Enhancement of Caisson Capacity by Micro-Fine Cement Grouting --A Recent Case History--

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Abstract

Pressure grouting techniques have been used for many years to enhance the performance of axially loaded caissons, either as a remedial technique, or as an integral step in the foreseen construction program. This paper describes the work undertaken with microfine cement to upgrade the capacity of existing caissons at an industrial facility in Jonesboro, AR. Details are provided of the test program, and specifically the performance of the test caisson, load tested before and after permeation grouting of the bearing stratum. Grouting produced an improvement in load-bearing capacity by over three times. The procedures used in the subsequent production program are also described.

The Problem

The Owner wished to expand a cereal production facility at his plant in Jonesboro, AR. This expansion involved adding a new structure outward from the exterior wall of the east side of the existing building. However, additional loading from this new structure was determined likely to overload four of the existing 14 foot long belled caissons under the common exterior wall, installed 6 years earlier.

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Site Conditions and Caisson Load Test Performance Before Grouting

Data from boring E13 (Figure 1) indicated loose, moist, brown, clayey sand for the upper 12 feet, and N values of 3-10. Therebelow were a series of medium dense to dense brown and grey silty fine sands, with N values of 17 to 38. The water table was about 23 feet below the surface. Mechanical grain size analyses indicated a portion 6 to 13% finer than the #200 sieve.

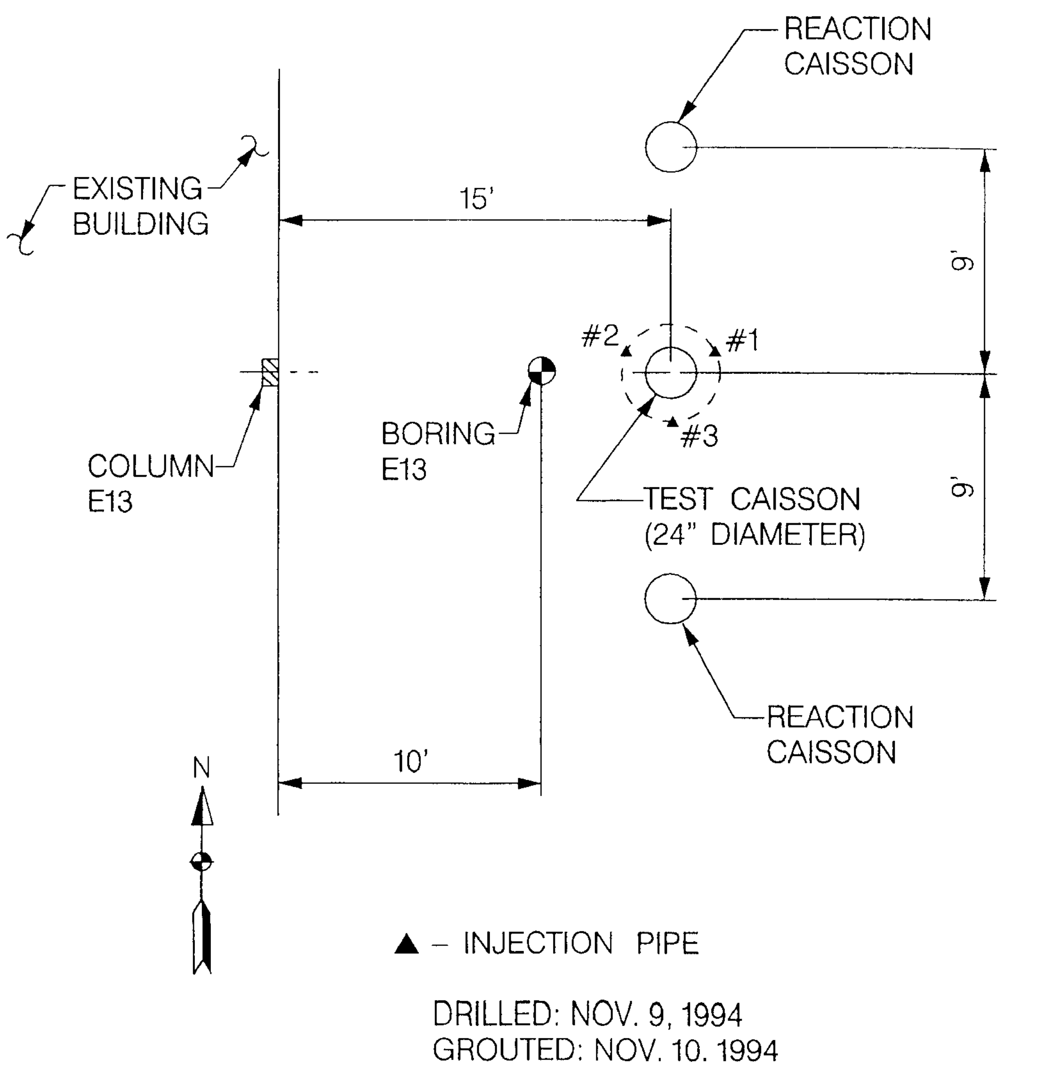


Figure 1. Plan of test caisson arrangement.

It was agreed to install and test a new caisson to better define the bearing capacity of the lower sand, the founding stratum for the existing piles. The test comprised a 24 inch diameter, straight shaft, reinforced concrete caisson, 14 feet long - the same depth as the existing belled caissons. It was cast inside a 24 inch diameter lubricated sonotube form to eliminate any skin friction component. Two reaction caissons were installed adjacent (Figure 2) to anchor the load frame.

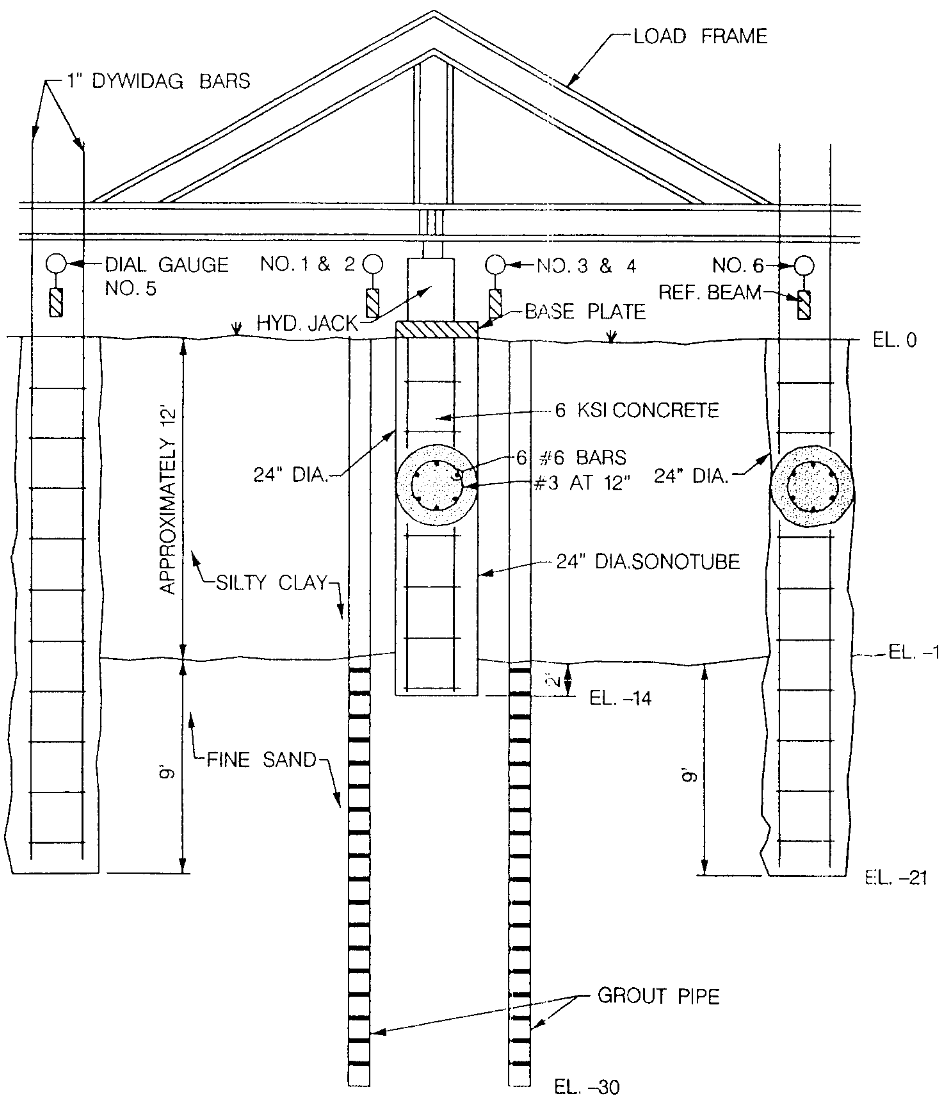


Figure 2. Section of test caisson arrangement.

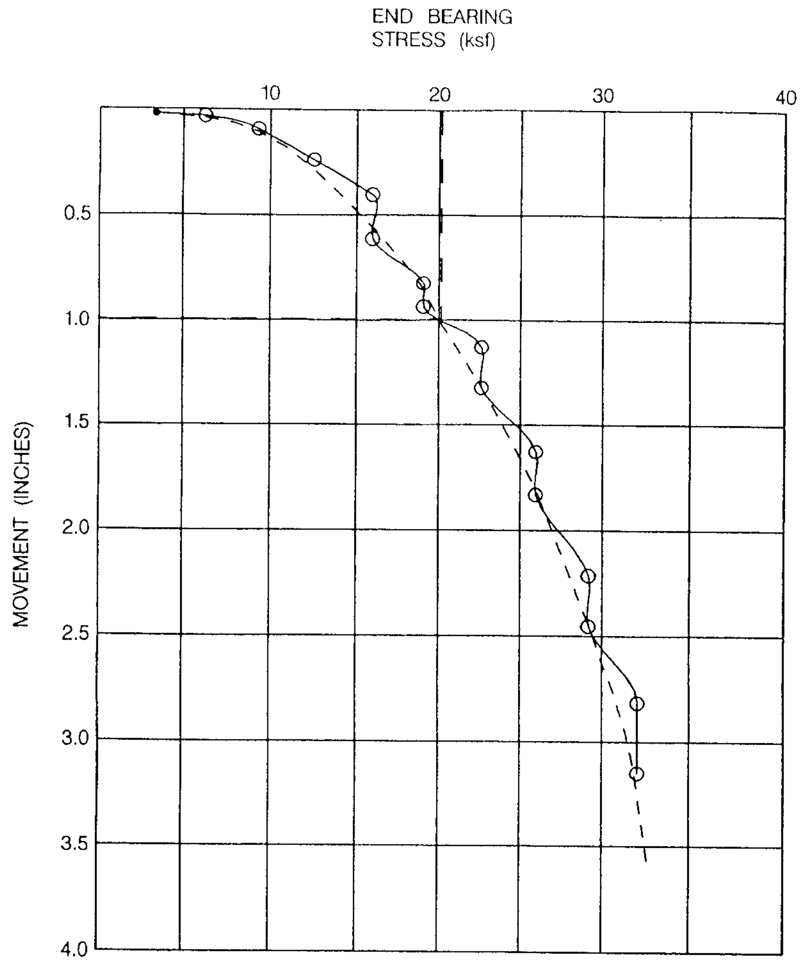


Figure 3. Movement/end bearing stress data for the test caisson, before grouting.

A compressive load test was conducted four days after caisson installation and in accordance with ASTM D-1143. This progressive incremental loading sequence showed that a test load of barely 40 tons could not be maintained with a creep rate less than 0.01 inch per hour. (Figure 3). The Engineer had indicated that the structure could withstand a further total movement of 1 inch. The analysis of the load test data confirmed the ultimate bearing capacity, at this displacement, was 20 ksf. Using a safety factor of 2, and so an allowable end bearing stress of 10 ksf, the Engineer calculated that the bearing capacity of the sand would be exceeded under four of the existing caissons, by factors of 11 to 20%, as shown in Table 1.

Caisson	Bell Diameter	Existing Allowable Load*	Required Future Load	Problem
E9	11 feet	950 kips	1133 kips	19% overload
E11	12 feet	1131 kips	1251 kips	11% overload
E13	12 feet	1131 kips	1357 kips	20% overload
E14	11 feet	950 kips	1102 kips	16% overload

Table 1. Details of existing caissons exceeding original allowable capacities
(*based on allowable bearing capacity of 10 ksf)

Concept of the Solution

Various options were considered, with regard to their impact on cost, time, practicality, likely effect on the existing structures, and likelihood of technical success. The most appropriate solution was agreed to be increasing the bearing capacity of the soil by some form of ground treatment. The contractor proposed a permeation grouting procedure, since this had met with success in similar conditions on other sites (Bruce, 1986), while consideration of the soil granulometry indicated that a microfine cement grout would be suitable. Given that a test caisson was already available, and that, by having tested it in advance of any grouting, it had provided a "baseline" performance level, it was elected to grout under this caisson, and to retest it as a way of demonstrating the effectiveness of the proposal.

Grouting of the Test Caisson

Three vertical grout holes, approximately 4 inches in diameter, were spaced equally around the caisson, and drilled to a depth of 30 feet. Much of the production work was to be conducted inside the building where low headroom restraints and tight controls on effluent and spoil had to be accommodated Therefore, the opportunity was taken to drill these holes, even though they were outside, with the short-mast crawler rig equipped with the 3 foot sections of continuous hollow stem flight augers, foreseen for the later production work.

Sheath Grout

5% Bentonite	9.4#
22.5 Gal. Water	188#
1 bag cement	94#
Specific Gravity	1.32
Marsh Funnel	80+ sec.
Bleed	<2%
Yield per bag of cement	3.5CF

Microfine Grout Mix #1 (W/C Ratio 2:1)

13.5 Gal. Water	110#
25 kg Microcem 900	55#
0.75% Eucon 37	0.4# (approximately 5 fluid ounces)
Specific Gravity	1.26
Marsh Funnel	28 sec.
Bleed	<1%
Yield per bag of cement	2.28 CF

Microfine Grout Mix #2 (W/C Ratio 3:1)

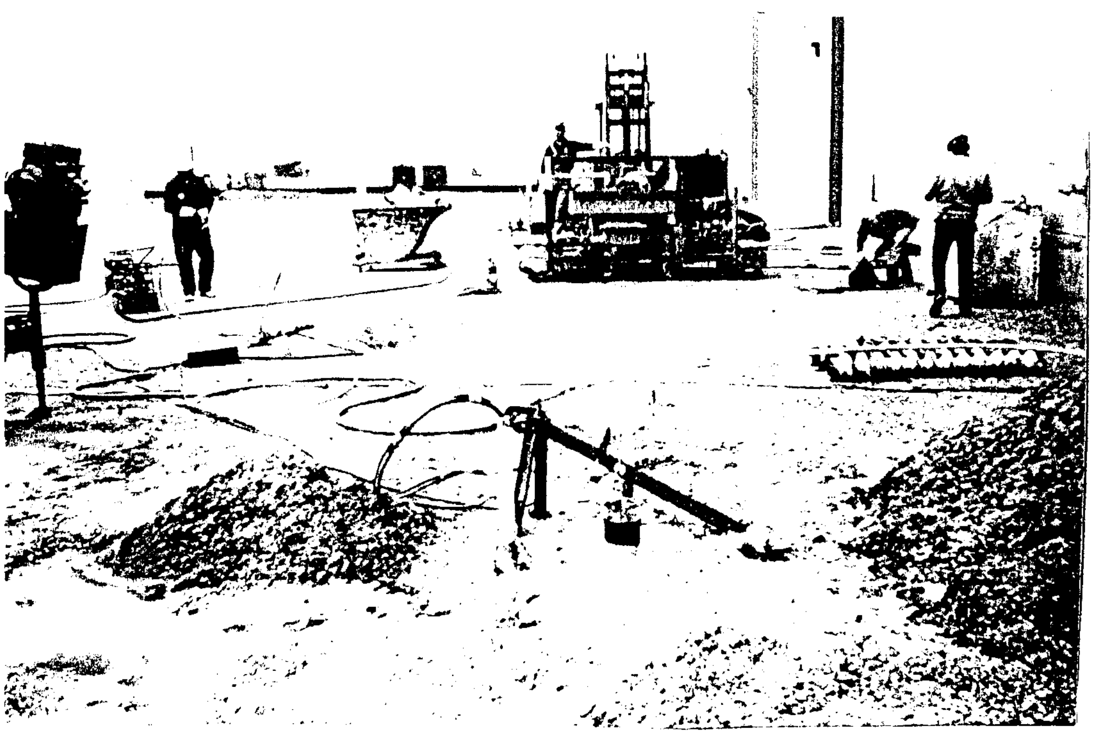
20 Gal. Water	165#
25kg Microcem 900	55#
0.75% Eucon 37	0.4# (approximately 5 fluid ounces)
Specific Gravity	1.19
Marsh Funnel	28 sec.
Bleed	-- (no data)
Yield per bag of cement	2.95 CF

Table 2. Details of grout mixes used.

Each hole contained a 1-1/2 inch diameter sleeved plastic pipe, with sleeves at 1 foot intervals over the lower 20 feet. The annulus grout was tremied in place, and consisted of a low strength, brittle, stable, water-cement-bentonite mix, as shown in Table 2.

The following day, injection through the sleeves was conducted with an inflatable double packer. Microcem 900 was selected as the microfine cement on grounds of technical and cost superiority. It was mixed in a colloidal mixer and pumped via a piston pump (Photograph 1). A water/cement ratio of 3:1 (by weight) was initially used, to verify rheological characteristics and ease of penetration. Manual records were maintained of the injection characteristics of each sleeve, and they quickly suggested a reduction in the water/cement ratio to 2:1.

Based on calculated grout travel distances and soil porosity, an upper limit volume of 1 bag per foot of grout hole was established, in the region between 29 and 15 feet below surface. Due to grout breaking out at the surface from injections into shallow sleeves, the total actually injected was 39 bags. Results from the fluid tests conducted on the various mixes are detailed in Table 2. Injection pressures ranged up to 225 psi and injection rates varied up to 1.7 cf/min. No upwards movement of the pile was recorded during grouting.



Photograph 1. Grouting underway around the test caisson.

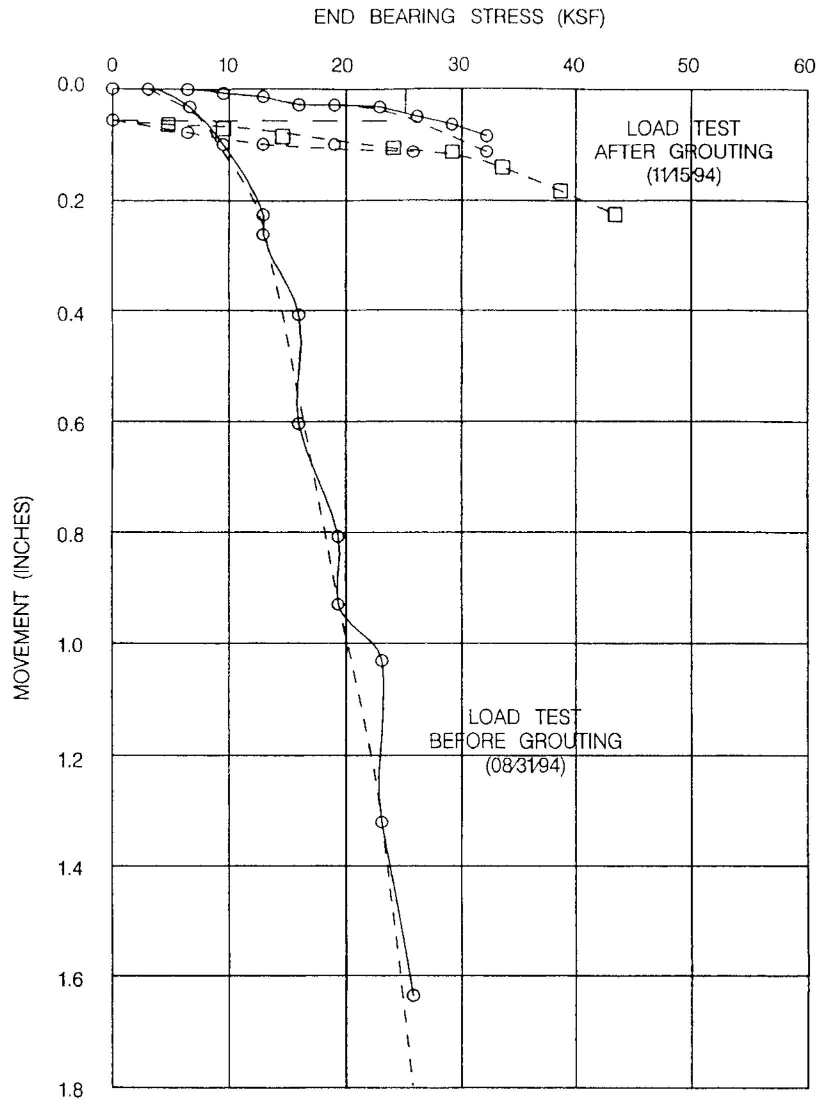


Figure 4. Movement/end bearing stress data for the test caisson, before and after grouting.

Caisson Load Test Performance After Grouting

Five days after grouting, the caisson was retested (Figure 4). The initial test load of 50 tons was held for 3 hours with a total pile head movement of 0.101 inches including 0.020 inches of creep. In the following 23 hours, a further 0.009 inches of creep was recorded. Upon unloading to zero, the permanent movement was 0.050 inches. Thereafter, the owner gave permission to reapply load up to the effective maximum capacity of the loading system, namely 70 tons. This was achieved with a total movement (from start of test) of 0.311 inches, and minimal additional permanent movement.

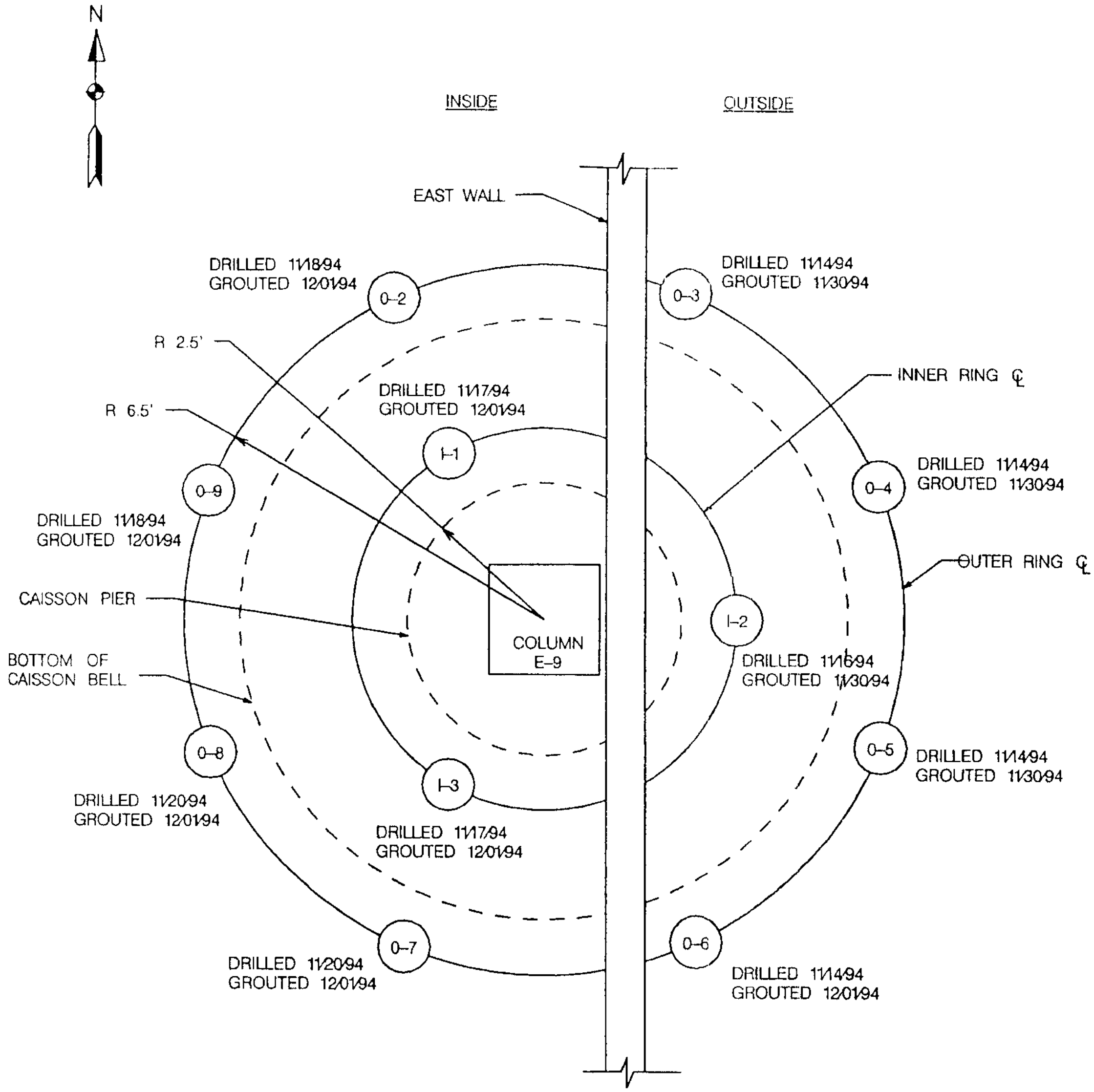


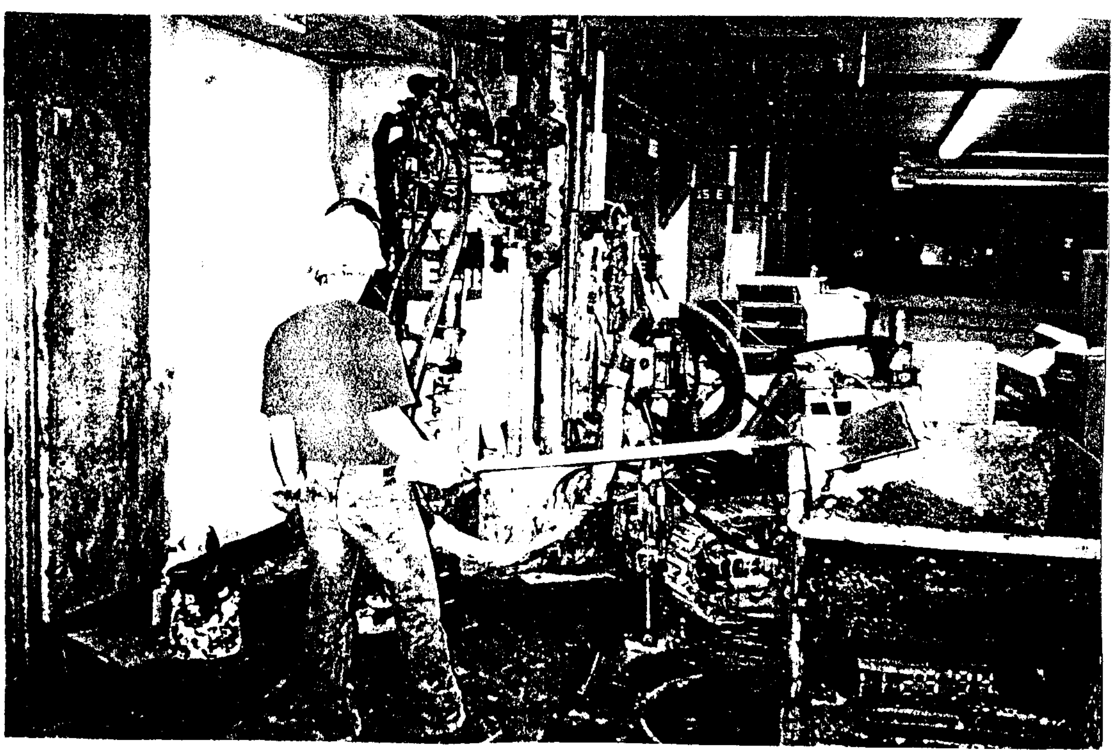
Figure 5. Typical grout hole layout plan for grouting existing caissons.

As a consequence, the allowable bearing pressure for piles in grouted sands was increased to 12.5 ksf at an estimated movement of 0.100 inch. (The tested capacity, at this movement was recorded as about 32 ksf).

Subsequent Treatment of Existing Caissons

Given the extremely positive results from the test caisson, it was decided to enhance the performance of these four existing caissons by similar methods. Eleven grout holes were drilled through and around each bell in concentric rings (Figure 5), to a depth of 15 feet below its base. Six of the eleven holes had to be installed and grouted from within the building (Photograph 2), necessitating precoring of the 6-12 inch thick floor slab. Drill methods and tooling had to be adjusted to accommodate the concrete and soil, but the grouting proceeded as for the test caisson with the 2:1 mix. Columns and floor slab were monitored during injection for uplift. Upon completion of grouting, the holes in the floor slab were backfilled with non-shrink grout.

Strong quality assurance/quality control measures were observed during each of the drilling and grouting processes, and detailed construction records were maintained. No accidents were recorded, the specialty grouting work was completed one week ahead of schedule in about 3 working weeks, and the overall facility expansion projection was not delayed as a consequence of having to conduct the caisson grouting program. Additional work of similar nature is to be carried out as the expansion program unfolds.



Photograph 2. Grout hole drilling in low headroom conditions for existing caisson 13E.

Final Remarks

Grouting to enhance the performance of caissons has been conducted for many years in Europe or by European contractors working abroad, and especially in the Middle East. More recently these techniques have begun to be applied in North America. This case history is a good example of the real benefits that a well conceived, properly managed and correctly executed grouting program can provide. Many technical points are described, and the effectiveness of the work clearly demonstrated. However, it is important to note that this project was allowed to proceed in a team atmosphere which fostered the design-build approach, and encouraged trust and respect amongst all the parties, to mutual benefit.

Acknowledgements

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References

1. ASTM-D1143-81 (1981). Method of Testing Piles under Static Axial Compressive Load. Section 04, Vol. 04.08.

2. Bruce, D.A. (1986). "Enhancing the Performance of Large Diameter Piles by Grouting." Ground Engineering 19 (4) 7 pp and 19 (5) 7 pp.