Correlation Between Actual and Predicted Settlements for a Large Test Footing

by

K. C. PILE, M.E., M.I.E.Aust.

Senior Lecturer, School of Civil Engineering, South Australian Institute of Technology

SUMMARY. A field loading test on a 3'9" square test footing founded at a depth of 9'10" on a saturated silty clay strata is described. Settlements of each corner of the footing are reported during loading, unloading and re-loading. The results of laboratory soil tests are used to compute settlements by four different methods. Field penetrometer data is also presented and used to estimate footing behaviour. Actual and predicted settlements are compared, and the merits of the different methods for estimation of settlement are evaluated. It is concluded that the Skempton-Bjerrum method and the Davis-Poulos method are best for practical use.

1 INTRODUCTION

The S.A. Institute of Technology have a 4.7 acre building development site on the east side of Frome Road, Adelaide. The location is shown in Figure 1. The site investigations and laboratory testing described in this paper were undertaken for the first building constructed on the site (the Reid Building, now completed) and to enable more accurate interpretation of soil testing data for future buildings.

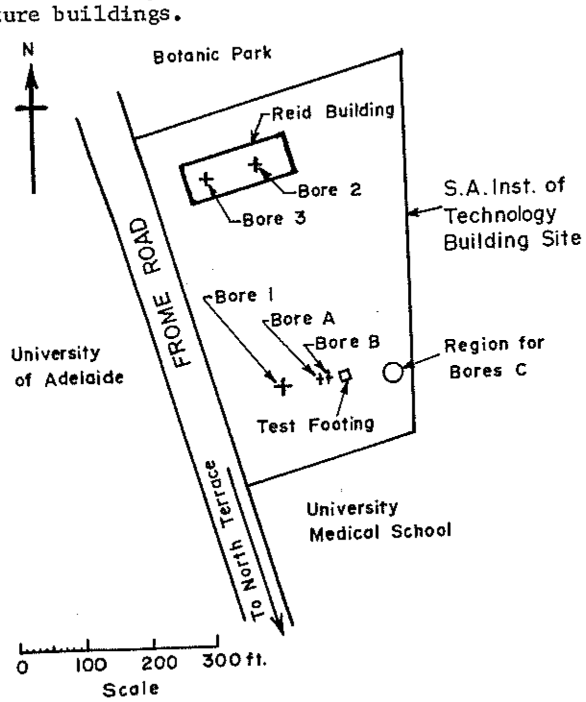

Fig. 1 Plan of site

It was decided to carry out a fairly large-scale field loading test because the accurate prediction of footing settlement and rate of settlement from laboratory soil test results still presents, in practice, many difficulties, partly due to uncertainty in the best method for settlement estimation, and partly due to the complexities of soil testing. The loading test was conducted on a reinforced concrete footing measuring 3'9" x 3'9" x 1'6" deep, and founded at a depth of 9'10" on a uniform, saturated silty clay layer.

The results of the field test greatly assisted the interpretation of laboratory test data, and influenced the decision to use an economical raft footing for the Reid Building, instead of a more expensive piled foundation. Further, the opportunity was provided to compare the accuracy of different methods of settlement prediction, when applied to a footing on a silty-clay soil of soft to medium consistency.

2 GEOLOGY AND SITE EXPLORATION

The site falls within the Torrens River valley, which bisects the City of Adelaide and North Adelaide. The soil strata in the valley have been deposited in Recent times, and consist chiefly of gravels and sands, together with some silts and clays, none of which appear to have been subjected to the severe desiccation experienced by the Pleistocene clays underlying the City. Ground water level is at the relatively shallow depth of 10'0", and is influenced by the level of the River Torrens, in which the water level is now maintained constant by a weir.

Site investigations consisted of:

(a) Three boreholes put down by the S.A. Department of Mines, shown as boreholes 1, 2 and 3, Figure 1. Maximum depth was 49'6".

(b) A power-auger hole, in which standard penetration testing was carried out to a depth of 25'0", and some 2½" dia. soil samples were taken. Shown as borehole A, Figure 1.

(c) A hole drilled to 10'0", and then Dutch cone sounding carried out to 24'6". Shown as borehole B, Figure 1.

(d) Two hand-auger holes to 15'0", in which 4" diameter thin-walled samples were taken from 9'6" to the bottom of each hole. Located in region C, Figure 1.

The bores disclosed uniform strata over the site. Figure 2 shows the soil profile determined by the Department of Mines borehole 1, and plots driving resistance and consistency of samples as measured by a pocket penetrometer. The results from the standard penetration and Dutch cone tests are also plotted on Figure 2.

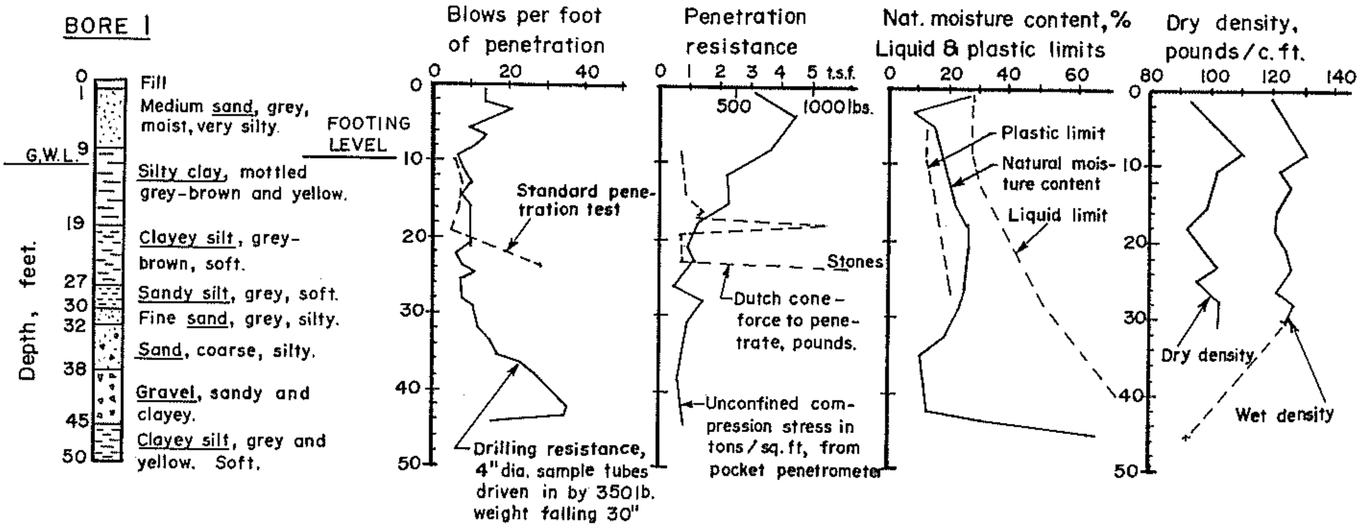

Fig. 2 Soil profile and site investigation data.

3 FIELD LOADING TEST

The chief objective of the field loading test was to correlate the predicted and actual settlements of a footing of reasonable size. It was decided to rest the test footing on the silty clay at 10'0" depth, partly because of the uniformity of the soil below, but principally because the Reid building was to have a semi-basement requiring 8 to 10 ft. of excavation.

After considering several alternatives for applying the load, it was decided to use two corrugated galvanized iron water tanks each of 5000 gallons capacity, supported on a platform above the footing. This scheme had the advantage that the load could be controlled accurately by filling the tanks with water to the required level, and that long-term settlement would not cause any load variation. Figure 3 shows the set-up.

The footing size was chosen as 3'9" square because preliminary soil tests indicated that the maximum load that could be applied, approximately 80,000 lbs, would be close to the ultimate bearing capacity of the footing. The footing was cast in-situ to ensure good contact with the soil.

To observe settlements, a steel levelling bolt was built in to each corner of the footing. Two benchmarks were established nearby, each consisting of a steel pipe within a cased borehole, the bottom of the steel pipe being built into a concrete block at a depth of 15'0". Settlements were measured by levelling from the benchmarks to the corners of the footing using a Wild N3 level reading directly to 0.1 m.m.

Over a 10-month period, two loading and unloading cycles were carried out. The first cycle consisted of loading to original overburden pressure, and then increasing to maximum load in three steps, with a wait after each step until settlement reached a constant value. The footing was then unloaded to the overburden pressure, and finally subjected to another complete cycle of loading and unloading. Unfortunately, the full final loading step in each cycle was not quite attained due to cracking of some of the supporting beams.

Settlement readings are plotted against load in Figure 4. It will be seen that a considerable amount of tilting occurred, [illegible]arly during the second loading increment in [illegible]st loading cycle. This was probably due to non-uniformity of the packing at the base of the loading post. Nevertheless the magnitude of tilting seemed high in relation to the maximum possible eccentricity. The first unloading and the second cycle of loading and unloading resulted in no further tilting of the footing, and hence only the centre settlement is plotted in Figure 4.

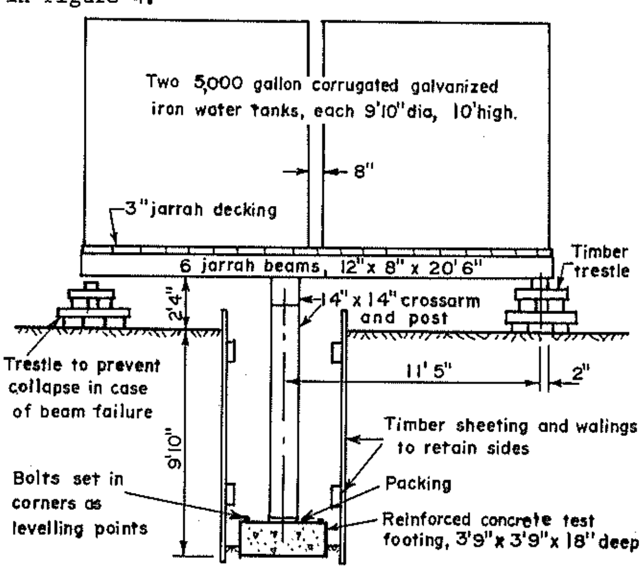

Fig. 3 Field test loading rig

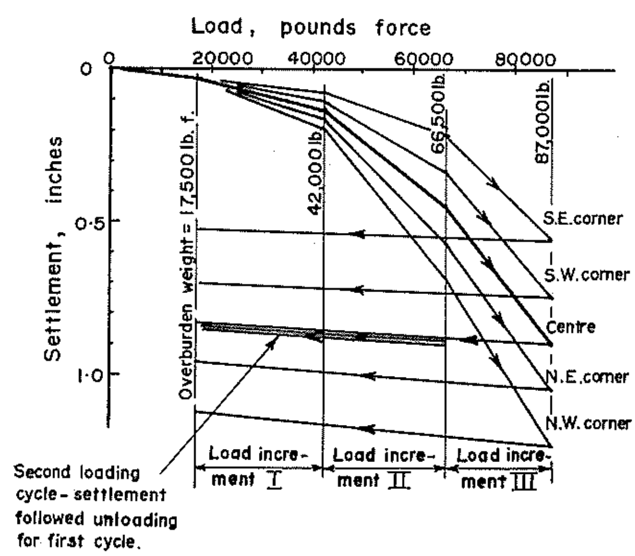

Fig. 4 Load-settlement graphs.

In Figure 5, settlement is plotted against time for the first loading increment. It is clear that settlement follows the application of load fairly quickly. For the second loading increment, the time required to reach full settlement was even smaller.

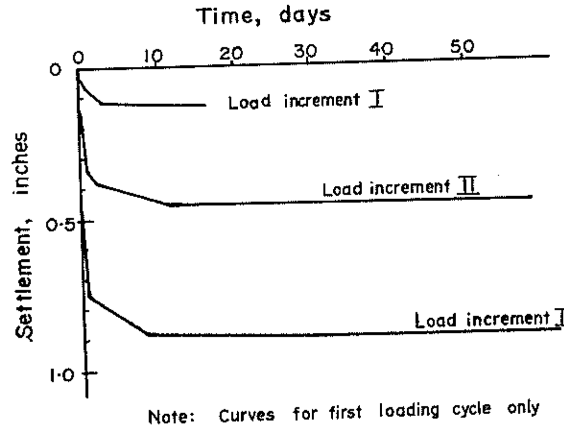

Fig. 5 Settlement-time graphs

4 LABORATORY TESTING

An extensive programme of laboratory testing was carried out, consisting of routine tests for the design of the Reid Building, and special tests associated with the field loading experiment. The range of tests and results are as follows:

(a) Index tests - moisture content, liquid and plastic limits, and dry density, on samples from the three Department of Mines boreholes. Results are plotted on Figure 2.

(b) Undrained triaxial shear and consolidation tests. Results are given in Table 1 and Figure 6 respectively.

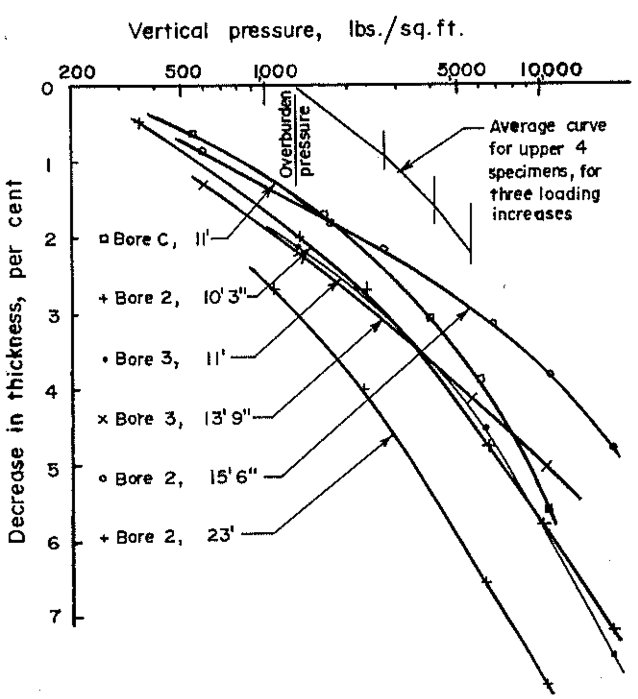

Fig. 6 Consolidation curves.

(c) One drained and three consolidated-undrained triaxial shear tests on 1½" dia. specimens from depths of 12' - 17', Borehole A (Figure 1). These tests were done after completing the footing test, when it was apparent that the rapid consolidation and consequent increase in strength of the foundation soil were significant.

The results obtained are:

	Cohesion	ϕ
Consolidated-undrained tests	8 p.s.i.	12^o
Drained test	8 p.s.i.	25^o

The drained strength values are based on the single drained test plus the effective stresses at failure for the consolidated-undrained tests.

The non-zero cohesion values suggest that the soil is overconsolidated, probably due to mild desiccation.

(d) Seven triaxial tests on nominal 4" dia. samples were carried out for settlement prediction by the Davis and Poulos (Ref.1) and Lambe (Ref.2) methods. The samples were taken in thin-walled tubes (1/16" and 1/8" wall thickness) by knocking into the soil at the bottom of a 5" dia. auger hole using the end of a heavy balk of timber: excellent samples were thus obtained.

The above methods for settlement estimation require soil testing techniques in which the in-situ stresses are first established under Ko conditions, followed by vertical and horizontal stress increments identical to those beneath the actual footing, i.e. in which the appropriate stress path is followed. Previous reports of the application of stress-path testing by Davis and Poulos (Ref.3) and by Moore and Spencer (Ref.4) have used special 1½" dia. triaxial apparatus developed at the University of Sydney, in which the cell pressure automatically reaches the Ko value as the initial overburden pressure is applied. The author did not have similar equipment available, and attempted to carry out the testing as accurately as possible using commercially available equipment. The basic items were a Wykeham Farrance pore-pressure board, and a lateral strain indicator of the mercury capsule type, described by Bishop and Henkel (Ref.5). Cell pressure was controlled from a water-air tank using two differential pressure regulators, and measured by a mercury manometer and a Budenberg Standard Test Gauge. With this equipment, the major problem was the accurate establishment of Ko conditions, firstly because the lateral strain indicator only measures strain on one diameter, and secondly because the magnitude of lateral strain

TABLE I

UNDRAINED TRIAXIAL SHEAR STRENGTHS

Borehole No.	Depth, ft.	Cohesion p.s.i.	Friction angle ϕ degrees
2	8'9"-10'0"	8	19^o
2	11'3"-12'6"	3½	0
2	13'9"-15'0"	3½	0
2	17'6"-18'7"	3	0
2	22'6"-23'9"	2½	1
2	25'6"-26'3"	2	13
3	6'0"- 7'6"	18	26½
3	9'0"-10'6"	11	8½
3	12'0"	2.5	1
3	14'0"	1.6	0
3	28'0"	4.5	1
3	48'0"	4.5	2½