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Synopsis: One of the problems regularly facing engineers in designing additions to buildings or other structures is dealing with excavating for footings directly adjoining existing footings but at a deeper level.

This was accomplished in sandy soils economically and quickly for a noted Conference Center in 1983 by using compaction grouting. Compaction piles were utilized to pick up existing loads as well as the horizontal loads which would normally allow the building to tip, settle and crack. We believe this was the first use of compaction piles as "anchor" piles to pick up horizontal loads. By using this process, the sandy soils along the excavation stood without other support when excavating with a backhoe.

The paper presents the criteria used in developing this method, summarizes the critical loads, and explains the operation. There has been no settlement at the site.

One of the problems regularly facing architects and engineers designing additions to buildings or other structures is dealing with excavation directly adjoining present structures where new footings need to be placed below the existing foundation level. That typical problem presented itself at the Harrison Conference Center in Glen Cove, NY, on the north shore of Long Island.

An addition incorporating an indoor sports center was planned to attach directly to a two story wing used as sleeping quarters at the Center. The exterior walls for the existing two story brick structure were supported by continuous spread footings on natural soils, a mixture of loose to medium dense glacially deposited beach sand, stones, and silt. The ground floor was a slab on grade. The addition was to be connected at its enclosed stairwell to allow direct passage to the second story of the new addition. The new section was a three story structure set so the roof lines would match. The new basement was to be placed below the level of the existing first floor with the new continuous strip footings to be placed from 6.5 to 13.5 feet below the existing footings.

The existing building was about eight years old at the time. It had been well constructed. Examination showed no evidence of settlement and no cracks, internal or external. Existing continuous footing loads ranged from about 2.1 to 3.6 kips/lin. ft. The site is some 200 feet in elevation above ocean level. Soil borings showed the soils to be well-drained.

The most common method of providing support for an existing structure where a new structure is to be built next to it, but at a lower level, is to underpin it with concrete piers. Pier holes at relatively wide spacing are excavated below the existing footings to a depth below the excavation level required for the new structure, then lagged with timber prior to placing reinforcement and filling them with concrete. After the first set of piers have sufficient strength, additional piers are constructed in between in a similar manner until a continuous wall exists. This work requires hand labor and is slow and tedious. Even though great care is taken, loss of ground during the excavation for the piers often occurs which results in settlement of the existing structure.

Compaction grouting has the attributes to solve the potential problems associated with this situation. Compaction piles are placed through small 2 inch diameter holes which create no potential for settlement during pile placement. No excavation for the new building takes place until the compaction piles are in place. During the grouting, the soil is compacted and densified so that when excavation does take place, neither settlement nor lateral failure can occur.

The concept for the Conference Center project was to provide vertical support for the existing building footings by using compaction piles placed through those footings. These piles extended a suitable distance below the eventual excavation depth. The piles were angled slightly inward so that excavation equipment would not cut into them. Horizontal support to the soils and support to prevent lateral movement of the building was provided by 45 degree anchor piles. The bases of these piles were placed beyond the shear line of the soil, and the top end anchored into the foundation. Each pile was attached to the footing by a threaded reinforcing bar extending through a hole cored in the footing, and the whole assembly epoxied in place.

After the grouting was complete, the existing building was fully supported on its own piles. Soils for the new excavation were then cut away adjacent to the existing structure, and there was no need for backfill nor to allow for the usual, eventual settlement.

The general plan of the existing footing is shown in Figure 1. That plan shows the pattern of piles placed under the building. Pile and soil calculations were based on three criteria:

- Settlement potential of the existing soil
- Lateral pressure and forces
- Bending forces on the piles

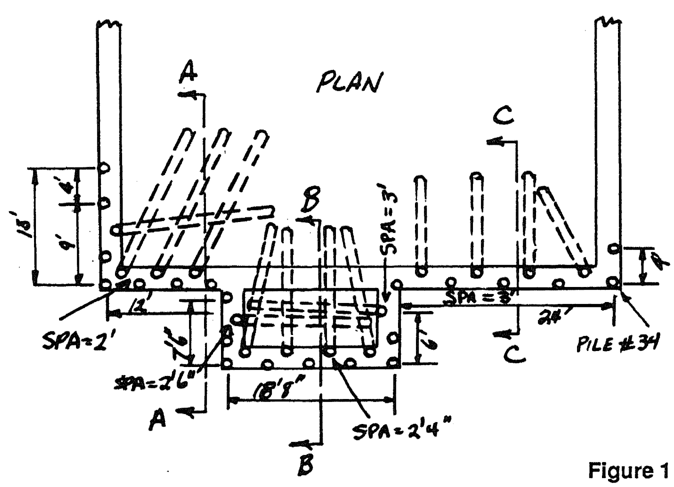
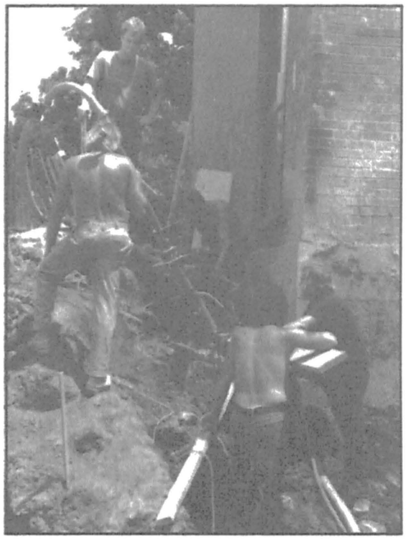


Figure 1

It was judged that a pile with a nominal and minimal diameter of one foot was reasonable to attain in these soils. When the first trial calculations were completed, it was evident that the lateral forces would govern and would become the limiting design criteria.

The advantages of the compaction grouting method are that loss of ground and subsidence during the underpinning operation are virtually eliminated. Furthermore, the underpinning can be completely installed prior to excavating to a level below the existing structure's foundation.



Grouting an anchor pile

For the Glen Cove project, compaction grout piles were designed to provide both vertical support for the existing continuous spread footing foundation and lateral support to the wedge of soil beneath the existing structure which would tend to slide into the excavation if not restrained. Vertical support was provided by compaction grout piles on 4 to 6 foot centers having a batter of 1 horizontal to 10 vertical. The purpose of the batter was to minimize their intrusion into the area of the new structure. It was not considered necessary to make the piles form a continuous wall since the water table was below the depth to be excavated. These piles were designed for both axial compression and flexure. The tops of the 1:10 batter piles were restrained laterally by compaction piles having a batter of 1 horizontal to 1 vertical. The 1:1 batter piles were located midway between the 1:10 batter piles and were designed for tension.

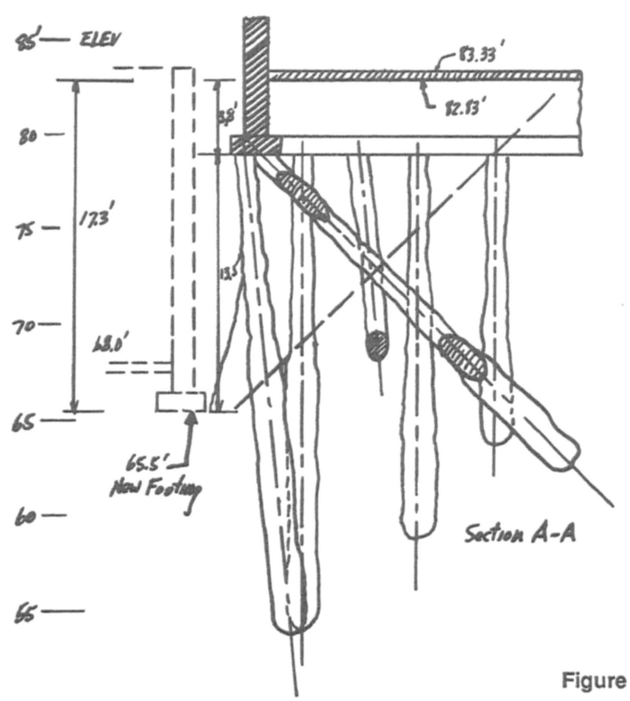


Figure 2

Both types of piles were reinforced with a single steel threaded bar over their full length. All bars extended through the existing footings. The bars had bearing plates at the top, and were grouted into the top of the footings. Either no. 8 or no. 10 bars were used depending on the design requirements. The 1:10 batter piles were designed for a diameter of approximately 12 inches at the top, increasing to 15 inches at 5 feet, to 20 inches at 10 feet, and continued at that diameter to the tip. The 1:1 batter piles were designed for a diameter of approximately 12 inches for the first 10 feet, increasing to 15 inches at 15 feet, to 20 inches at 20 feet, and continuing at 20 inches. Pile lengths ranged from 15 to 25 feet. The required grout strength was 3000 psi and grade 60 steel reinforcement was used.

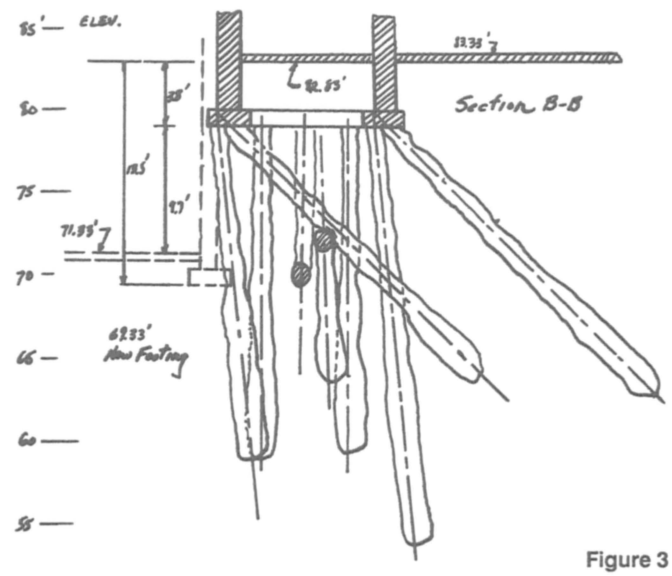
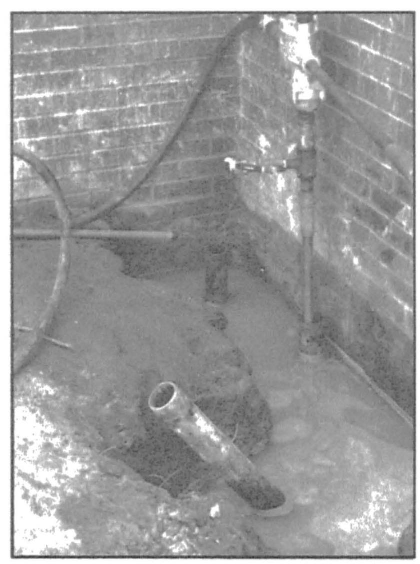


Figure 3

Design loading for the piles was based on a lateral earth pressure loading of one-half the vertical pressure from the underside of the existing floor slab to the underside of the existing footings. Below this level, the lateral pressure was assumed to remain constant to the depth where it is equal to the active pressure; that active earth pressure was assumed to be one-quarter of the vertical pressure.

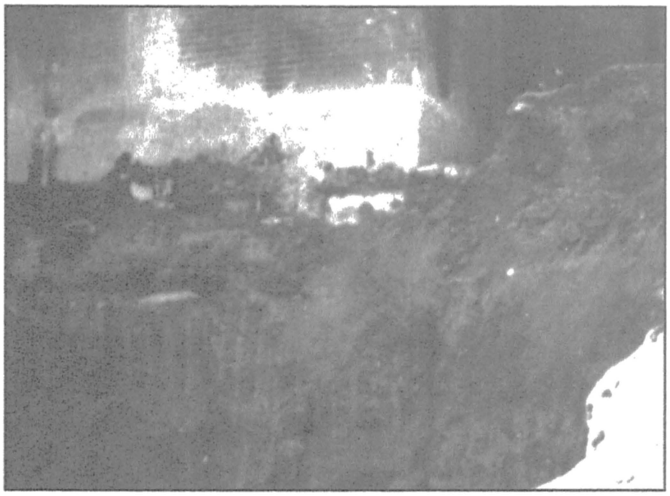
The calculations for the design axial loads at the top of the piles were calculated based on the assumption: the lateral earth pressure, from the level of the existing floor subgrade to a level midway between the bottom of the existing footing and the excavation level of the new footing, will be supported by the 1:1 batter piles. The lateral earth pressure below this was assumed to be supported by the embedded portion of the 1:10 batter piles below the level of the new excavation.



Grout casings and drilling

The 1:1 batter tension piles had calculated design loads ranging from

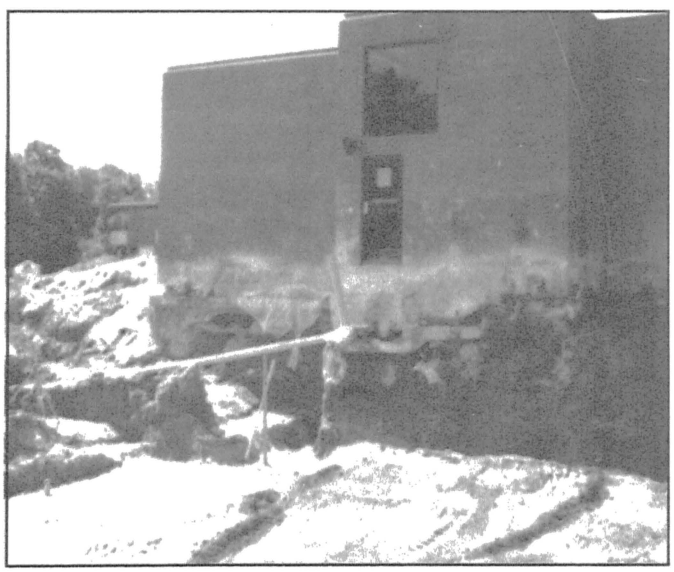
17.5 to 20 kips. Their design length was such that they extended approximately 14 feet past a 1:1 slope up from the nearest excavation level. The calculated pile friction in this zone was in excess of three times the calculated design load.



Excavation done by backhoe

The 1:10 batter compression piles had calculated axial design loads ranging from 22.5 to 35 kips. Since the end bearing capacity of a 20 inch diameter pile in compact sand is much greater than the axial design loads, the lateral loading governed the required pile penetration below the new excavation level. The calculated lateral load to be supported by the embedded portion of the pile ranged from 5 to 12 kips depending on the depth of the excavation. Using laterally loaded pile analysis methods, it was found that penetrations of 9 to 12 feet were suitable. Maximum bending moments resulting from this analysis determined a suitable pile diameter, size for reinforcing steel, and required concrete strength.

The selection of pile size and length took into account the compressibility of the soil. In the vicinity of the existing foundation and floor slab, the size of the pile was to be no larger than 12 inches since the ground may not have been able to compress that much and heave of the structure may have occurred. The diameter of the lower portion of the piles was increased up to 20 inches to meet design requirements.



Corner showing sewer connection

The resulting layout is shown in Figure 1 and sections through the footings and shown in figures 2-4. Load calculations are summarized in the Table below:

Criteria	Units	Req'd	Design SF=3	Excess over SF
End bearing				
Min. dia. = 1 ft	tons	17.5	87.0	69.5
Bending (max case)				
Rebar size	sq. in.	1.04	1.27	0.23
Concrete strength	psi	2,200	3,000	800
Lateral earth pressure				
Rebar size (tension)	sq. in.	0.63	0.79	0.16
Min. embedment depth	ft.	7.6	18.8	11.2

Final excavation before new footings

In order to obtain adequate support directly under the existing strip footing and to get the minimum 1 foot diameter at shallow depths, stage grouting from the top down was chosen as the best technique. This is often done in compaction grouting where exceptional support near the bottom surface of the existing footings is needed and where confinement of the surrounding soil may be inadequate. The procedure minimizes the tendency for grout return, ground heave, and floor lift before the desired amount of material can be introduced near the surface.

Holes were drilled in the footing and 2 inch diameter grout casing installed. Earth drills then carried a pilot hole to about 5 feet below the footing and the first stage of grouting began. Grout slump was 0 to 1 inch. The grout was allowed to set, usually overnight for operational convenience. The casing was then drilled out and drilling continued through the first stage and into the earth below for another 5 feet. The next stage of grout was placed below the first and the process continued by approximately 5 foot stages until the design level was reached. After the second stage, there is minimal danger of uplift because point forces of injection are being transferred to such a large mass above. This is particularly important on the 1:1 batter piles where the upper restraint is provided only by a light floor slab.

During the last and deepest stage of grouting, the reinforcing bar was placed in the hole and grouted in place. The top of the threaded rebar extending through the footing had washers and nuts placed on them. The

1:1 batter rebar had bearing plates placed over the ends at 45 degrees and the nuts drawn up tight to accept the tension loads.

During grouting on one end of the building, an unexpected perched water zone was encountered at a depth of about 20 feet. The sand and gravel turned to a flowable mush and drilled pilot holes would not stay open for the next stage grout. Conventional methods of holding a hole open with drilling fluids do not work with compaction grouting where the grout is near zero slump and injection pressures run to several hundred psi. In order to get past this obstacle, the grout holes from the 20 foot level down were cased to the bottom, the reinforcing bar installed, and the bottom of the pile grouted from bottom up by pulling the casing in 1 foot increments. This turn about method was used on 12 piles where the perched water was encountered.

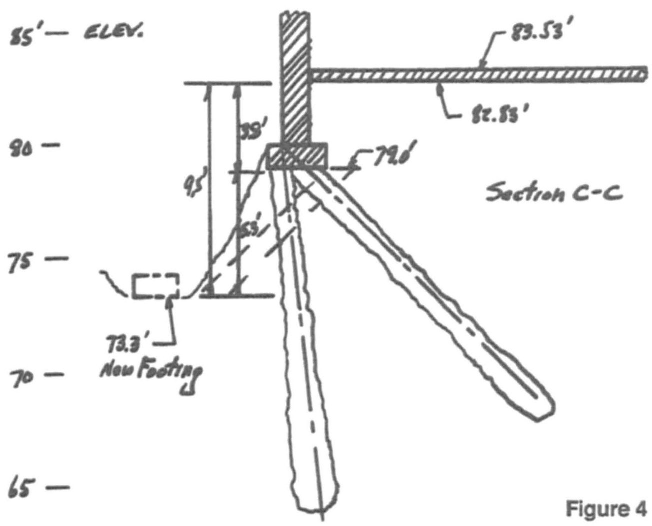
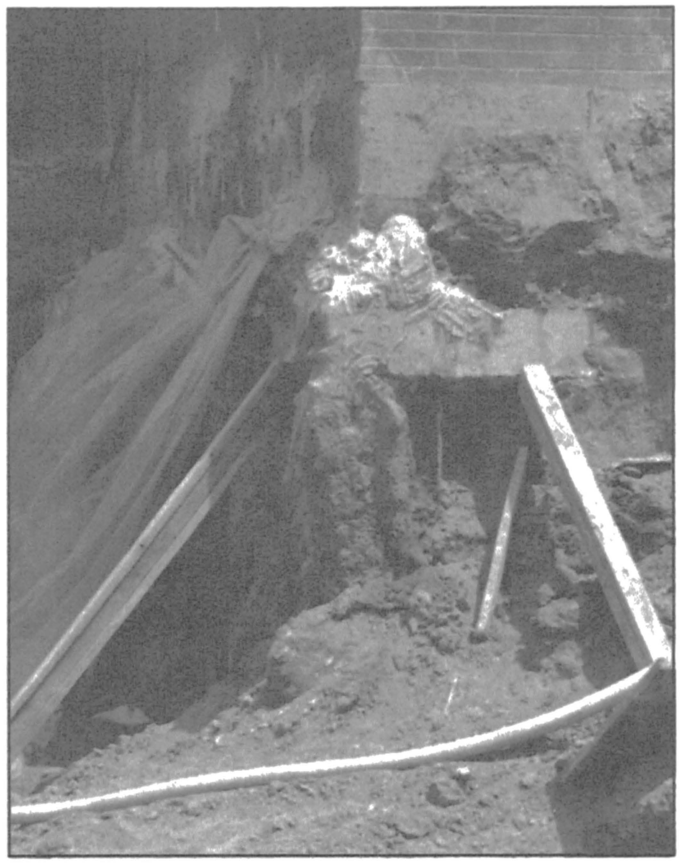


Figure 4

During excavation, a few piles were partially exposed. Close digging in the area of section B scraped against the grout at the top. On the right corner, pile number 34 was hit during excavation by earth moving equipment breaking away sizable sections. In the end, no harm was done and the digging contractor returned to using a backhoe rather than a bulldozer for excavation near the structure. It is interesting that the shape of the exposed pile, number 34, is roughly square rather than roughly round as might be surmised.

No special precautions were observed during excavation. Because of construction scheduling, the vertical face was exposed and unsupported for about a month. The soil between the piles along the face had been compressed so densely during grouting that there was no noticeable difference in appearance after the month passed.

When the new footings and walls were in, the space behind the new walls was filled with concrete to prevent any major migration of soil from beneath the building. However, no attempt was made to pump the space full so the end of the old structure will remain supported only on its compaction pile base.



Pile #34 bracing is for personal protection, not structural support

No settlement has occurred. Minor cosmetic cracking to the inner floor and some inner walls resulted from small uplift during the upper stages during the grouting process. Use of compaction grouting on this project gave a solid and probably the best technical solution to this common construction problem, and with no settlement. The project was completed in about one-third the time estimated for conventional underpinning and at 52% of the contractor's budgeted cost for the best alternate.