, hereinafter termend Project A, is an unusually large industrial development x), which is to be constructed on the outskirts of the City of Los Angeles in Los Angeles County, California. The development will contain structures having individual column loads of 2,000,000 pounds and double column loads of 4,000,000 pounds, with column spacings varying from 14 to 36 feet. In addition to six buildings, the completed project will contain ten reinforced concrete storage bins, each 18 feet in inside diameter and 130 feet in height. The bins will impose real, direct loads of approcimately 6,000 pounds per square foot over an area approximately 40 by 100 feet in plan. A comprehensive foundation investigation of the site of Project A disclosed that the site is immediately underlain by 20 to 30 feet of geologically recent alluvial deposits of the Los Angeles River; underlying the recent alluvium are firmer, less compressible soils of Upper Pleistocene age. The foundation investigation indicated that driven piles would be the most suitable foundation type for the support of proposed structures. The supporting capacities of several types of driven piling were predetermined from the results of the explorations and tests by a method described in U.S. Patent No. 2,296,466 1) It was felt advisable to perform field tests to determine both the depths to which the piling could be installed and to check the computed capacities. Since the piling will eventually obtain their entire support from the less compressible underlying Pleistocene deposits, some method was desired by which the relative capacities of both the more compressible recent alluvium and the underlying Pleistocene deposits could be evaluated during the relatively short period of the load tests. It was decided that such measurements could be made only with electrical resistance strain gauges, and the apparatus and procedures described in the following section were developed for that purpose.

Project B is concerned with a 15-story steel frame structure with a full basement which The Pacific Telephone and Telegraph Company is constructing in Oakland, California. The structure will be approximately 125 by 150 feet in plan and will impose real loads varying from approximately 5,000 to 14,000 pounds per square foot over the area of its base. Excavations for a basement, boiler room, and elevator pit will remove from 18 to 29 feet of the surface material and will reduce the effective soil pressures at the bottom of the foundation to values from 1,500 to 9,500 pounds per square foot. Based on the results of a foundation investigation of the site, the structural engineer selected a mat foundation for the support of the structure.

The major portion of this mat will be supported directly on the soil, but in the area of greatest load, approximately 250 steel pipe piles 50 feet in length will be employed to reduce the settlements which would otherwise occur. Purely as a research project, electrical resistance strain gauges of a type different than was used on Project A were installed in a centrally located pile of the pile group to provide data concerning the transfer of load from the pile to the soil over a period of years. The apparatus and procedures developed for these measurements are described in the following section.

APPARATUS AND EXPERIMENTAL PROCEDURE.

PROJECT A:

The apparatus developed for Project A was built around a type of electrical resistance strain gauge manufactured by the Baldwin Southwark Division of The Baldwin Locomotive Works and known as the SR-4 gauge; the particular gauge used in the apparatus is called Type A1 and is illustrated by Figure 1. Essentially, the strain gauge determines small linear chan-

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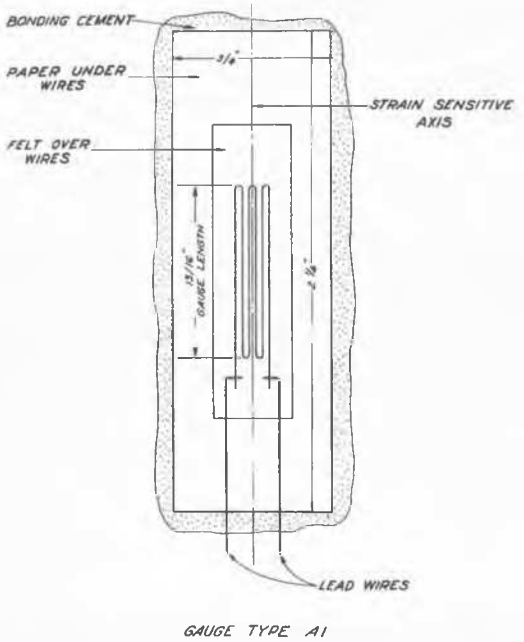
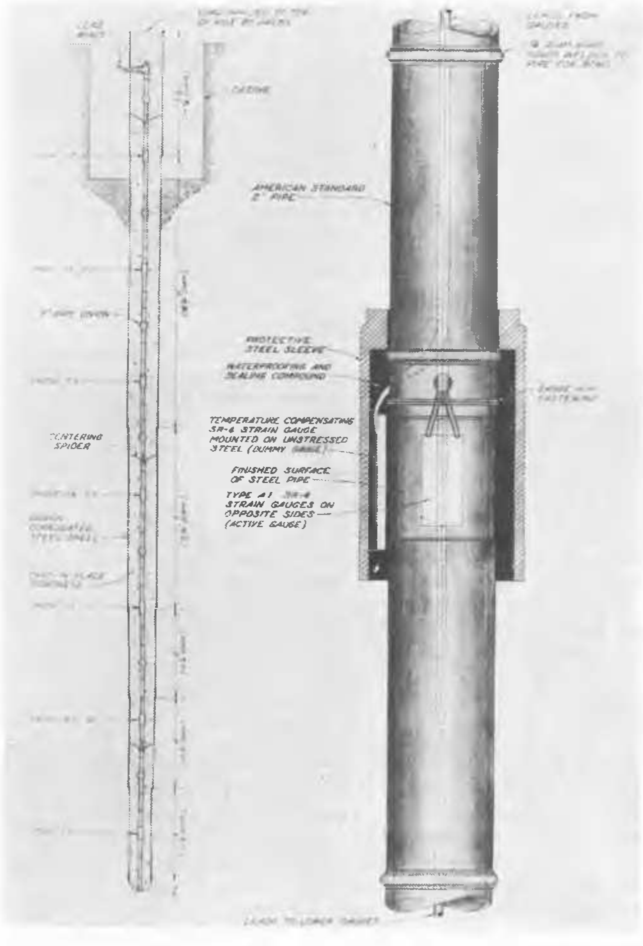
x) For business reasons, we have been requested not to divulge the exact nature of the project or the name of the owner.



SR-4 gauge.
FIG. 1



Typical installation and detail of strain gauge unit.
FIG. 2

ges of dimensions of the surface to which it is attached by measuring the proportional change of electrical resistance of the gauge produced by the strain; the strain measurements can, by appropriate calculations, be readily converted to stress. The gauge consists of a rectangular grid of wire about 0.001 inch in diameter, supported and held in place by a film of elastic cement which may be strengthened with a paper backing. This structure is in turn cemented to the surface on which strain is to be measured. Electrical connections to the strain sensitive wires are made through a pair of heavier lead wires, which must be anchored securely so that movements of the connection wires do not reach the strain sensitive grid.

Since the three piles to be tested were cast-in-place concrete piles of the type supplied by the Raymond Concrete Pile Company(consisting of a corrugated steel shell driven with a steel core, the shell being filled with concrete after driving), some means had to be devised for satisfactorily mounting the strain gauges within the pile. This was done by providing a two-inch-diameter steel pipe which would run up the center of the pile for almost its full length. To provide flexibility in handling, the pipe was made up in five-foot sections. A finished surface was machined in the center of each pipe section for the attachment of the strain gauges; holes were drilled in the pipe at the center so that the lead wires from the gauges could run up the inside of the pipe to the ground surface. Two active strain gauges, those gauges which are attached directly to the pipe, were cemented on opposite of each pipe section, to compensate for any bending which might occur. In addition to the active gauges, one "dummy" gauge was installed for every three active pairs. The function of the "dummy" gauge, which was mounted on a separate piece of steel which would not be stressed under load, was to compensate for any changes in length of the pipe due to temperature changes. To prevent the gauges from being damaged by the placing of concrete in the pile, a protective steel sleeve was provided to cover the gauges after they had been mounted on the pipe. To develop the full bond between the pipe and the concrete, five ¼-inch-diameter rings were welded at intervals around the circumference of each five-foot pipe length. For waterproofing, it was intended that each gauge would first be heavily coated with vaseline and that the space between the pipe and the protective steel sleeve would then be filled with melted beeswax. Unfortunately, the use of the vaseline was neglected for two of the assembled units,so that the gauges in only one of the piles were protected as planned. All pipe joints were treated with waterproofing compound to seal the joints.

By means of pipe unions, as many of the five-foot sections could be assembled as were required to fit the length of the pile,giving a strain gauge unit at the center of each section. The assembled pipe unit was then lowered into the pile shell prior to the placing of concrete; the pipe was kept in the center of the shell by centering spiders welded to three or four of the pipe sections. A sketch of a typical assembly installed within a pile and a detail of the strain gauge portion of a typical pipe unit are shown by Figure 2.
Photographs of a unit being assembled and installed within a pile shell are presented in Figure 3 and Figure 4.

Measurements of strain as determined by variations in resistance of the gauges were made with a portable strain indicator manufactured by the Baldwin Southwark Division

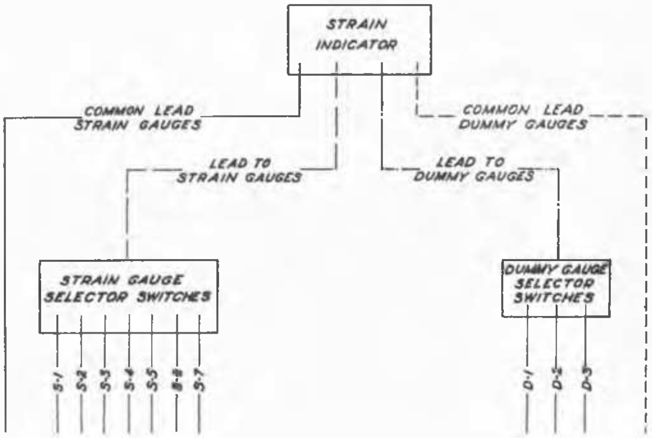
Assembling 5-foot sections of pipe preparatory to installing in pile.

FIG. 3

Installing assembled unit in pile.

FIG. 4

of the Baldwin Locomotive Works especially for use with SR-4 gauges. This indicator reads directly in micro-inches of strain and consists of a manually balanced Wheatstone Bridge with an electronic null balance indicating system. All leads were connected to a series of selector switches which enabled the instant selection of any gauge for observation. A simplified sketch of the wiring diagram is shown by Figure 5.



Simplified wiring diagram.

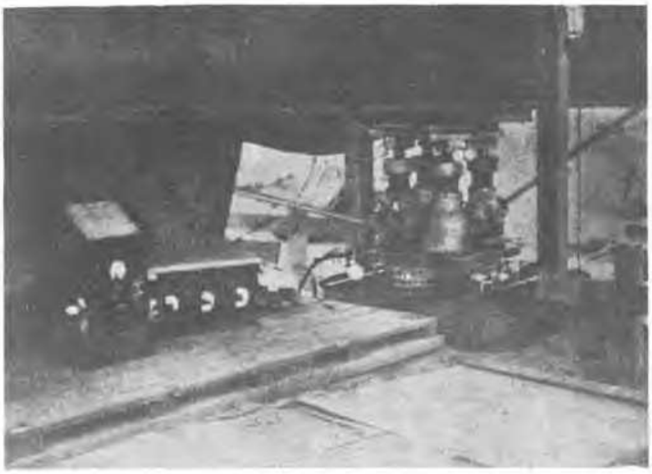
FIG. 5

Assembling 200-ton-capacity reaction frame.

FIG. 6

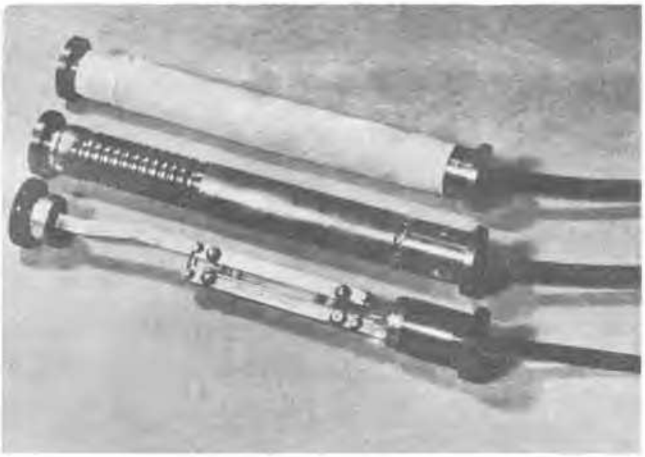
The test piles were driven within excavations carried to the elevation of future excavations so that the test conditions would represent the construction conditions as nearly as possible. The test loads were applied to the pile in increments by means of jacks, and the applied loads were measured with calibrated beam gauges. Since the concrete piles were to be tested to a load of 200 tons, the use of anchor piles and steel beams to develop the required reaction was found to be both more economical and more advantageous then the conventional dead weight reaction. Photographs of a typical reaction frame and of the loading and gauging mechanism are shown by Figure 6 and Figure 7. Several rather unique methods of measuring the deflection of the piles were developed, but a discussion of that subjeet is beyond the scope of this paper.

The use of jacks and reaction frames permitted the load to be applied and released as desired and enabled the complete and accurate determination of the load-settlement characteristics of each pile tested. The test load was generally applied in increments of 20 tons, and each increment was maintained constant for a period sufficient to assure that the deflection of the pile under the applied load had substantially ceased-- this condition was assumed to exist when the movement of the pile was less than 0.001 of an inch per hour. At several times during the progress of each



Loading and testing mechanism during test. Strain indicator on left.

FIG. 7



Carlson strain gauge. (Photo furnished by Mr. Carlson)

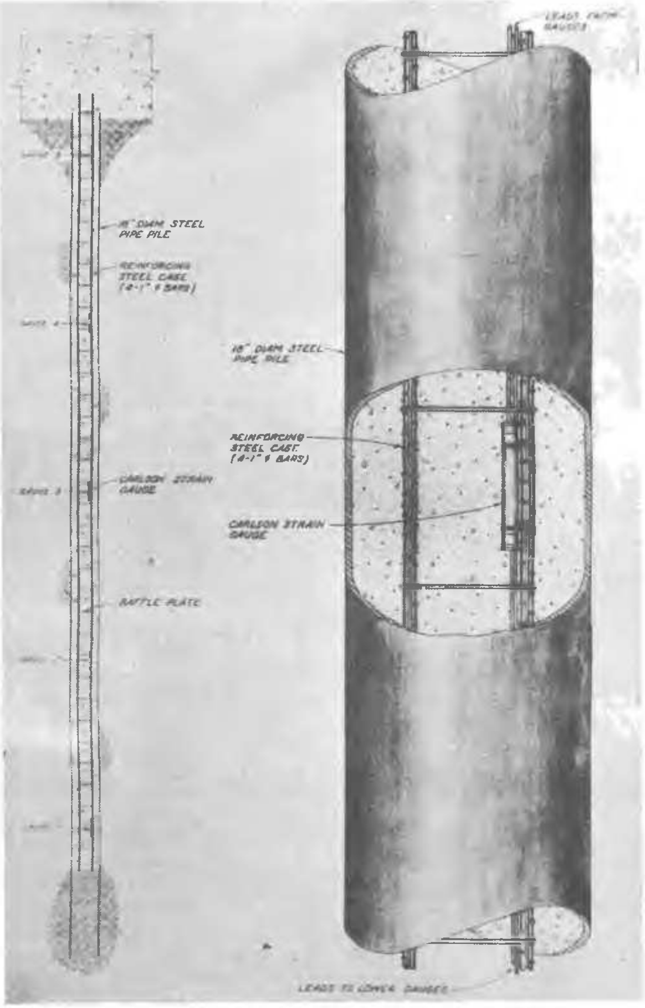
FIG. 8

test, the test load was released and reapplied in increments to measure the "rebound" of the pile. These rebounds assisted in determining when the yield point of the test had occurred. All of the tests were under continuous supervision for 24 hours a day.

Observations of the strain gauges were made immediately after the application of a load increment and immediately prior to a change in the load. In addition to the two terminal values, several readings of the strain gauges were taken during the period each load was maintained. The values of strain so determined were converted to stress in the steel pipe to which the gauges were attached; the moduli of elasticity of the steel and of the concrete, which had been determined from physical tests, were then used to compute the stress in the concrete at the elevation of each strain gauge. These values of stress enabled the determination of the total load carried by the piling at the elevation of each strain gauge.

PROJECT B:

To compare the performance of different types of electrical resistance strain gauges, a gauge of the type developed by Mr. Roy



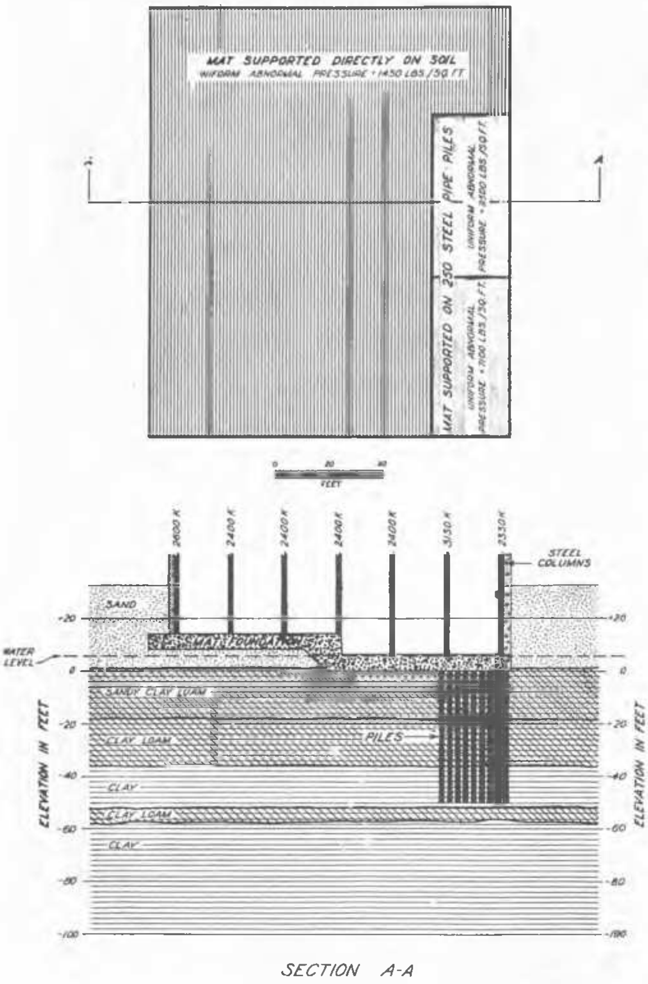
Installation and detail of strain gauge unit.

FIG. 9

Carlson of Berkeley, California, was selected for use on Project B. The Carlson strain gauge, the details of which are shown by Figure 8, has been described by Mr. Carlson as follows:

"The elastic-wire coils are threaded on small porcelain spools that are rigidly secured to steel bars connected one to each end of the meter. One coil is immediately within the other but not touching it. This arrangement insures that the coils be at equal temperature, which is important because a difference of temperature of one-fortieth a degree produces a sensible error. The mounting of the coils is such that the tension in the outer coils is decreased as the meter is compressed, while the tension in the inner coil is increased. Due to linear relationship between resistance and tension, the resistance ratio of the two coils is changed in direct proportion to the change in gauge length. The coils are connected to a portable testing set, forming a Wheatstone Bridge Circuit. Direct readings are made of the ratio of the resistances of the two coils. The ratio is not affected by temperature change even though the resistances themselves are affected".

Five of the Carlson gauges were attached at intervals of ten feet to a 50-foot cage of



Loading plan and section for project B.

FIG.10

reinforcing steel which was to be lowered inside the 18-inch diameter steel pipe pile The steel cage consisted of four 1-inch-round bars and was approximately ten inches on a side. A sketch illustrating the assembled unit installed within the pile and a detail of the strain gauge attachment is shown by Figure 9. The wires from each gauge were brought to the surface independently of the other gauges. To prevent damage to the gauges as concrete was deposited in the pile, a triangular steel plate was welded in a corner of the cage approximately two feet above each gauge.

The resistance readings of the Carlson gauges are made with a portable Wheatstone Bridge. The readings obtained are converted to strain, which is used to compute the stress in the concrete and in the steel of the reinforcing cage and the shell of the pile. From these data, the transfer of load from the piles to the soil may be determined.

Figure 10 presents the plan of the proposed building and a typical section through the structure. The abnormal loads which will be imposed by the several portions of the mat foundation have been entered on the plan. The pile in which the Carlson gauges were installed is the center pile of those shown on the section.

TEST RESULTS.

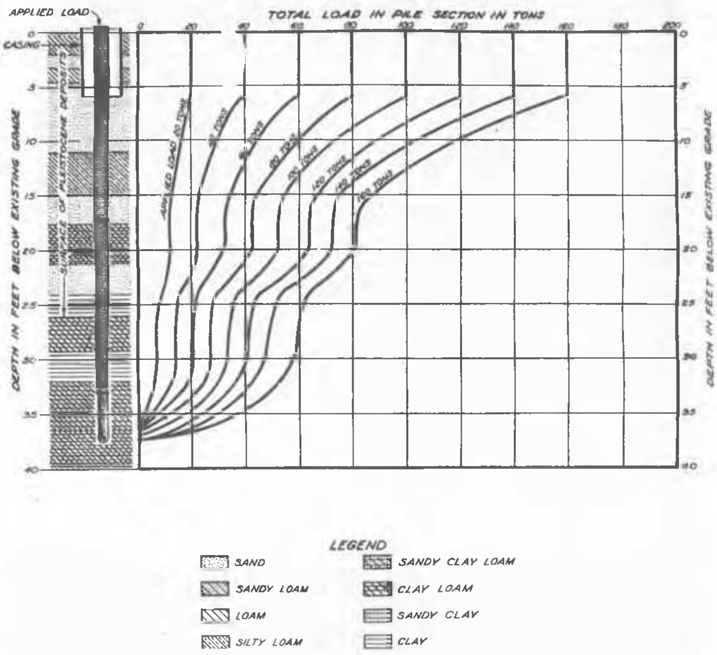
PROJECT A:

The results of the strain gauge readings for the two piles for which the gauges were not coated with vaseline were too erratic to be of value --studies made after completion of the tests indicated that the beeswax alone had not been effective in waterproofing the gauges. While the data for the third pile were consistent, the results obtained were of a qualitative rather than a quantitative nature. Since the uppermost gauge was located above the elevation of the soil surface, the load computed from readings of the uppermost gauge should have checked the load actually applied to the pile. However, it was found that the computed load was nearly three times the applied load. No explanation for this condition has been developed; an error of possibly as much as 100 per cent could be ascribed to lack of agreement between the modulus of elasticity of the concrete as placed and the modulus of the concrete in the test cylinders, but it seems improbable that the characteristics of the concrete could be sufficiently in error to account for the threefold difference observed.

In view of the difference between the computed and applied load, it was necessary to correct the computed load for each gauge; this was done by multiplying all of the values by the ratio of the applied load to the computed load at the uppermost strain gauge.

The values of load so obtained correlate reasonably well with the anticipated load distribution. Curves illustrating the variation in load within the pile for various values of applied load are shown by Figure 11. The soil section presented on the sketch is for a location approximately 15 feet from the test pile; because of the variations in the soils beneath the site, slight differences in the soil conditions at the location of the test pile can easily be imagined. With this in mind, the curves describing the load in the pile can be fairly well correlated with soil type.

From the curves of Figure 11, it may be seen that the recent alluvial soils overlying



Results of test at project A.

FIG.11

the Pleistocene deposits are carrying the major portion of the load from the pile. It is believed that a gradual transfer of load from upper portion of the pile to that portion embedded in the Pleistocene deposits will take place; this effect was not observable in the short period to which the test was necessarily limited since the strain gauge readings were not sufficiently accurate to detect the short-time changes in the load distribution.

PROJECT B:

While insufficient structural loads have been applied as yet to permit definite conclusions about the transfer of load or the behavior of the Carlson-type strain gauges, the consistency of the early readings is very encouraging. The self-contained nature, simplicity of installation, and waterproof features of the Carlson gauge are all factors in favor of obtaining satisfactory results. If sufficient data are available in time, the present paper will be supplemented with factual information.

CONCLUSIONS.

Although the results of the series of tests on Project A left much to be desired,the use of electrical resistance strain gauges appears to be entirely feasible for determining the transfer of load from driven piling to the supporting soil. Not enough information has yet been obtained to enable a selection between the SR-4 gauge and the Carlson gauge. However, it is evident that the completely successful use of the SR-4 gauge will require considerable thought and planning to achieve a satisfactory method of installing the gauges and making the measurements.

In order that subsequent investigations may profit from the experiences obtained from the tests on Project A, the following suggestions regarding apparatus and test procedure are offered.

(1) Problaby the most important consideration is that the apparatus should be thoroughly waterproof, since any infiltration of moisture, or even any condensation, may mounted on the inside of the pipe would reduce the difficulties of waterproofing.

(2) No soldering flux or acid core solder should be used in the electrical connections because of the electrolytic action that is set up

(3) All connecting wires should be of solid wire to avoid possible variations in resistance due to broken strands.

(4) It appears that "dummy" gauges are not necessary and may even be undesirable for tests of this type. After the concrete has set and temperature changes. The use of thermocouples is suggested to detect any temperature variations that might occur; the gauge readings could then be corrected, if necessary, from the temperature measurements.

(5) If used, selector switches should be of the best quality on order to avoid variations in resistance of the switches.

(6) Although the portable SR-4 Strain Indicator used in the tests functioned satisfactorily, a simple direct current Wheatstone Bridge is believed to be less subject to error and also permits the conditions of the gauges to be checked.

ACKNOWLEDGEMENT.

The cooperation and support offered by the following are gratefully acknowledged:
Harley, Ellington and Day, Inc. Architects and Engineers, Detroit, Michigan, who were the designers of Project A;
Raymond Concrete Pile Co., Los Angeles, California, who drove the test piles at Project A;
Carl Thiele, Electrical Engineer, Los Angeles, California, who reviewed the strain gauge instrumentation and installation at Project A;
The Pacific Telephone and Telegraph Company, San Francisco, California, the owners of Project B;
Harry A. Thomsen, Jr., Architect, and John Gould, Structural Engineer, both of San Fransiseo, California, who designed Project B;
Roy Carlson, Consulting Engineer, Berkeley, California, who offered valuable suggestions concerning the installation of the Carlson gauges at Project B.
Raymond Concrete Pile Co., San Fransisco, California, who assisted in the installation of the gauges at Project B.

REFERENCE.

1)"Experiences With Predetermining Pile Lengths" by William W. Moore, Proceedings of the American Society of Civil Engineers, November,194

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THE OCCURRENCE OF HYDRODYNAMIC STRESSES IN THE PORE WATER OF SAND-LAYERS DURING THE DRIVING OF PILES IN IT; THE CONSEQUENCE OF THIS PHENOMENON ON THE APPLICATION OF PILE DRIVING FORMULEA.

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It happens that during the driving of piles in sandlayers, even with acceptable sounding resistances, great "sets per blow" occur. On account of this fact hydrodynamic stresses in the saturated sand-layers were supposed in principle. Since this supposition was confirmed by a series of measurements, we can state the following.

Driving a pile in sand-layers we notice hydrodynamic stresses acting in the pore-water surrounding it. This may amount to several tons per m^2 and may consequently cause a decrease of the effective normal stress and the shearing resistance, prevailing in the sand-layers. Consequently the resistance, met by a pile toe driven in sand-layers, will also be determined by the hydrodynamic stresses caused in these layers. Moreover, since this overstress varies in different cases, the bearing capacity cannot be only gathered from the data of the "set per blow" during the driving, were it not already difficult because of other reasons.