Lymon C. Reese & Associates
LCR&A Consulting Services – Tests of Piles Under Axial Load

Nature of Services

The company has a long history of performance of tests of piles and pile groups under a variety of loadings. This document relates to the testing of single piles under axial loading. While services can be offered for the testing of un-instrumented piles, the emphasis in this presentation is on the testing of instrumented piles with Strain Bars (telltales may also be used as discussed below). A separate document presents information on the nature and use of Strain Bars.

Strain Bars have been used mainly for the testing of drilled shafts but also may be applicable to precast concrete piles. In the discussion that follows, the term *pile* may be used to apply to a precast pile or to a drilled shaft.

For all load tests, LCR&A can provide a highly qualified, experienced engineer for the test and other support personnel as needed. Personnel for assisting the engineer from LCR&A often are more economically provided by the Owner, Engineer, or Contractor.

Types of Tests

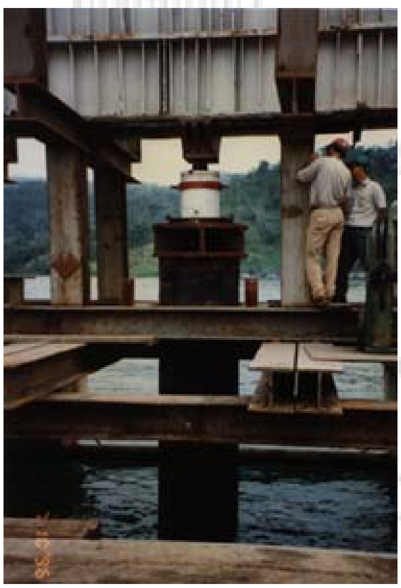
Three types of tests for top loading are discussed: (1) proof test of an un-instrumented pile; (2) test to failure of an un-instrumented pile, and (3) test of an instrumented pile. A representative soil boring is assumed to be available for any load testing. The procedures of the American Society for Testing and Materials (ASTM) will be followed where applicable. The proof test (Type 1) merely requires that the pile be loaded in increments to some multiple of the service load (usually twice).

The load to failure (Type 2), in the view of LCR&A, should be employed in all cases if the loading system has sufficient capacity. A valuable service can then be offered by LCR&A in which the experimental capacity is compared to the computed capacity, yielding information for improving the design of the production piles.

The assumption is made that the Type 3 Load Test will be carried to failure in order to justify the use of the instrumentation. The Type 3A Load Test will employ a reduced amount of internal instrumentation and has the limited aim of indication the portion of the load at failure carried in side resistance (skin friction) and in end bearing. The Type 3B Load Test will employ a sufficient amount of internal instrumentation of develop a family of curves showing the distribution of

axial load as a function of depth. The Type 3B Load Test is discussed in detail in the following sections of this document.

The axial loading test for bottom loading is called Type 4 Load Test and is special because in almost all instances both side resistance and end bearing cannot both be determined. A possibility is to design the test so that the load in side resistance is larger than the load in end bearing. In that case, multiple loading cells can be used in the upper portion of the test pile to allow the full load transfer is side resistance to be developed. If the multiple loading cells are employed, the installation of internal instrumentation is difficult to install in such a test will not be discussed in detail herein. Discussion of the Type 4 Load Test, therefore, will be restricted to bottom loading with only one load cell. Further, the assumption is made in this document that internal instrumentation will be used.



For all three types of top loading tests, the measurement of axial load and pile-head deflection is required for top loading; for bottom loading, Type 4 Test, only pile-head deflection is required.

Selection of Dimensions of Test Pile

The exact location of the test site is to be selected by interested parties according to available soil investigations and locations of production piles. Careful attention to the selection of the diameter and length of the pile is worthwhile. While the diameter can be changed in the design of the production piles, the results of changing the pile penetration would not be straightforward.

The test layout may have a configuration typical of tests under axial load for top loading, and will include a reaction system, reference beams, and loading system. However, internal instrumentation may also be used for bottom loading.

Measurement of Pile-Head Movement

Vertical movements at the top of the test piles and for telltales, if used, are measured by extensometers (direct-current-displacement transducers, or DCDTs) that are mounted on a stationary reference frame. The extensometers are placed 90 degrees apart around the top of the concrete shaft. Four extensometers are used in order to obtain an average movement in case tilting occurs as load is applied.

The displacement transducers from LCR&A are electronic and will be connected to the automated data acquisition system (ADAS) . LCR&A will also provide a recent calibration record for each displacement transducer. The sensitivity of the transducers is in the order of 2.5 mV per 0.001 inches, which translates to a sensitivity of about 4/100,000 inches using the ADAS from LCR&A. A secondary system is recommended for backup to the electronic devices. The secondary system may consist of dial gauges, or perhaps of a scale and stretched piano wire.

Measurement of Axial Load at the Pile-Head and Dealing with Possible Eccentricity

LCR&A has on hand a series of calibrated load cells up to a capacity of 2,500 kips along with a high capacity spherical bearing for concentric loading. The Contractor is assumed to provide the system for application of loading, along with a hydraulic ram of appropriate capacity. The area of the piston in the ram, along with the measurement of hydraulic pressure with a pressure gauge, can serve as a backup to the measurement of axial load with the calibrated load cell.

Examination of the top of the drilled shaft or driven pile does not always reveal the axis where the load is to be applied. Some trials with light loads are recommended , where evidence of eccentric loading can be revealed by movements of the pile head. The loading system can be moved by trials in order to achieve concentric loading. Installing a pair of dial gauges for measuring lateral deflection of the pile head can be useful. If a drilled shaft or a driven pile is constructed with a significant mount of accidental batter, the loading of the pile without some lateral deflection of the pile head will be difficult.

Testing with Internal Instrumentation

Types of Internal Instrumentation

LCR&A recommends to use of strain bars, described in a separate document, for measuring the strain along the length of a test pile. Hundreds of the bars have been used successfully in past tests and data-acquisition systems are available for readily acquiring data and for its interpretation.

An alternate system, recommended by LCR&A as a back-up system is telltales. Open tubes are embedded in the pile to contain an unstrained bar. The reading from a dial gauge, mounted at the top of the pile, resting on a bar extending to a particular depth yields the shortening to the pile for the particular depth. A family of telltales, usually placed in pairs, extending

to various depths in the pile will yield data that allows the strain along the length of the pile to be determined.

Products of the Testing

The Type 3A Load Test could have the limited aim, as noted earlier, of merely determining the amount of load at the failure condition carried in side resistance (skin friction) and in end bearing. Internal deformation is not computed. The limited aim is valuable to allow the designer to make a check of the computations made in the design of the production piles.

The Type 3B Load Test, on the other hand, will be performed with sufficient internal instrumentation to allow curves to be measured to show the distribution of axial load as a function of depth for each of the increments of load applied during the testing. Preferably, the instrumentation will be placed to allow the load to be determined carried by each of the significant soil strata supporting the pile.

The Type 4 Load Test for bottom loading will have sufficient internal instrumentation to all the distribution of the load in side resistance to measured for each increment of loading. If the load carried in end bearing is larger that the load in skin friction, the load at failure will reveal the ultimate load in skin friction.

The next section presents the mechanics of the transfer of axial load and will indicate the value of the use of internal instrumentation over the full length of a drilled shaft or precast pile.

Mechanics of Transfer of Axial Loading

A realistic model of a pile under axial loading is shown in Figure 1. The pile is simulated with a coiled spring (Fig. 1c) shown in the sketch as uniform with depth and as having a linear relationship between load and deformation but the properties of the pile may vary with depth and it may have a nonlinear relationship between load and deflection. The soil has been replaced with a set of mechanisms that consist of a spring and a sliding block merely to indicate that the soil behaves in a nonlinear fashion under the application of load. The sliding block indicates that there is a limiting value of resistance from point to point along the length of the pile. Figure 1b is a set of mechanisms to indicate load transfer in side resistance and similar load transfer in end bearing can be applied at the pile tip.

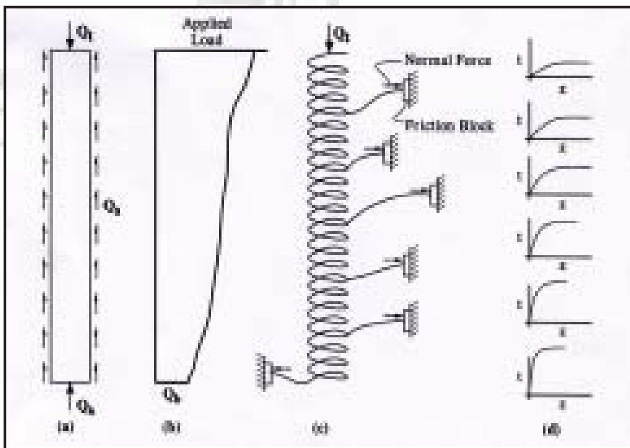


Fig. 1 Model of Pile Under Axial Loading

If the load transfer functions, t versus z in side resistance, and q versus in end bearing, can be predicted with confidence, the engineer can readily make computations to find the load-settlement curve and the distribution of axial load as a function of depth. Therefore, the emphasis in the testing of an instrumented pile under axial loading is to produce the load transfer curves. Such curves can be compared to previous curves for similar soils and similar piles, or can be used to make predictions based on the relevant data on soil and pile that may be used in future designs.

The method of analysis of data from the testing of an instrumented pile under axial loading is shown in Fig. 2. The measurement of axial load versus settlement is shown in Fig. 2a and the measurement of axial load versus distance along the pile, from the internal instrumentation, is shown in Fig. 2b. One of the load-distribution curves is selected, as shown in Fig. 2c and a particular depth is selected for analysis. The integration of the area under the curve, divided by the axial stiffness of the portion of the pile above the selected depth, will yield the shortening of the pile to the selected depth. The computed shortening, subtracted from the observed movement of the pile head for the particular load, will yield the downward movement of the pile w_z at the selected point with respect to the soil.

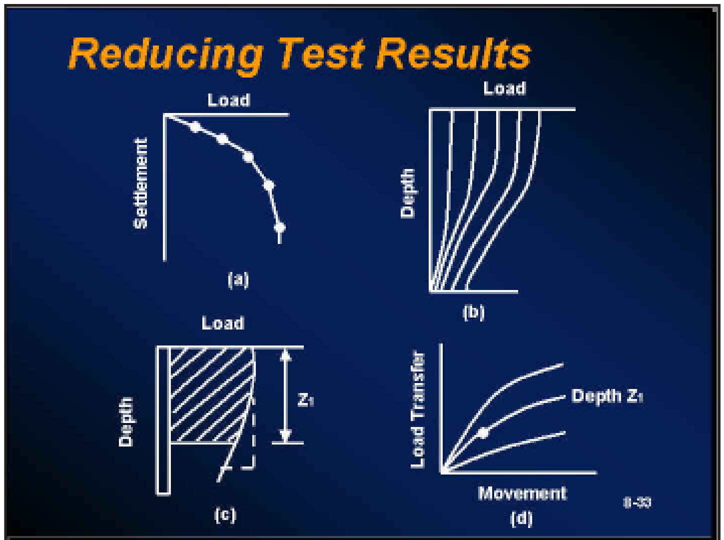


Fig. 2 Method of Analysis of Data from Testing of Instrumented Pile

The slope of the selected load-distribution curve may be determined, as shown in Fig. 2c, and divided by the circumference of the pile to yield the unit load transfer for the selected depth along the pile. The procedure can be repeated at the selected depth for the various load-distribution curves to produce the load transfer in side resistance for depth along the pile as shown by the plotted curve in Fig. 2d. The same procedure may be employed for other depths along the pile to allow the development of the family of load-transfer curves for side resistance as shown in Fig. 2d.

The curve showing load transfer in end bearing can be obtained by computing the movement of the end of the pile as for load transfer in side resistance except that the area under a load-distribution curve is integrated over the full length of the pile. That movement is subtracted from the observed movement at the top of the pile to obtain the movement of the pile tip. The unit end bearing is found by reading the value of load at the end of the pile by extending the curves from the internal instrumentation (see dashed lines in Fig. 2d) because it is not possible to measure the strain at exactly the pile tip. That load divided by the area of the end of the pile yields the unit end bearing.

Site-specific curves, such as shown in Fig. 2d, are of great value to the engineer in the design of the production piles. Methods of installation of piles have an affect on their response and the test pile and the production piles should be installed in similar manners.

Details Relating to Internal Instrumentation

The leadwires extend from each Strain Bar to an appropriate distance away from the test shaft, for safety, where they connect to an automated data acquisition system (ADAS) that is in turn connected to a notebook computer. Readings of load cells will also be registered by the ADAS at each reading interval. LCR&A will provide load cells that have been recently calibrated. The Contractor will provide the reaction system with a hydraulic ram. A calibration chart with the hydraulic ram is used during testing for the application of the selected load.

LCR&A will provide at least three full lengths of all-thread bars each containing approximately 8 strain bars at predetermined depths. These bars (along with their fixed lengths of

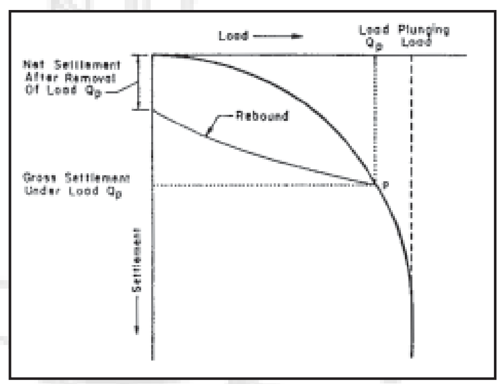
leadwires) and other bar extensions without instrumentations will be provided by LCR&A, assembled on site, and tied to the longitudinal bars after rebar cage is assembled.

A Campbell Scientific Model 23X ADAS will be used to scan all readings of displacement and applied load. The ADAS will be programmed to scan data every 10 seconds during loading/unloading. Data will be stored in temporary memory and retrieved in every load stage with a notebook computer. Appropriate plots of load and displacements may be made available immediately for evaluation and to compare with predicted values.

Instrumented depths will be defined according to soil profiles and expected load transfer. One electrical strain bar may be placed near the top of each test shaft, where no axial load is being transmitted to the soil, to allow for a calibration curve to be developed experimentally which may help to convert strain into axial load in the column. The concrete cylinder strength at three different depths should be tested. These values will be used by LCR&A to evaluate the load transfers for each instrumented depth.

LCR&A can design and supervise the installation of telltales if desired. Strain at points along a pile is found indirectly by differentiating the curve showing pile movements from telltales and is less accurate than data from strain bars. However, telltales give check of pile movement and a limited number may be installed as a validation of the strain-bar readings.

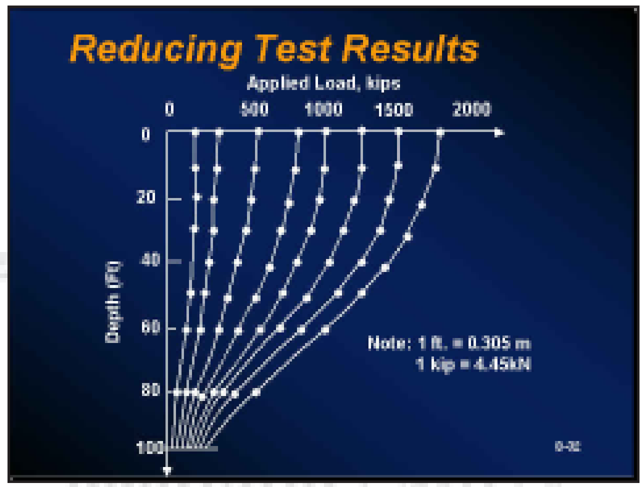
Relevant Comment



Most of the following comments relate to the testing with internal instrumentation but some relate to any of the types of tests that are offered by LCR&A.

1. The following equipment will be necessary during testing:
    a. A pump operator will be desired for the duration of the test.
    b. Vehicular access to test site is desired in order to maintain electronic instruments inside a vehicle, plus to obtain backup power for computer from 12V receptacle in vehicle. Otherwise, a small work table, plus a tent or some other method of protection from direct sunlight and rain may be necessary.
    c. Lights and small generator may also be necessary during testing.
2. Immediately after testing, LCR&A will deliver preliminary test measurements in electronic form. In a period not exceeding five business days after the last test is completed, LCR&A will deliver a brief report containing the following items:
    a. Short textual introduction.
    b. Charts of axial load vs settlement showing raw measured values from each displacement sensor.

c. Charts of axial load vs settlement showing averaged values of all working displacement sensors.
d. Charts of axial Load vs settlement before and after creep, if relevant.
e. Charts of comparison between load readings from electronic load cell and converted pressure gauge readings.
f. Charts of readings from digital strain bars embedded in the drilled shafts (only strain readings, conversion to stress depend on moduli of elasticity of concrete samples and on optional data-interpretation contract with LCR&A).
g. Electronic spreadsheet of measurement tables that were used for preparing all charts.
h. Electronic spreadsheet of raw measurements.
i. Printout of most recent calibration curves of all electronic instruments used during the test.
j. Final electronic files.



3. Data reduction and presentation will be submitted in a timely manner. All measurements logged during testing operations need to be reduced after eliminating accidental readings, and electrical noise or other erroneous measurements. Results will be presented with graphical readings of strain for each instrumented depth, and using load and settlement from instrumentation on top of the test column.
4. Data interpretation and complete test reporting will be presented in an agreed time period and will include the following items.
   a. Charting of load distribution curves based on measurements from digital strain bars