SEGMENTED FOOTING SYSTEM EVALUATION

by

Tadeusz W. Lewis

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APPROVED:

R.D. Krebs

G.W. Clough

T.L. Brandon

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Committee Chairman: Robert D. Krebs

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(ABSTRACT)

Foundation construction for spread wall footings normally involves constructing formwork, placing reinforcement, and pouring and curing concrete, regardless of footing size or the amount of anticipated load. Recently, the National Concrete Masonry Association (NCMA) has developed a complete foundation system called the Footer Block system. It was designed to reduce the costs of foundation construction for 1 and 2 story buildings. The footer block system consists of interlocking concrete blocks 10.2 x 40.6 x 20.3 cm (4 x 16 x 8 in). Because they are placed with no mortar, delays associated with the curing process or providing access for concrete are unnecessary.

The purpose of this study is to compare traditional cast-in-place footings and the Footer Block system using full-scale load tests. Full-scale models of each type of footing were constructed and tested on uniform sand contained

in a special chamber large enough to avoid problems with boundary affects of the chamber wall on the sand sample. The chamber is designed to accommodate the placement of sand samples that have very consistent and easily duplicated properties.

During a three month period, four tests were conducted at the Prices Fork Research Facility. The tests consisted of forming a sand sample, fabricating the model, loading the model, and then removing the sample. From these tests, response to load of the Footer Block system as compared to a monolithic wall footing was evaluated, with no significant difference found. Also, the settlement measurements recorded were compared to predictions of settlement based on Schmertmann's procedure for estimating settlement of shallow foundations using cone penetration results recorded by Eid (1987) on samples with similar properties. Schmertmann's procedure provided a range of settlement values depending on the value of overburden pressure used. The settlement values of the footings tested were found to be either at the upper end of the predicted range or slightly higher than predicted.

ACKNOWLEDGEMENTS

I would like to express my thanks to my adviser, Dr. Robert D. Krebs, for his support, time and many helpful suggestions. His advice was invaluable in the completion of this project. Also I would like to thank Dr. Tom Brandon for his help in setting up the data acquisition system and Dr. G. W.Clough for all his help in dealing with the calibration chamber operation.

Many components had to be fabricated for this project, and for this I thank the machinists, craftsmen and technicians who aided in the design and fabrication of these components. Also I would like to thank and the NCMA for funding this project.

The process of preparing a sample, conducting a load test and removing the sample was very tedious and time consuming. I would like to thank two graduate students for their time and effort in this regard. was extremely helpful in carrying out these processes, and also a pleasure to work with. was also a big help with the load testing.

Lastly, and most importantly, I would like to thank my family. Without the love and support of my parents and two brothers, , my accomplishments would not be possible. I will be forever grateful to them.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

Traditionally, foundation systems for one and two story buildings consist of reinforced concrete footings. These footings require formwork and a grace period to allow the concrete to cure adequately. A complete foundation system of interlocking concrete masonry units was developed by the National Concrete Masonry Association (NCMA) under the trade name Footer Block. This system was developed by the Innovative Design Research (IDR) Division of NCMA to lower the foundation costs of 1 and 2 story buildings. It can be used at sites where access to large and heavy ready-mix concrete trucks is restricted or undesirable. Installation of these blocks can be performed by unskilled labor and wall construction can begin immediately after placement of the system. The Footer Block system, shown in Figure 1, interlocks without mortar in both directions, regardless of orientation. The design of these units is based on the belief that the most important function of the spread wall footing is the distribution of load laterally, in a direction normal to the length of the wall. To span longitudinal distances, the "arching action" of the foundation wall is utilized. In situations where the grade beam span requirements exceed the arching action limits, or where

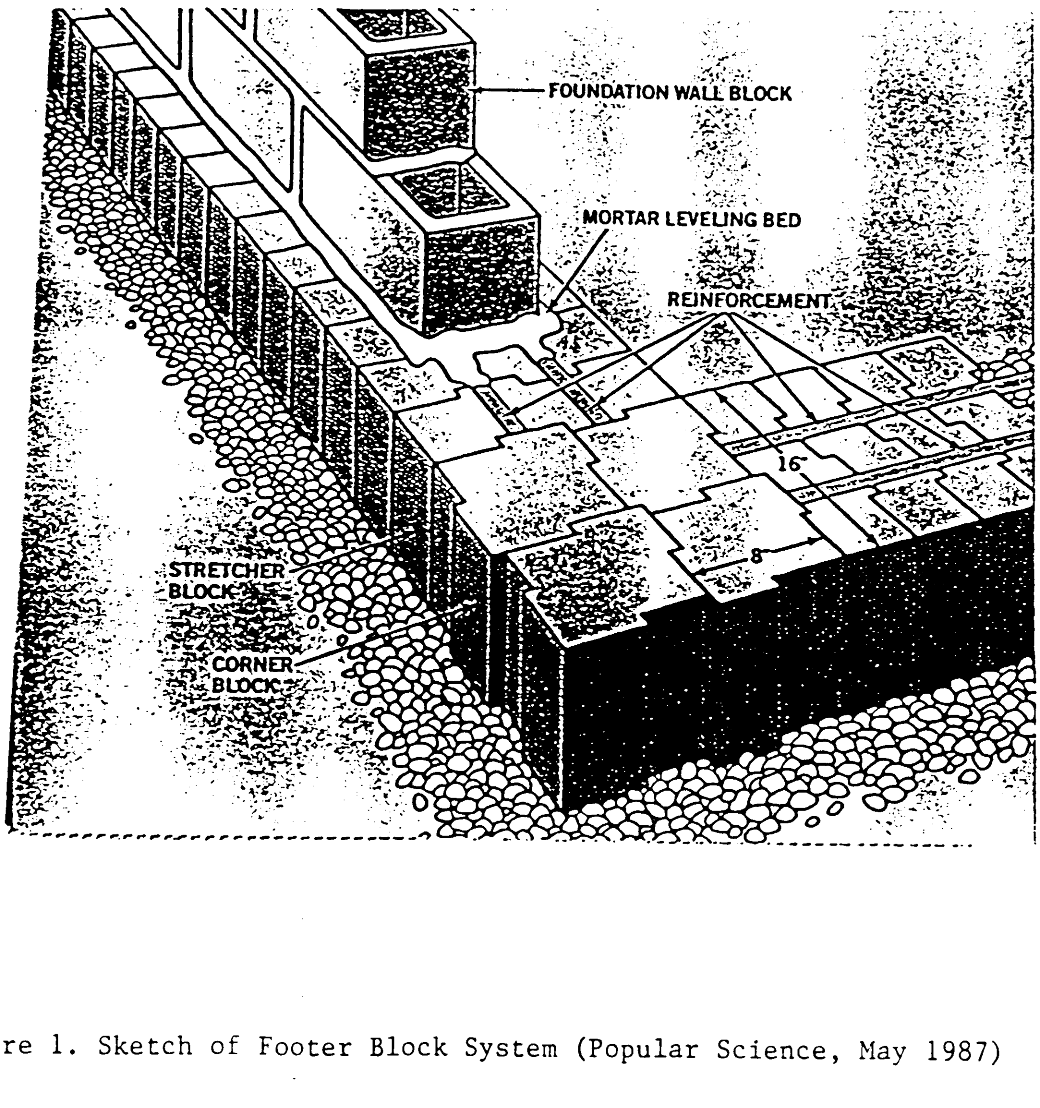


Figure 1. Sketch of Footer Block System (Popular Science, May 1987)

structural tie-in of foundations is required by seismic considerations, tension reinforcement is provided longitudinally at the bottom of the foundation. With the Footer Block system, the additional tension steel requirements are met through the use of a bond beam located at the first course of the foundation wall, immediately above the Footer Block itself.

The purpose of this research is to : 1) evaluate the effectiveness of the Footer Block system when compared to a conventional monolithic footing and, 2) compare predictions of settlement based on the semi-empirical procedure developed by Schmertmann (1970) to settlement values recorded from the test results of this project.

TEST PROGRAM

There are many factors which contribute to the accuracy of results in which a comparison of two products is made. For this project, the biggest concerns were reducing the possible scaling effects produced when other than full scale models were used, and also insuring that the soil conditions in which the tests would be conducted would be constant and reproducible. At Virginia Tech a large scale calibration chamber was fabricated in 1986 by Sweeney (1987) and Eid (1987) for calibrating the cone penetrometer and other in situ devices. This chamber, shown in Figure 2, uses a process that places or rains a sand sample that has a uniform relative density. The sample is circular with a diameter of 1.5 m (4.9 ft) and a height of 1.5 m (4.9 ft). With such a large size, a full-sized section of the Footer Block foundation system and the monolithic footing can be used.

After the sample was in place the appropriate footing section was constructed in the chamber. This entailed placing the footing section on top of the sand sample and then constructing a section of wall that was comprised of concrete masonry blocks. The wall was constructed using standard masonry practices and building codes for small (1 to 2 story) buildings.

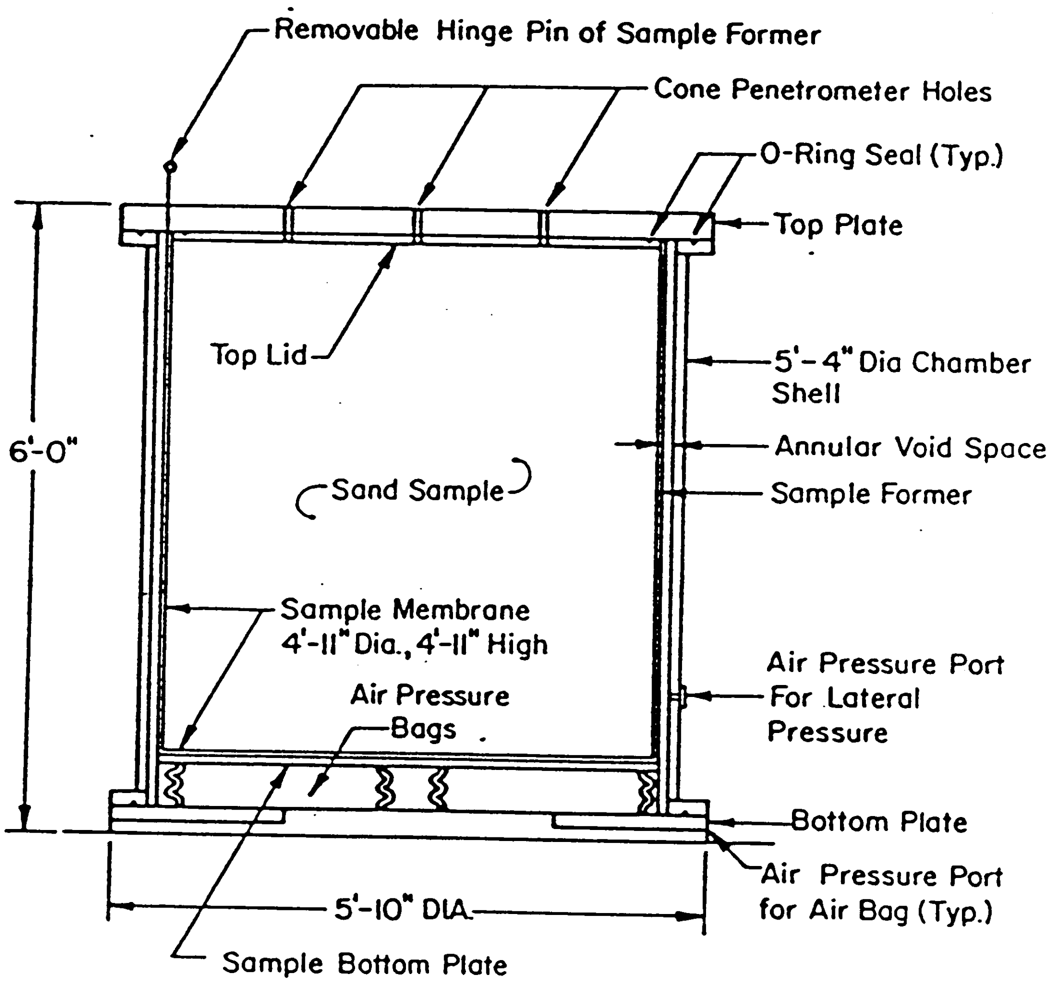


Figure 2. Cross Section of the Calibration Chamber
(After Sweeney, 1987)

The models were loaded by means of a hydraulic cylinder mounted on the chamber which was capable of applying a maximum load of 4535.9 kg (10000 lbs.). The models were loaded in 453.6 kg (1000 lb) increments up to the previously stated maximum with settlement values being recorded after each increment was applied.

Five load tests on the footing models were conducted at the Prices Fork Research Laboratory in the Spring of 1987. Although model loading took approximately one hour to complete, sample preparation and removal each took four to five hours of work per test. Also, one week was required to allow the mortar of each model to cure properly. Therefore the time to complete one test was approximately 8 to 9 days. It should be noted that the time required for sample preparation will be reduced significantly when the calibration chamber is moved to a facility more suited to the chamber's operation. Presently a building at the research laboratory is being prepared to house the chamber and make the entire operation much more efficient.

Because no previous tests of this nature had been conducted with the calibration chamber, the first test was used to observe and correct any problems with the testing procedure. It was during this time the adjustments on piston speed, methods of recording settlement measurements, and other such changes were made. The Footer Block and the monolithic footing sections were tested first on medium dense sand, and then loose sand.

After the models were loaded, the settlement values of each type of footing were compared by plotting the settlement vs. bearing pressure for both sample conditions. These values were then compared with predictions of settlement using Schmertmann's procedure with a bearing pressure of 1 ksc (1 tsf).

SOIL PREPARATION

Monterey # 0/30 sand was used as the test soil. This sand is very uniform and poorly graded which is beneficial when conducting tests that require reproducible conditions. A sieve analysis was conducted on the test sand and is presented in Figure 10 of the Appendix.

The chamber is designed to rain samples at two densities: medium dense (63%) and loose (24%). These densities are achieved depending on the spacing and size of a series of machined holes located on the rainer bottom plate. The procedure for raining a sample requires the raising of the sand diffusers at a pre-established interval and height. For tests on medium dense sand, data from previous work on the chamber was used to determine an in-place density of 1603.4 kg/m^3 (100.1 pcf) and a relative density of 63%. In contrast, the procedure for raining the loose sample was not completely developed in that the time interval to raise the sand diffusers was not available. For this reason an arbitrary time interval of 15 seconds was used. After the sample was rained the volume of the sand was measured, and then after the test, the sand was weighted. In this way the in place density could be estimated and the relative density calculated. It was found that both tests conducted with the loose samples produced an in-place density of 1510.5 kg/m^3 (94.3 pcf) and a relative density of 23.2%.

It should be noted that for this project a couple of variations in the raining procedure were used. First, the soil sample was not sealed with the top plate of the chamber shell because the footings had to be placed on the sample surface. Since there was no top on the sample, no confining pressure was applied to the sample and the sample did not need to extend to the top of the chamber shell. This made it unnecessary to use as much sand as normally is used and thereby saved a considerable amount of time in sample preparation. Also, because there was no confining pressure to be applied, the sample former, which is slightly smaller than the chamber shell, was not used. Instead, the chamber shell was used as the outer boundary and therefore a wider sample could be produced to further reduce boundary effects.

After a test was conducted, the test sand had to be removed for use in the following test. A large industrial size vacuum machine was used to remove the sand. The sand was vacuumed into a holding unit and then transferred to the sand storage bins. While the vacuum unit was relatively large, the holding unit had to be emptied into the storage bins every five minutes. This and the large size of the sample made emptying the chamber a very time consuming process that usually required four hours to complete. For more specific information on the design or operation of the calibration chamber refer to Sweeney (1987).

CONSTRUCTION OF MODELS

Footer Block System

The Footer Block system tested was composed of interlocking concrete blocks with nominal dimensions 10.2 x 40.6 x 20.3 cm (4 x 16 x 8 in) weighing approximately 10.9 Kg (24 lbs). The length of the footing section to be tested was directly related to the diameter of the calibration chamber. A section with a length of 76.2 cm (30 in) would provide a distance of 37 cm (1.2 ft) between the edge of the footing and the wall of the chamber when the footing was aligned in the center of chamber. It was decided that this distance would be sufficient to reduce the boundary effects of the chamber when applying loads in the ranges used for this project.

After the sample of sand was rained, the sand surface was leveled off to create a smooth pad in which the footer blocks would be placed. This leveling procedure was carried out with the intention that the final, more accurate leveling would be conducted as the first course of concrete block is placed. The footer blocks were then placed one at a time on the pad using a string line to insure the footing was aligned properly. It should be noted that the only connection between adjacent blocks was the grooved interlock on the vertical face of each block. At this time a truss and ladder type reinforcement with 0.5 cm (3/16 in) diameter longitudinal wires was placed on the top of the footer block system. The blocks have two horizontal grooves designed to align the reinforcement. Once the reinforcement is placed, a generous amount of mortar is applied to the base of the foundation just as one would for a conventional cast-in-place footing.

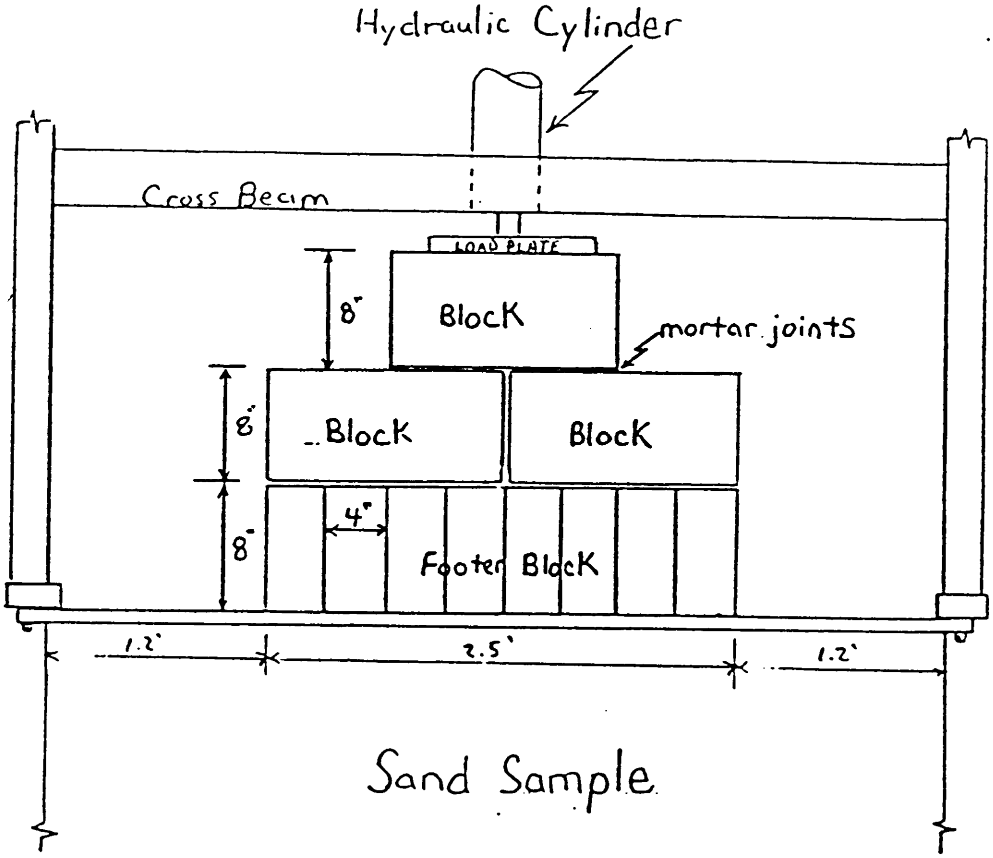
Cast-in-Place Footing

Because it would be impossible to actually pour a footing section inside the chamber without considerable waste of the testing sand it was decided to use a model that would simulate a conventional monolithic, cast-in-place footing. After viewing building codes for spread wall footings, it was decided to use a section of lintel as the monolithic footing section. The lintel was composed of three U-shaped concrete blocks that were filled with concrete along with four # 5 reinforcement bars. The lintel was cut with a concrete saw to the same length of 76.2 cm (30 in) as the footer block section, and had a width of 30.5 cm (12 in) and a height of 20.3 cm (8 in). The lintel, or monolithic footing, was lifted into the chamber and placed on the leveled sand surface with lifting hooks that were welded to the footing. A string line was used to insure proper alignment of the footing section. After the footing was placed, a mortar bed was again prepared to lay the first course of concrete blocks.

Construction of Wall Section

Once the footing sections were in place, the rest of the construction was the same for both types of footing systems. This consisted of two courses of concrete block in which the first course contained two blocks and the second course one block. When the first course of block was placed on the bed of mortar the final leveling was completed using a masonry level. Because the load could only be applied at the center of the chamber it was imperative that the models be centered within the chamber and the walls be in line or straight. Without this accuracy the model could become tilted or overstressed in one area which would considerably reduce the accuracy of the results. Once the models were completed they were both 61 cm (24 in) high from the sand base to the top of the second course of block. A cross section of the model configuration can be seen in figure 3. Once construction of the model was completed the mortar was allowed to cure one week before applying loads.

The two types of footings were similar in both appearance and dimensions except that the Footer Block system had a width of 40.6 cm (16 in) and the monolithic footing had a width of 30.5 cm (12 in). Therefore, the Footer Block system utilized more area to distribute the applied load then the monolithic footing section. Also, the monolithic footing system contained a higher-strength reinforcement then the Footer Block section. However, with uniform soil conditions and a uniform compressive load application, the reinforcement was not seen as a significant factor in footing behavior.



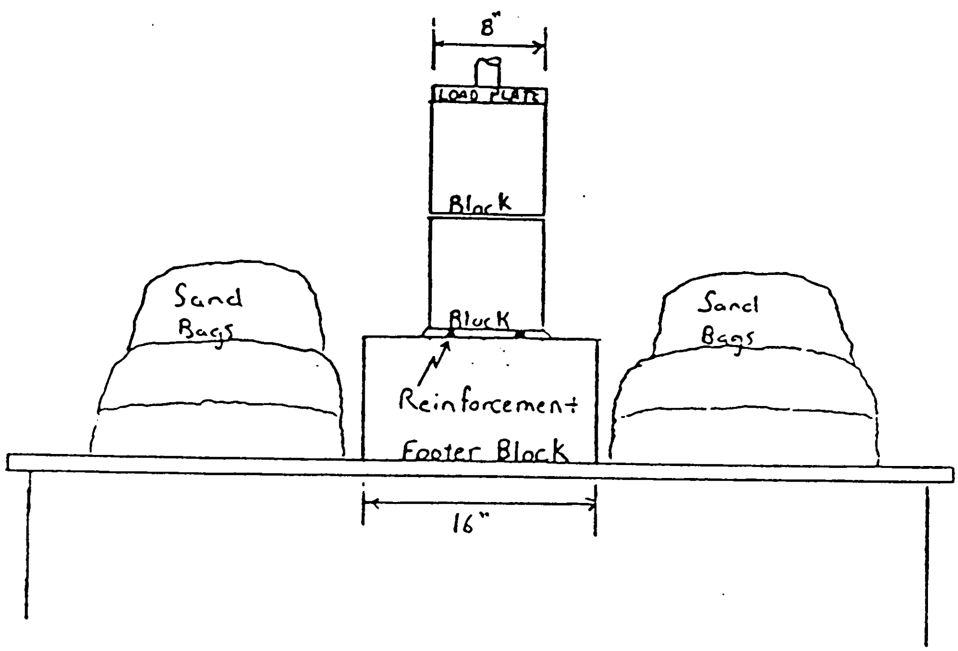


Figure 3. Cross Sections of Footing Model. Scale: 1"-1'

TEST PROCEDURES

The calibration chamber is equipped with a hydraulic cylinder mounted on a load frame which acts like a large mechanical press to insert a cone penetrometer into the sand sample. It was determined that this loading arrangement could be modified and used for this project. The load frame consisted of two wide flanges, as columns, and two structural channels mounted back to back with the cylinder installed between the channels at a height of 2.1 m (7 ft) above the base of the wide flange columns. The reason the cylinder is located so far above the chamber top is to enable a cone penetrometer and its accompanying drill rods to be attached to the cylinder before penetration. The piston force is generated by a 2 H.P. hydraulic pump having a flow control valve to control the speed of cone penetration and a pressure relief valve to control the magnitude of the load applied. Since the footing models were only 61 cm (24 in) high, there would be a large distance between the cylinder and the application of load. For this reason the distance between the cylinder and the base of the columns was reduced by drilling an identical pattern of holes in the columns to the pattern used at the top of the columns and then lowering the channels or cross beam. A distance of 0.91 m (36 in) between the cross beam and the base of the columns was chosen as adequate to provide space for the model and the load plate.

The load plate consisting of a base plate 20.3 x 30.5 cm (8 x 12 in) and 2.5 cm (1 in) was designed and machined at Va. Tech. Welded to the middle of this plate was a solid steel rod 5 cm (2 in) in diameter and 5 cm (2 in) long. The end of this rod, or the point of load transfer between the cylinder and the model, was spherical to insure that the connection to the cylinder would be moment-free. If the connection were rigid, a load applied off center would produce a moment large enough in the cylinder to damage the seals.

Because the load was applied incrementally, there was no need to control piston speed. Therefore, the flow control valve was left open. The magnitude of load applied was regulated by changing the pressure relief setting of the hydraulic pump. A 12 kip load cell was installed between the cylinder piston and the load plate and connected to a voltmeter. By knowing the calibration factor of the load cell (280.25 kg/mv) and reading the voltage output from the voltmeter, the magnitude of load could be calculated. As a result the magnitude of load applied could be increased incrementally by increasing the pressure relief setting of the hydraulic pump.

Ordinarily, the load frame is bolted to the chamber top plate, which seals the sample in the chamber. Since the top plate was not used, another method of sercuring the frame was needed. This was accomplished by designing two load frame plates that attached to the 5 cm (2 in) flange to which the top plate of the chamber is usually bolted. The plates, which were machined at Va. Tech, were 76.2 x 12.7 cm (30 x 5 in) and 5 cm (2 in) thick. A series of seven 3.2 cm (1.25 in) holes corresponding to the holes used to bolt the top plate down were drilled in the plates. Also a series of holes corresponding to the holes located on the top of the chamber plate used to bolt the load frame to the top plate were machined. In this way the load frame was bolted directly to the calibration chamber without any changes being made in either the chamber or the load frame.

Because it was desired to simulate field conditions as closely as possible, the effects of overburden pressure on the footing models had to be taken into account. In order to facilitate this, 100 lb bags of monterey # 0/30 sand were placed on each side of the models. A total of five bags were stacked on each side of the model in an area of approximately 2.5 square feet to produce a surcharge of 200 psf around the footings. While every effort was made to simulate the actual overburden pressures encountered in the field, it is recognized that physical constraints of the model prevent an exact value of surcharge being obtained. From Figure 3, one sees that there is a gap between the model and the bags of sand. Also the distribution of pressure from the bags was assumed to be constant when in fact the exact distribution is unknown. And the ends of the models were left unconstrained because there was no room to place sand bags between the footings and the chamber wall. Therefore the overburden pressure was assumed to vary from 100 psf to 300 psf when predicting the settlement of the footing sections. In this way a range of expected settlement can be obtained and compared with the observed settlement of the footing sections.

The total load to be applied was limited by the capacity of the hydraulic pump and was 4535.9 kg (10000 lbs), applied in increments of 453.6 kg (1000 lbs). Settlement was measured after each load interval, as with a standard plate load test, using two procedures. Assuming that the footing sections responded as one rigid unit, settlement was measured with a dial gauge located at the center of the footing. This dial gauge was attached to the cylinder mounts of the cross beam and was able to detect movements of the footing sections of .0254 mm (.001 in). Secondly a survey of the footing model was taken using a standard transit capable of taking measurements to .25 mm (.01 in). Both these methods have the degree of accuracy required for the settlements expected for this project. The survey was taken for two reasons: as a

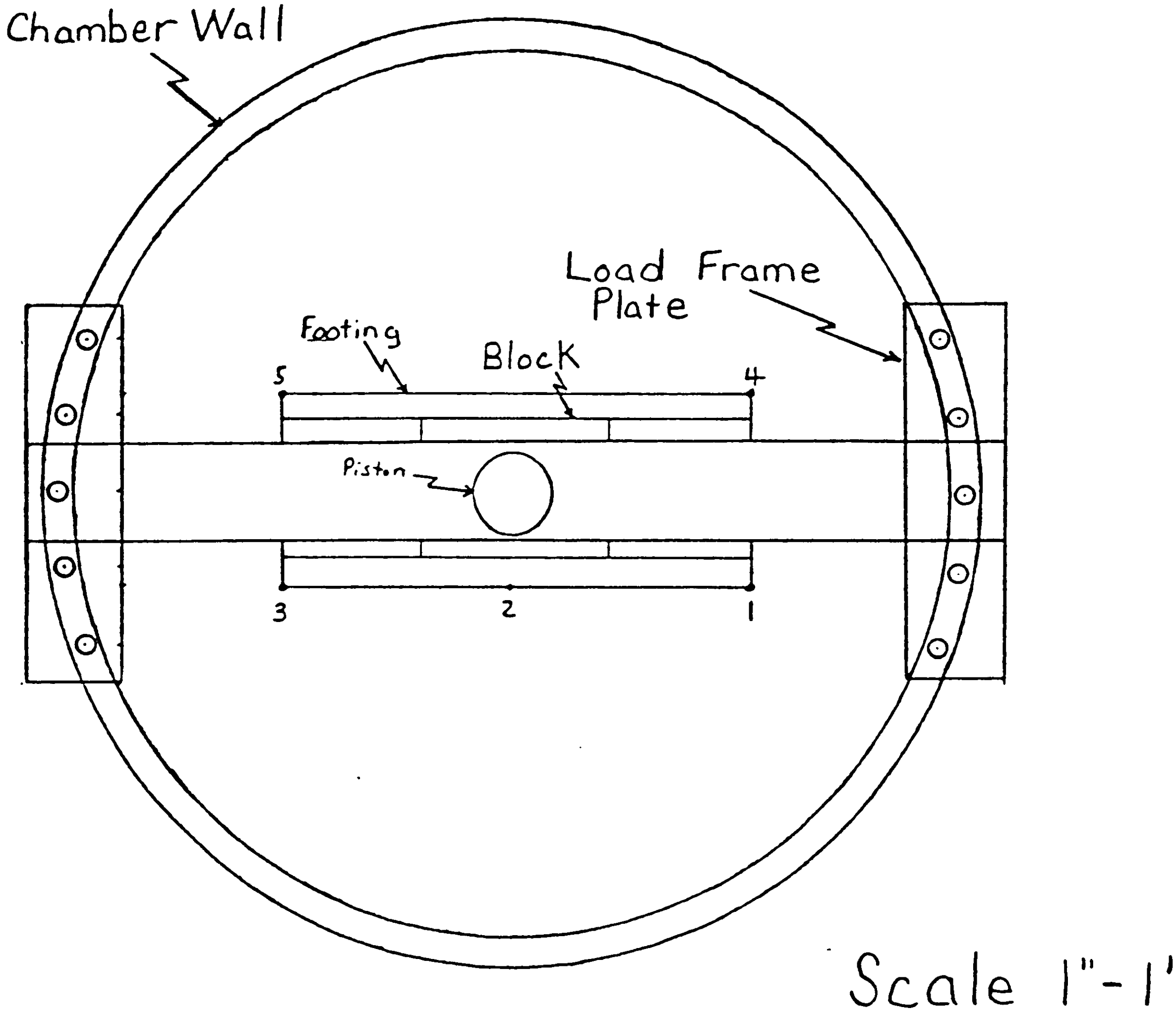


Figure 4: Top View of Testing Configuration and Survey Points in Calibration Chamber

check to the accuracy of the dial gauge readings, and as a method to detect any tilting or uneven settlement within the model. A drawing of the survey points used is provided in Figure 4, and the location of these points was the same for every test. From this drawing one sees that the survey was taken with shot # 1 and # 4 at the corners of one end of the model, and shot # 3 and # 5 at the other. Relative elevations were taken at both ends and the middle of the footing models to detect differential settlement within the footings, and also to insure no tilting of the models was occurring during application of load. Tilting of the model would indicate uneven distribution of the load by the footings or that the application of the load from the cylinder was off center. Either of these situations could cause damage to the cylinder and complicate interpretation of the test results.

The procedure used to conduct a test on a footing model was the same for each footing. After the sandbags were placed the load frame was bolted on the chamber. Before the load frame was in place the cylinder piston was moved in and out of the cylinder several times to insure that the hydraulic hoses contained no air, which would cause an inaccurate measurement of the magnitude of load applied. Once the load frame was secured on the chamber, the load cell located on the cylinder piston was connected to a voltmeter and the dial gauge was clamped on the cross beam. Running a test required three people be present. One person stayed on top of the chamber to read the dial gauge and hold the measuring rod for the survey; another person controlled the pressure relief valve to maintain a constant load while measurements were being taken; and a third person ran the transit and recorded all measurements. As stated earlier, the load was applied incrementally in steps of 453.6 kg (1000 lbs) to a maximum of 4535.9 kg (10000 lbs). Also, once the maximum was reached, the load was reduced to 2723.4 kg (6000 lbs) and then 907.8 kg (2000 lbs), and finally increased back up to 4535.9 kg (10000 lbs). Once the tests were completed the load frame was removed and the footing models were inspected for any visual evidence of cracking or irregularities.

While the models were loaded to approximately twice the allowable foundation load, the loads applied were well below the bearing capacity of both the medium dense and loose samples. Using a footing width of 1 foot and assuming a uniform sand sample the bearing capacity of a footing on a medium dense sand (Dr=63%) is 5.5 ksc (11000 psf), and the capacity of a footing on a loose sand (Dr=23%) is 3.25 ksc (6500 psf). The maximum bearing pressure applied to the footing sections was 1.6 ksc (3200 psf).

TEST RESULTS

The results from the last four tests can be seen in tables 1 thru 4. These tables contain the bearing pressure applied, the dial gauge displacements and the survey of the footing section. From the survey it is seen that the two corners at each end of the footing sections have relatively equal settlements. A difference in settlement of 3 mm (0.12 in) in adjacent corners was the maximum amount recorded. Based on the accuracy desired for this project, this difference in settlement had no significant effect on the test results.

The settlement of the model was measured directly with a dial gauge and checked with shot # 2 of the survey. Figures 5 and 6 are graphs of settlement vs. bearing pressure. The Footer Block system is designed mainly for one and two story buildings with bearing pressures up to 1 ksc (2000 psf). The plotted results show that for bearing pressures up to 2000 psf, settlement of the Footer Block was nearly the same as that of the monolithic footing, the greatest difference being 2 cm (0.08 in). As the pressure was increased above 1 ksc (1tsf) the settlement of the footing sections became less consistent in all cases. Results show that with the loose sand, the Footer Block section settled less than the monolithic footing, while the opposite was true for the

Table 1. Settlement Measurements of Monolithic Footing on Medium Dense Sand (Dr=63%)

Bearing Press. (psf)	Dial Gauge Displacement (in)	Survey of Footing Displacement (in) #1	#2	#3	#4	#5
0	0.000	26.75	26.75	26.81	26.69	26.63
400	0.031	26.75	26.69	26.69	26.69	26.63
800	0.085	26.75	26.75	26.81	26.75	26.75
1200	0.152	26.81	26.81	26.88	26.75	26.75
1600	0.223	26.88	26.88	26.94	26.81	26.88
2000	0.333	26.94	27.00	27.06	26.88	27.00
2400	0.430	27.00	27.06	27.19	26.94	27.13
2800	0.539	27.06	27.19	27.31	27.00	27.25
3200	0.734	27.19	27.38	27.56	27.13	27.50
Settlement	0.734	0.44	0.63	0.75	0.44	0.87

Table 2. Settlement Measurements of Footer Block on Medium Dense Sand (Dr=63%)

Bearing Press. (psf)	Dial Gauge Displacement (in)	Survey of Footing Displacement (in) #1	#2	#3	#4	#5
0	0.000	26.06	26.00	26.19	26.13	26.31
300	0.025	26.06	26.00	26.25	26.19	26.38
600	0.083	26.06	26.06	26.31	26.25	26.44
900	0.139	26.13	26.06	26.38	26.25	26.44
1200	0.206	26.19	26.19	26.38	26.31	26.56
1500	0.276	26.25	26.25	26.50	26.38	26.63
1800	0.365	26.31	26.31	26.56	26.44	26.69
2100	0.459	26.38	26.44	26.69	26.44	26.75
2400	0.546	26.44	26.50	26.81	26.56	26.81
2700	0.684	26.56	26.63	26.94	26.69	27.00
3000	0.899	26.63	26.75	27.06	26.75	27.13
1800	0.773	26.69	26.75	27.06	26.75	27.13
600	0.727	26.63	26.75	27.00	26.75	27.13
1800	0.773	26.63	26.75	27.06	26.75	27.13
Settlement	0.899	0.56	0.75	0.88	0.62	0.81

Table 3. Settlement Measurements of Footer Block on Loose Sand (Dr=23%)

Bearing Press. (psf)	Dial Gauge Displacement (in)	Survey of Footing Displacement (in) #1	#2	#3	#4	#5
0	0.000	24.25	24.44	24.63	24.38	24.81
300	0.090	24.25	24.56	24.69	24.44	24.81
600	0.175	24.31	24.63	24.69	24.44	24.94
900	0.273	24.44	24.69	24.81	24.56	25.00
1200	0.416	24.50	24.81	25.00	24.69	25.19
1500	0.610	24.75	24.94	25.13	24.88	25.31
1800	0.773	24.88	25.13	25.31	25.00	25.50
2100	0.926	25.06	25.38	25.44	25.13	25.63
2400	1.136	25.19	25.50	25.69	25.38	25.88
2700	1.359	25.44	25.69	25.94	25.56	26.06
3000	1.564	25.63	25.94	26.13	25.75	26.31
1800	1.534	25.63	25.94	26.06	25.69	26.31
600	1.491	25.63	25.88	26.13	25.69	26.25
1800	1.533	25.63	25.94	26.13	25.75	26.31
3000	1.619	25.69	26.00	26.13	25.81	26.38
Settlement	1.619	1.44	1.56	1.56	1.44	1.56

Table 4. Settlement Measurements of Monolithic Footing on Loose Sand (Dr=23%)

Bearing Press. (psf)	Dial Gauge Displacement (in)	Survey of Footing Displacement (in) #1	#2	#3	#4	#5
0	0.000	25.75	25.69	26.00	25.81	26.19
400	0.122	25.81	25.75	26.06	25.94	26.25
800	0.279	25.94	25.88	26.19	26.06	26.38
1200	0.453	26.13	26.19	26.38	26.25	26.56
1600	0.685	26.31	26.44	26.63	26.44	26.75
2000	1.027	26.69	26.75	27.00	26.81	27.13
2400	1.395	27.06	27.13	27.31	27.13	27.50
2800	1.782	27.44	27.50	27.69	27.50	27.88
3200	2.217	27.81	27.94	28.13	28.00	28.31
3600	2.461	28.06	28.13	28.38	28.06	28.56
4000	2.789	28.44	28.50	28.69	28.50	28.88
2400	2.759	28.38	28.38	28.69	28.50	28.86
800	2.713	28.38	28.50	28.69	28.50	28.88
2400	2.757	28.38	28.50	28.69	28.50	28.88
4000	2.883	28.50	28.63	28.81	28.63	29.00
Settlement	2.883	2.75	2.94	2.81	2.81	2.81

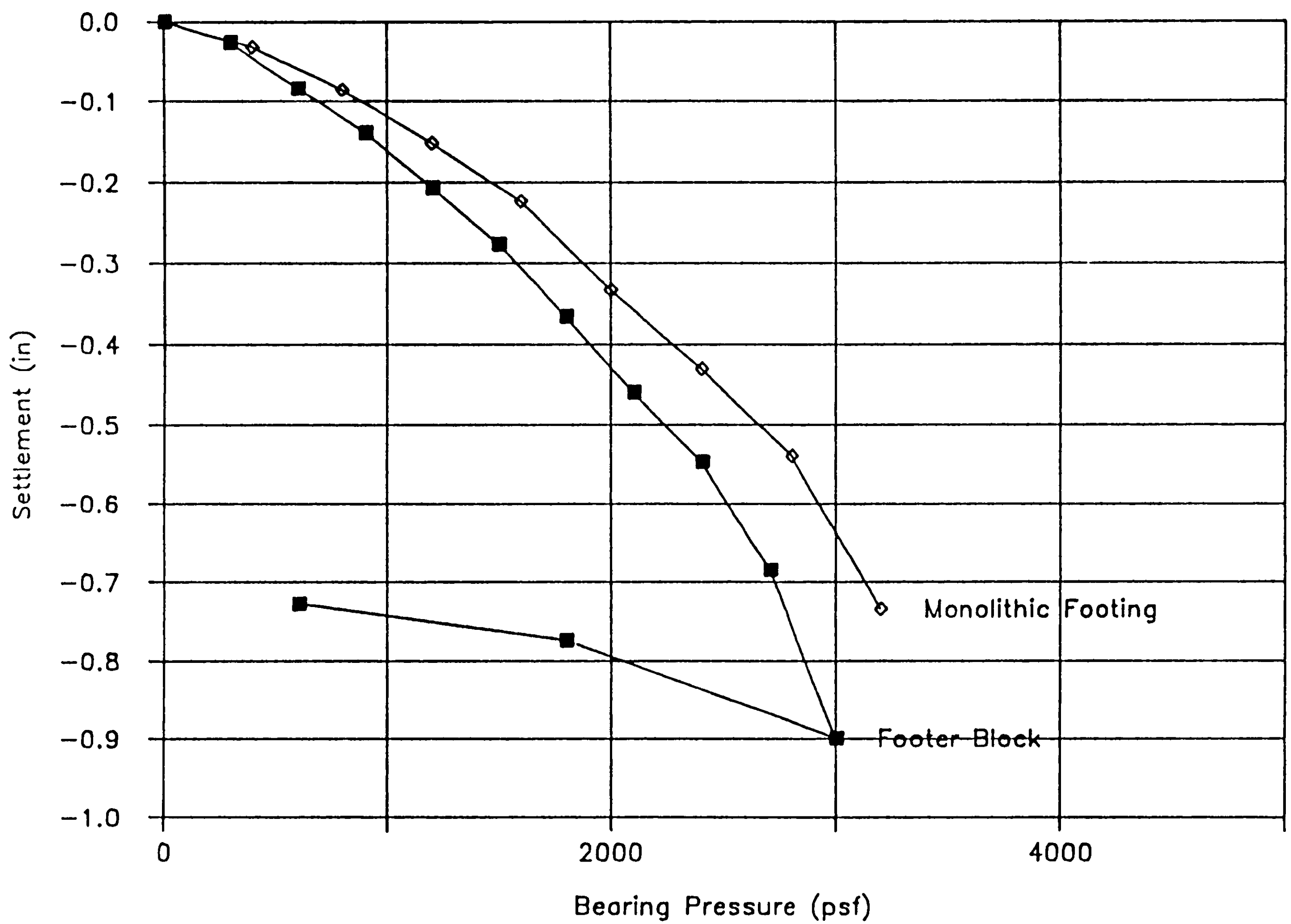


Figure 5. Settlement vs. Bearing Pressure
Medium Dense Sand (Dr=63%)

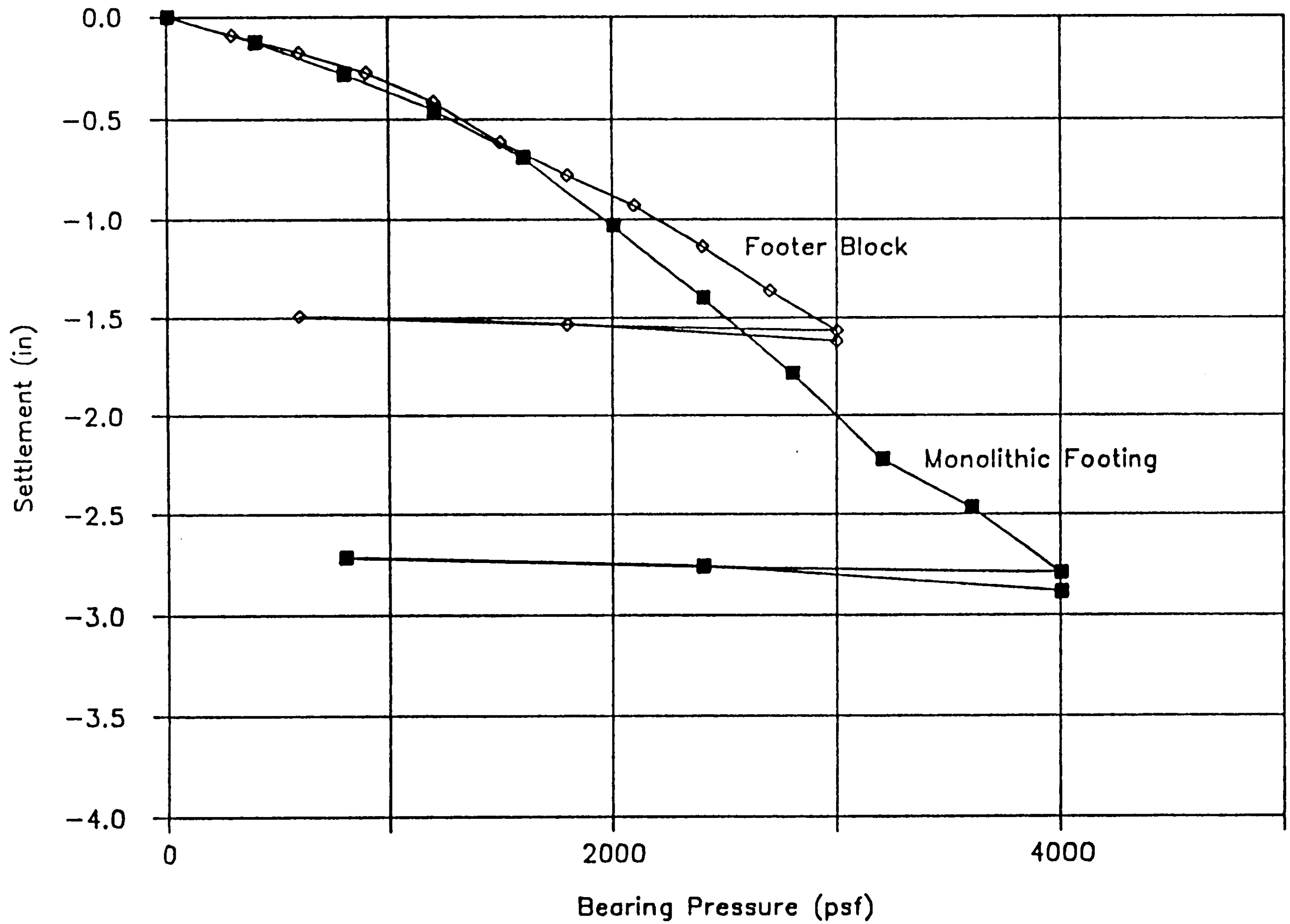


Figure 6. Settlement vs. Bearing Pressure
Loose Sand (Dr=23%)

medium dense sand. The reasons for this behavior are unclear, but are likely due to either experimental error or to some form of scale effect associated with the fact that the Footer Block system and the monolithic footing are not the same size.

Based on the four tests conducted on the footing models some general comments concerning the footer block system can be made. The tests conducted verify that the footer block system settles essentially the same amount as traditional monolithic footings when equivalent loads are applied. Also possibly because of the interlocking characteristic of the Footer Blocks, the blocks act as a single unit and distribute the load evenly throughout the foundation. It is entirely possible that where seismic activities are not present, the footer block system needs no additional reinforcement besides the interaction between adjacent blocks. While it may not necessarily be true that the Footer Block system provides a better foundation than traditional footing systems, it does provide a system that operates as well as traditional systems. The advantages of this system are related to the construction environment and procedure. The fact that this system is hand placed with no grace period between foundation placement and wall construction is of great importance to small construction projects, since it decreases the costs of such projects with regards to skilled labor and time needed for construction. Also with the segmented footing units, the use of this system is not dependent on limitation of access of large equipment such as concrete mixing trucks.

While the footing block system performed quite satisfactorily in the tests conducted, there are some points to keep in mind when evaluating the system. At loads above the recommended allowable load the performance of the Footer Blocks is still unclear. There is the possibility of chamber boundary effects at higher load levels. Also, these tests were conducted on a specific type of soil (Monterey # 0/30 sand) under laboratory conditions and care must be taken in applying the results to other soils and to field situations.

COMPARISON OF LOAD-SETTLEMENT RESULTS TO PREDICTIONS BASED ON SCHMERTMANN'S PROCEDURE

It is of interest to know the extent to which the results from the four load tests are similar to what one might expect based on past experience with field measurements. For example, do loose and medium dense sands in the field undergo the same settlement with the same conditions of load as shown by the sand in the test chamber? Or, conversely, is there something different about naturally-occurring sand deposits that makes them behave differently under load from artificially prepared samples? These questions will be examined in this section.

Field experience, together with rational thinking, is summarized in semi-empirical design formulas for calculating settlement in sands under load. There are many such formulas, with one of the more popular being the Schmertmann formula, which uses results of cone penetration testing (qc) to estimate settlement of shallow foundations. Schmertmann's formula is based on rational thinking coupled with a large amount of actual field measurements. Accordingly they provide an approximation of the accumulative experience with the settlement of shallow foundations on sand in the field.

Previous work by Eid (1987) with the calibration chamber produced a large data base for tip resistance values of medium dense and loose sand as a function of vertical effective pressure. This data is presented in Figure 7. As

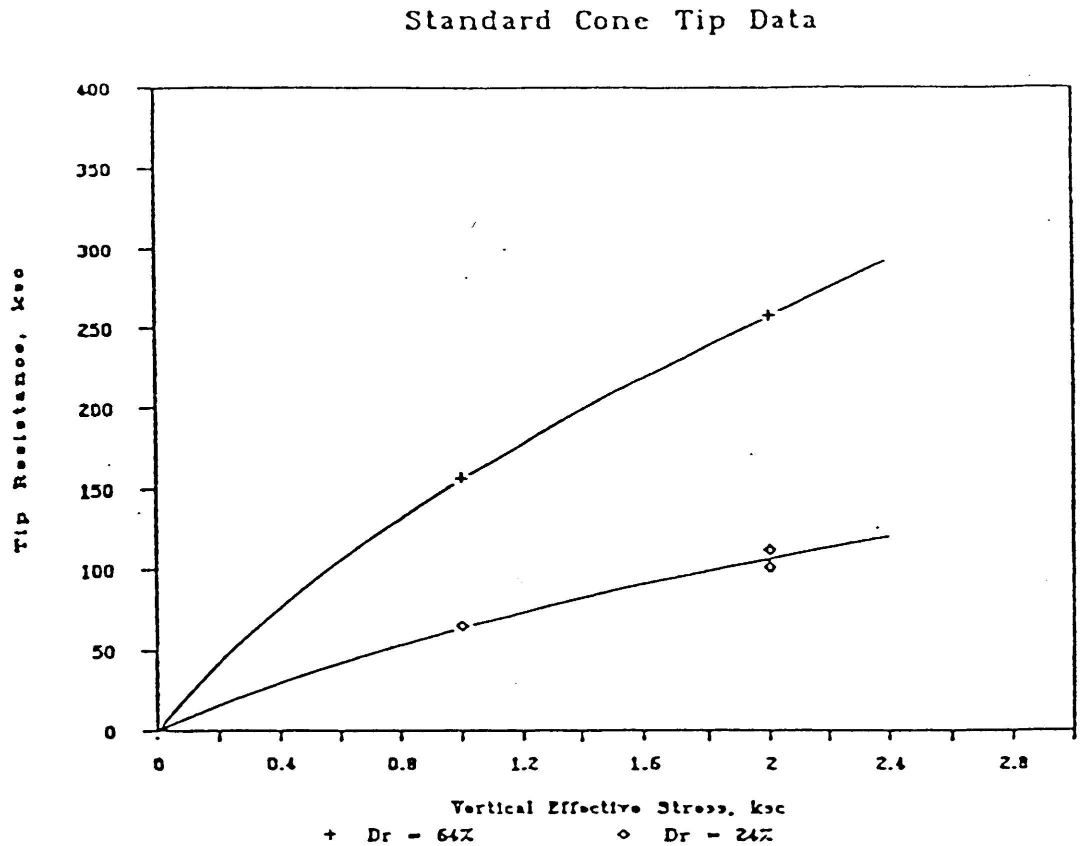


Figure 7 : Standard Cone Tip Resistance As a Function of Relative Density and Vertical Effective Stress (After Eid, 1987)

shown, when dealing with overburden pressures below 0.4 ksc (0.4 tsf), the accuracy of the tip resistance obtained depends a great deal on value of vertical effective stress used. At stresses of 1 to 2 ksc (1 to 2 tsf), a 10% variability in the vertical stress used produces almost no change in the tip resistance value obtained. Yet a 10% variability at vertical stresses below 0.2 ksc (0.2 tsf) results in a significantly different value of tip resistance. As stated earlier, the actual effect of the surcharge used with the footing sections was approximated to be 0.1 ksc (0.1 tsf) with the total vertical effective stress being 0.15 ksc (0.15 tsf). In order to provide for any inaccuracies in the approximation of this value, a range from 0.1 ksc (0.1 tsf) to 0.2 ksc (0.2 tsf) was used. These values were used to obtain a range of tip resistance and a corresponding range of predicted settlements using Schmertmann's procedure. Details of the calculations used are presented in the Appendix and the results reported in Table 5.

From Table 5 it is evident that in three cases the observed values are slightly higher then the predicted range, and in the other case, at the high end of the predicted range. It is likely that the reason for this trend is the nature of the artificially prepared samples. These samples, prepared in the laboratory, have relatively no stress

Table 5. COMPARISON OF THE RANGE OF PREDICTED SETTLEMENT VALUES WITH OBSERVED VALUES

	Medium Dense Sand (Dr = 63%)		Loose Sand (Dr = 23%)	
	Footer Block	Monolithic	Footer Block	Monolithic
Predicted Range of Settlement	0.34 - 0.18	0.28 - 0.14	0.97 - 0.46	0.79 - 0.37
Observed Values	0.42	0.33	0.87	1.02

* Settlement Value Units - (inch)
** All Values Obtained at q = 1 tsf

history. Whereas field soil, either through cyclic wetting and drying, previously applied loads, or some type of vibrational action, always has some significant stress history. Almost all of Schmertmann's data is from field testing.

SUMMARY AND CONCLUSIONS

From the results of load tests conducted on footing sections on loose and medium dense sand in this study some general statements can be made as follows: 1) Based on the construction of the footing sections under experimental conditions, the Footer Block system is much simpler and less expensive to construct than a poured footing. 2) This study demonstrates that footing load tests can be conducted successfully in the Virginia Tech calibration chamber as long as loads of less than 4535.9 kg (10000 lbs.) are used and boundary effects are minimized by limiting the size of the model tested. 3) For both loose and medium dense sand tested, there is no significant difference between the performance of traditional cast-in-place footings and the Footer Block system. 4) Settlements of footings observed in the calibration chamber are larger than would be predicted considering the relative density of the sand. It can be shown using Schmertmann's procedure that at the same relative density, the predicted settlement of the footing sections in the chamber is higher than expected for the test sample, probably because field soil has a stress history considerably different from the normally consolidated, rained samples in the experimental chamber.

There are still questions to be answered in order to more fully understand the results of this study. Additional valuable research in this area would be to test circular footings in the chamber. This way the boundary effects of the chamber would be equal on all sides of the footing. Also it would be beneficial to determine the actual influence of strain throughout the sand sample by installing strain gauges or pressure meters in the chamber and then conducting load tests on the samples.

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APPENDIX

Prediction of the Range of Settlement Using Schmertmann's Procedure and Values of Tip Resistance Reported by Eid (1987)

$\rho = q \; \Sigma(Iz/Es)\Delta z$

Medium Dense Sand (Dr=63%)

Range of Tip Resistance (qc): 40 tsf (σ = 0.2 tsf)
20 tsf (σ = 0.1 tsf)

Es = 3.5qc; Range of Es: 140 tsf - 70 tsf

Footer Block: (Es = 140 tsf, q = 1 tsf)

Referring to the Influence Diagram of the Footer Block (Fig.8)

Depth (in)	Δz(ft)	Iz	(Iz/Es)Δz
0-16	1.3	0.480	0.005
16-32	1.3	0.630	0.006
32-48	1.3	0.375	0.004
			Σ 0.015

ρ = (1 tsf)(0.015) = 0.015 ft = 0.18 in.

Footer Block: (Es = 70 tsf, q = 1tsf)

Depth (in)	Δz(ft)	Iz	(Iz/Es)Δz
0-16	1.3	0.480	0.009
16-32	1.3	0.630	0.012
32-48	1.3	0.375	0.007
			Σ 0.028

ρ = (1 tsf)(0.028) = 0.028 ft = 0.34 in.

Monolithic Footing: (Es = 140 tsf, q = 1 tsf)

Referring to Influence Diagram of Monolithic Footing (Fig.9)

Depth (in)	Δz(ft)	Iz	(Iz/Es)Δz
0-12	1	0.480	0.0034
12-24	1	0.630	0.0045
24-36	1	0.375	0.0027
36-48	1	0.130	0.0009
			Σ 0.012

ρ = (1 tsf)(0.012) = 0.012 ft = 0.14 in.

Monolithic Footing (E_s = 70 tsf, q = 1 tsf)

Depth (in)	Δz(ft)	Iz	(Iz/Es)Δz
0-12	1	0.480	0.0069
12-12	1	0.630	0.0090
24-36	1	0.375	0.0054
36-48	1	0.130	0.0019
			Σ 0.023

ρ = (1 tsf)(0.023) = 0.023 ft = 0.28 in.

Footer Block: Loose Sand (Dr=23%)

Range of Tip Resistance (qc): 15 tsf (σ = 0.2 tsf)
7 tsf (σ = 0.1 tsf)

Es = 3.5qc; Range of Es: 52.5 tsf - 24.5 tsf

Footer Block: (Es = 52.5 tsf, q = 1tsf)

Use the Same Depth Increments and Influence Factors as the Medium Dense Footer Block Calculations.

Σ (Iz/Es)Δz = 0.038

ρ = (1 tsf)(0.038) = 0.038 ft = 0.46 in.

Footer Block: (Es = 24.5 tsf, q = 1 tsf)

Σ (Iz/Es)Δz = 0.081

ρ = (1 tsf)(0.081) = 0.081 ft = 0.97 in.

Monolithic Footing: (Es = 52.5 tsf, q = 1 tsf)

Use the Same Depth Increments and Influence Factors as the Medium Dense Monolithic Footing Calculations.

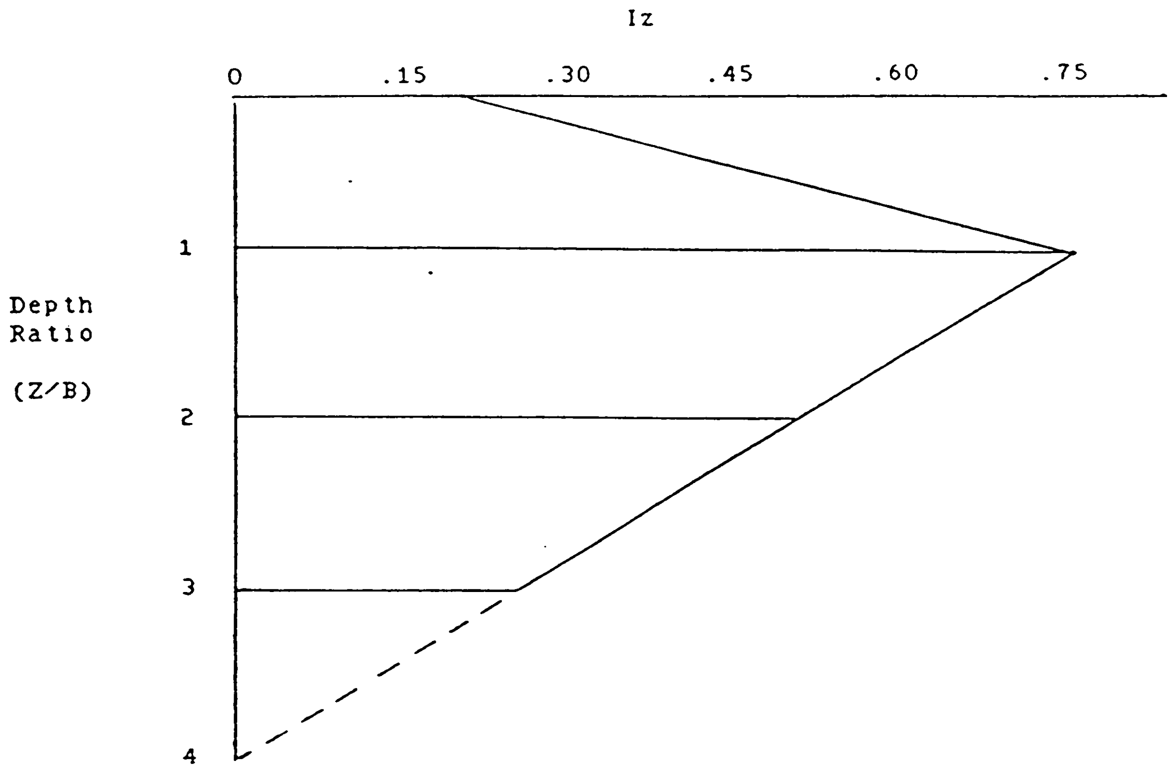
Σ (Iz/Es)Δz = 0.031

ρ = (1 tsf)(0.031) = 0.031 ft = 0.37 in.

Monolithic Footing: (Es = 24.5 tsf, q = 1tsf)

Σ (Iz/Es)Δz = 0.066

ρ = (1 tsf)(0.066) = 0.066 ft = 0.79 in.



Izmax = 0.5 + 0.1(q/σ)^0.5

where q = 1 tsf and σ = γ(at depth = B) + surcharge = 0.15 tsf

Izmax = 0.5 + 0.1(1/0.15)^0.5 = 0.76

Figure 8. Footer Block Influence Diagram

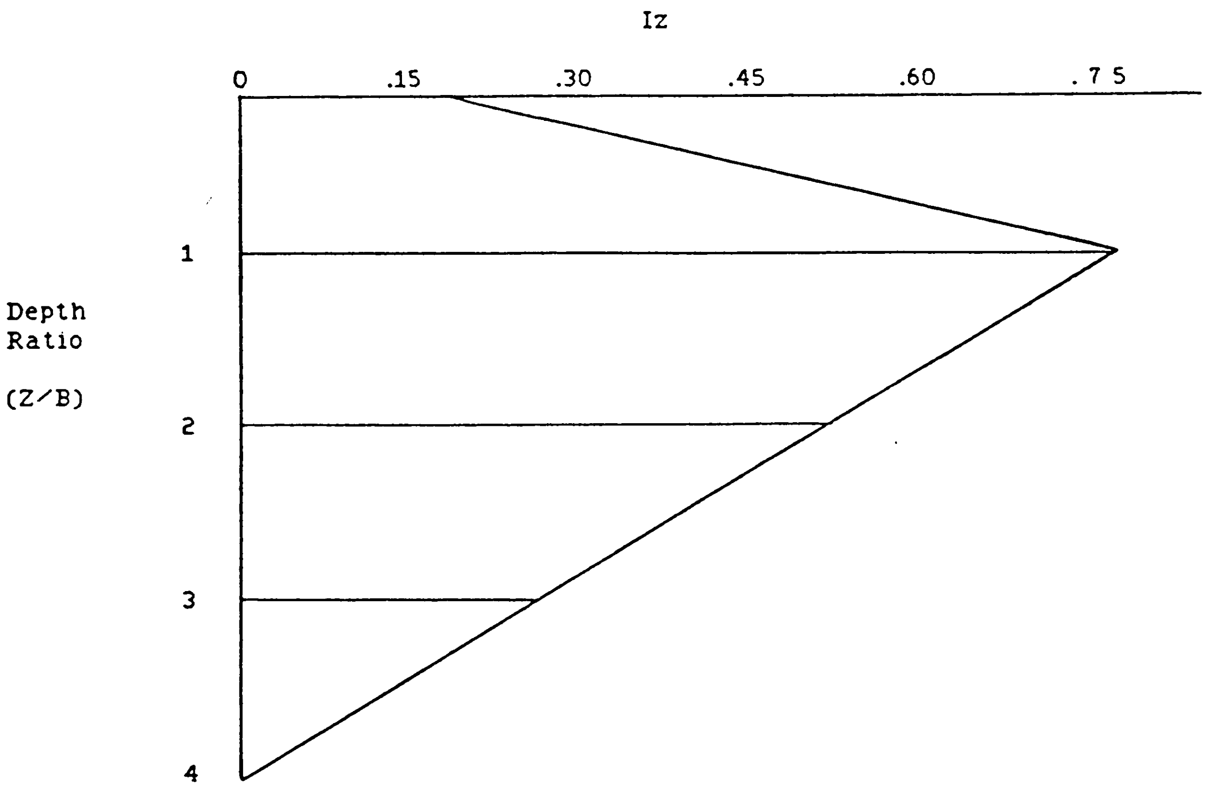


Figure 9. Monolithic Footing Influence Diagram

DEFINITION OF TERMS USED IN THE APPENDIX

ρ - Settlement (in)

q - Intensity of Load (tsf)

Iz - Strain Influence Factor

Es - Elastic Modulus of the Sand Medium

Δz - Thickness of Layer (in)

qc - Cone Penetration Tip Resistance (tsf)

Cb - Width Correction Factor

σ - Vertical Effective Stress

γ - Unit Weight of Soil (pcf)

GRAIN SIZE DISTRIBUTION CURVE

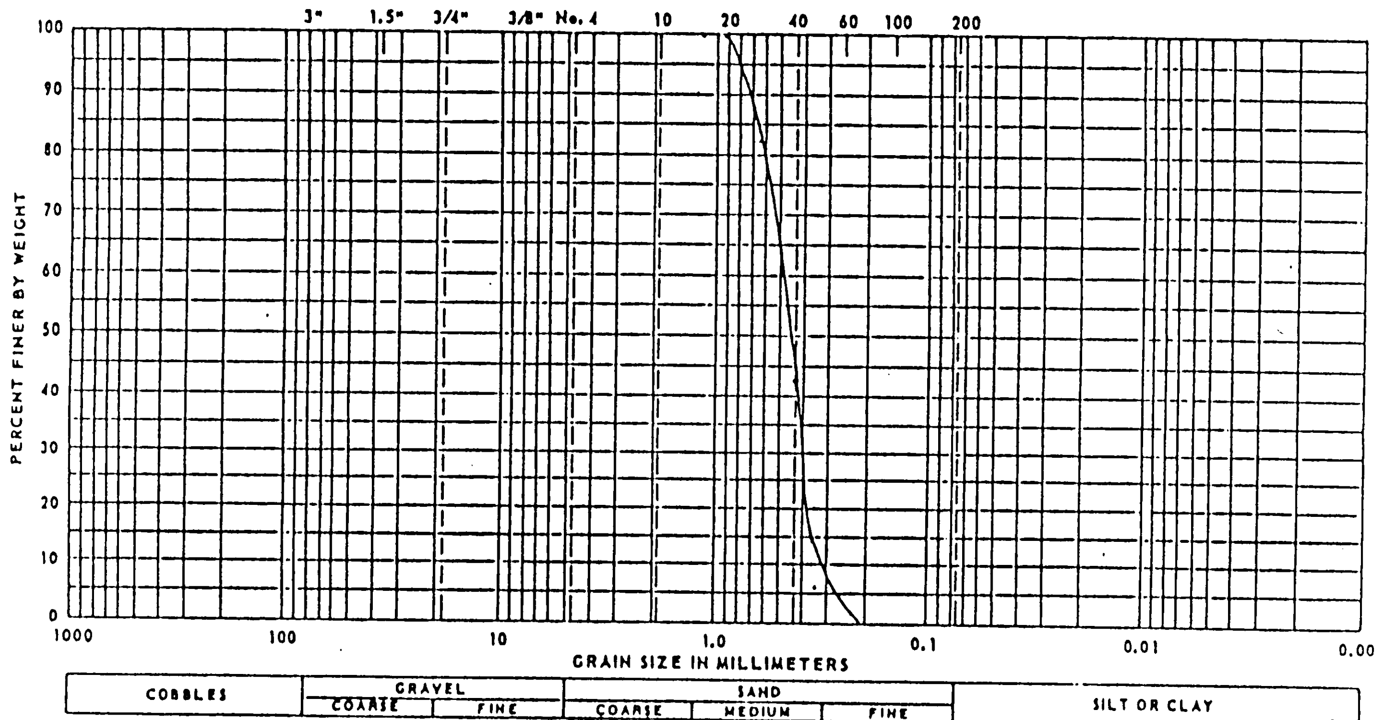


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Figure 10. Grain Size Distribution for Monterey No. 0/30

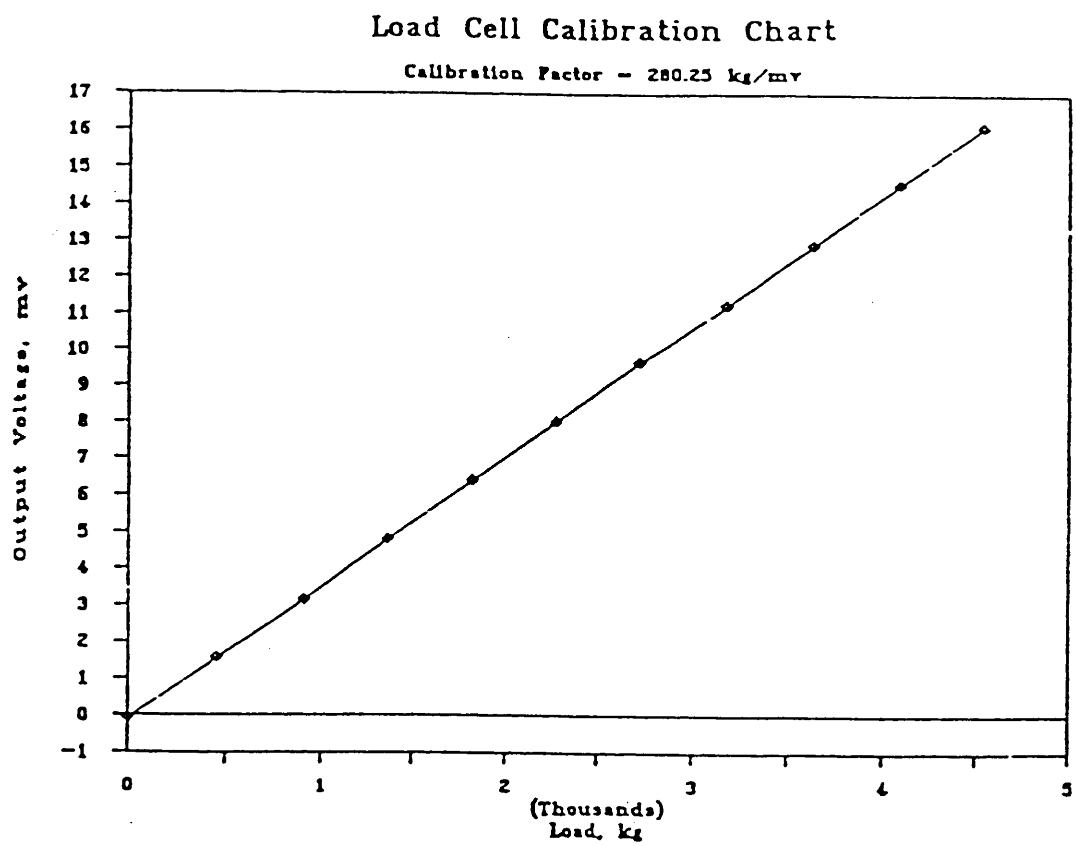

Figure 11: Load Calibration Chart for 12 Kip Load Cell
(After Sweeney, 1987)

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