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ABSTRACT

Excavation support is commonly provided using soil-nailed walls or tie-back walls. This paper describes two case histories where nails and anchors where installed using a hollow reinforcing bar and a disposable drill bit. A lean grout was pumped through the reinforcing bar as it was driven into the ground. This process created a reinforced grout column with a diameter of about 150 mm. This procedure reduced the time of installation and resulted in cost savings of about 25% in comparison with conventional procedures. The procedure was used successfully to install nails in sandy gravels and silty sands. It was also used successfully to install tie-back anchors and the measured horizontal and vertical movements behind the wall were well within acceptable limits. Pull-out tests indicated that the ultimate pull-out resistance of the nails/anchors was between 58.3 to 65.6 kN/m (4 to 4.5 kips/ft) in the gravelly sands and 49.6 kN/m to 56.8 kN/m (3.4 to 3.9 kips/ft) in the silty sand (30%) fines. The soil-nail approach was not found to be practical where thick sequences of clean sands were encountered due to surface raveling and caving.

KEYWORDS

Soil Nails, Tie-Back Walls, Anchor Capacity, Retaining Walls, Excavation Support

INTRODUCTION

Excavation support is commonly provided using soil nailed walls or tie-back walls. Soil nails are grouted full-length and produce a reinforced mass which resists the lateral pressures from the wall. Tie-back walls involve a structural member (soldier pile or sheet pile) which is anchored to the soil with a tie-back anchor. The structural capacity of the wall and the anchor resist the lateral pressure produced by the wall. Tie-backs are usually grouted for the fraction of the length necessary to provide adequate capacity for the anchor.

Soil nails and tie-backs are conventionally installed by drilling a hole with a hollow stem auger, installing a reinforcing bar and then grouting the hole as the auger is extracted. In this paper, two case histories are presented in which this process is combined into one procedure. A disposable cutting bit is placed at the end of the soil nail (38 mm meter threaded bar with a 20 mm dia. hole down the center) and as the nail is drilled into the soil, a thin grout is pumped down the center of the nail. This creates a grout column around the nail with a nominal diameter of 100 mm, but it may reach 150 mm or more in some cases. A typical soil nail installation is shown in Fig. 1. Experience with this method has shown it to be

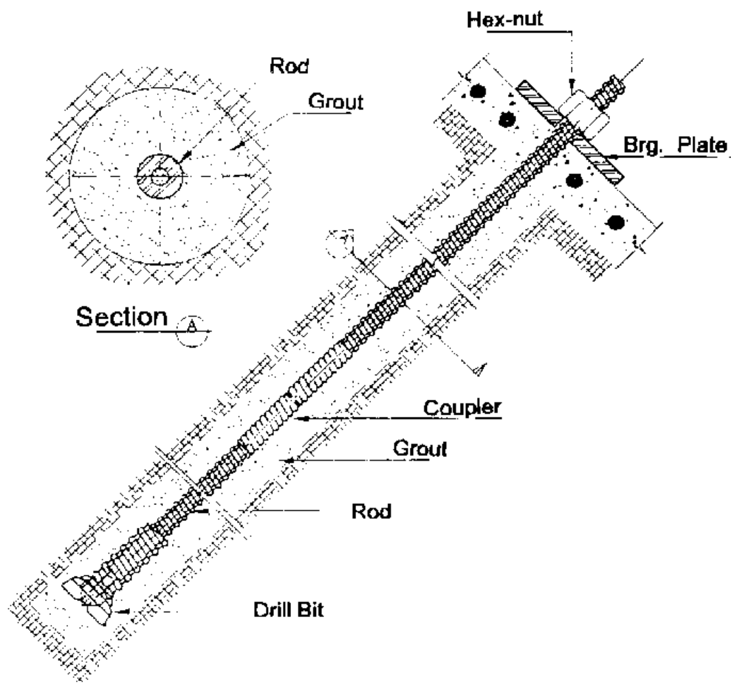

Figure 1: Cross-section showing hollow soil-nail with disposable drill bit surrounded by grout.

faster and at least 25% more economical than the conventional procedure. In addition, it eliminates concerns regarding centering the bars and caving of the hole.

BRIGHAM APARTMENT WALL

The first case history involves a 14 m high soil nailed wall with both temporary and permanent sections. This wall was for used to support an excavation behind a series of apartment buildings in Salt Lake City, Utah.

Soil Conditions

A typical boring log for the site is shown in Fig. 2. The soils at this site consist of weakly cemented silty sandy grave (GP-GM) l overlying a silty sand (SM). Gravel content in the GM

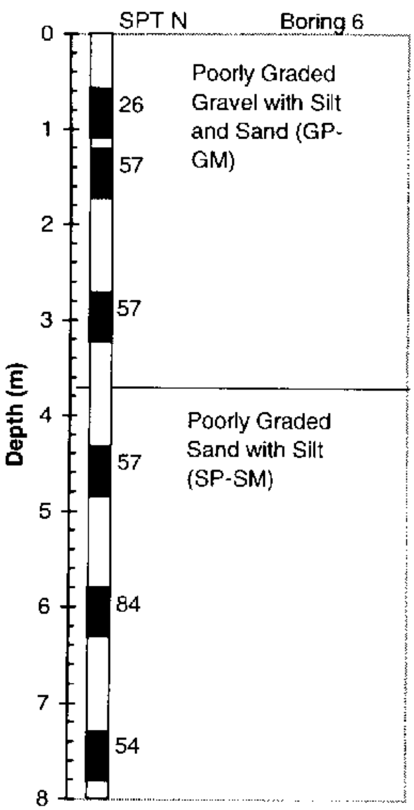

Figure 2: *Typical boring log near soil-nail wall at the Brigham Apartments.*

material was between 32 and 76% and fines content was between 4 and 24%. The standard penetration (SPT) blowcount in the gravels was typically greater than 50 in both the sands and gravels indicating that the soil was in a dense to very dense condition. The design was based on a friction angle of 36 degrees with 5 kPa (100 psf) for cohesion. Groundwater was encountered about 1 m below the base of the excavation. However, seepage from irrigation near the top of the slope made it necessary to provide drainage to prevent water from accumulating behind the wall facing.

Wall Geometry

A cross-section and elevation of the wall is shown in Fig. 3. The wall had a height of 12 m and was sloped at a 1H:12V batter. Nails were spaced at about 1.8 m on center both

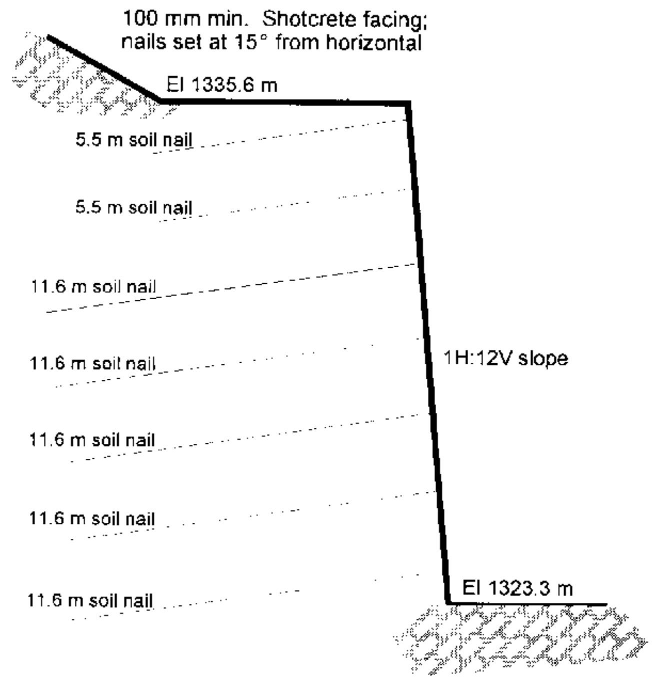

Figure 3: *Cross-section of soil-nail wall at the Brigham Apartments.*

horizontally and vertically, however, alternate rows were offset by 0.91 m horizontally to create a triangular pattern as viewed from the face. Soil nail lengths were typically 0.7 times the height of the excavation face.

Construction History

The construction proceeded by excavating a height of approximately 2 m then installing the nails. Even though the profile contained significant percentages of gravel-sized particles, no apparent difficulty was encountered in installing the nails. The grout was a 7 bag mix of cement (Type III) and water fluid enough to readily flow through the nail hole and into the annular space created by the drill bit between the soil and the nail. The grout pressure at the pump was 1.7 Mpa (250 psi) but the grout was free to flow out at the face so this should be considered a low-pressure installation technique. Grout return at the wall face was monitored to ensure that a continuous column was created. Even though the grout was fluid, the compressive strength of test samples after 3 days was still 17.6 to 28.2 Mpa (2500 to 4000 psi) and there was no difficulty in achieving the specified strength of 25.2 MPa (3500 psi).

After the nails were in place, 6x6 2.5W x 2.5W wire mesh reinforcing was placed against the excavated face. Vertical drainage panels were initially used. Installation, however, caused excessive surface raveling. Drainage was therefore accomplished using PVC weepholes. A 100 mm thick shotcrete layer with a minimum compressive strength of 21.5 MPa (3000 psi) was then applied to the wall. The typical required stand-up time was about 4 hrs.

Although some difficulties were encountered in keeping the wall face intact prior to shotcreting, the soil nails were generally successful in supporting the excavation face without significant movement. However, difficulties were encountered in a few cases when the fines content or cementation was low enough that the wall face began to ravel away from behind the shotcrete surface coat. In the worst cases, holes were cored in the shotcrete facing and a lean grout was pumped in to fill the gap after the shotcrete facing had been extended to the base of the excavation.

Testing and Performance

Pull-out load tests were performed on three test nails which were 4.9 m long and placed at a depth of 12 m in a 1.5H:1V slope. The ultimate frictional resistance ranged from 58.3 to 65.6 kN/m (4 to 4.5 kips/ft) of grouted length at an axial displacement of about 25 mm. The design for the soil nails used a working friction resistance of 43.7 kN/m (3 kips/ft) of length. Proof load tests to 120% of the design capacity were performed on about 2% of the 600 nails installed for this wall. All tests showed capacities greater than the design load at a displacement of 6 to 12 mm. This wall has been in service for about 2 years and is functioning in a satisfactory manner. Although buildings exist within 30 m of the crest of the soil-nailed wall, no distress was observed in any of these buildings.

BYU LEE LIBRARY WALLS

The second case history involves a temporary wall for construction of an underground addition to the library building on the campus at Brigham Young University in Provo, Utah. The library occupies an footprint area of over 13,750 m^2 (148,000 ft^2) and excavation depths ranged from 10.6 to 18.3 m (35 to 60 ft). Existing buildings are located immediately adjacent to the excavation on two sides and within about 20 m on another side. As a result, it was necessary to construct nearly vertical excavation faces in most cases.

Soil Conditions

The soil profile at the site consists of a brown sandy gravel 1.5 to 5.5 m thick underlain by a brown sand to silty sand. Considerable variation was present in the gradation characteristics of the sands. The silt and clay size content in the sands varied widely and ranged from less than 1% to as much as 49%. In addition, silt and clay lenses existed at several locations throughout the site. The gravels classified as GM- or GP-type soils while the sands typically classified as SM- or SP-type soils. Boring logs for two of the twelve borings at the site are shown in Fig. 4. At Boring 12 , on the northwest side, the soil profile contained a 5.5 m-thick sand layer with a low fines content (<5%) which classified as an SP-type soil. In contrast, at Boring 11 on the northeast side, the sand below the gravel all classified as SM-type soil and contained 18 to 42% fines. The SPT blowcounts are shown on the logs and generally indicate that the sand is in a medium dense to dense state. Groundwater was typically encountered at a depth 10 ft below the base of the excavation.

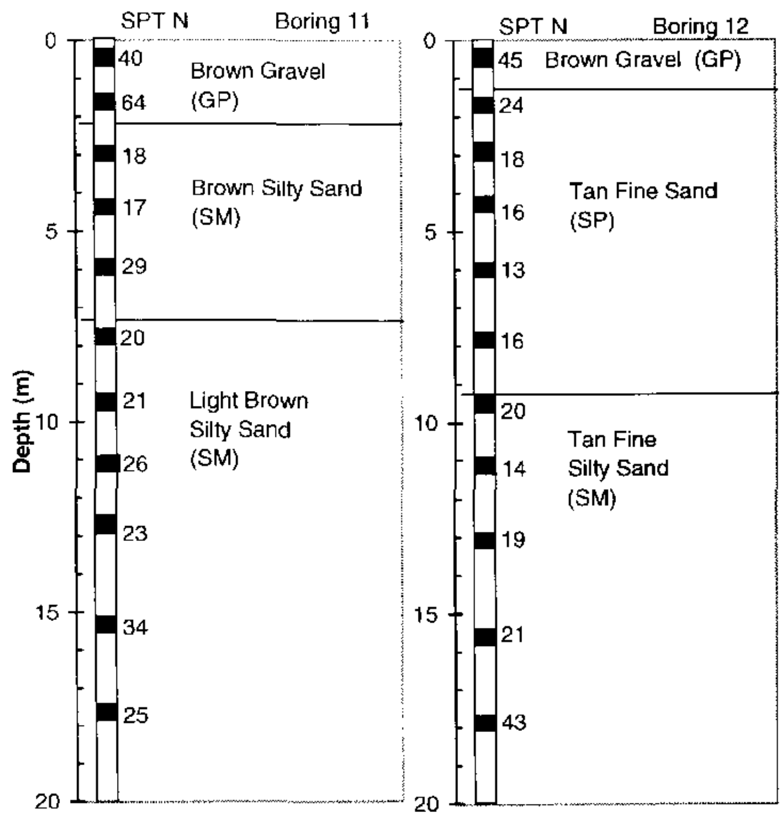

***Figure 4**: Boring logs on the east (Boring 11) and west (Boring 12) sides of the BYU library excavation.*

Wall Geometries

Both soil nailed walls and tied-back soldier pile walls were constructed at the site. A typical cross-section for the soil-nailed wall on the east side is shown in Fig. 5 while a cross-section though the tie-back soldier pile wall on the west side is shown in Fig. 6. The soil nails were spaced at 1.8 m (6 ft) vertically and 2.1 m (7 m) horizontally. Alternating rows were offset by 1.07 m (3.5 ft) horizontally to create a triangular pattern when viewed from the face. The nail lengths were somewhat longer than normal (0.8 times the wall height) because the soil behind the wall sloped at 1.5H:1V to an elevation 5.2 m above the top of the wall. No special drainage provisions were applied.

The soldier pile wall consisted of soldier piles spaced at 1.8 m (6 ft) on centers at the deeper south end of the excavation, and

3.5 m (10 ft) on centers at the north end. The soldier piles were anchored by tie-backs spaced at 2.7 m (9 ft) vertically. A 100 mm shotcrete surface reinforced with welded wire mesh was used in place of lagging to control surface raveling. The solider piles consisted of a W21 x 44 steel section reinforcing a 0.76 m (2.5 ft) diameter drilled shaft.

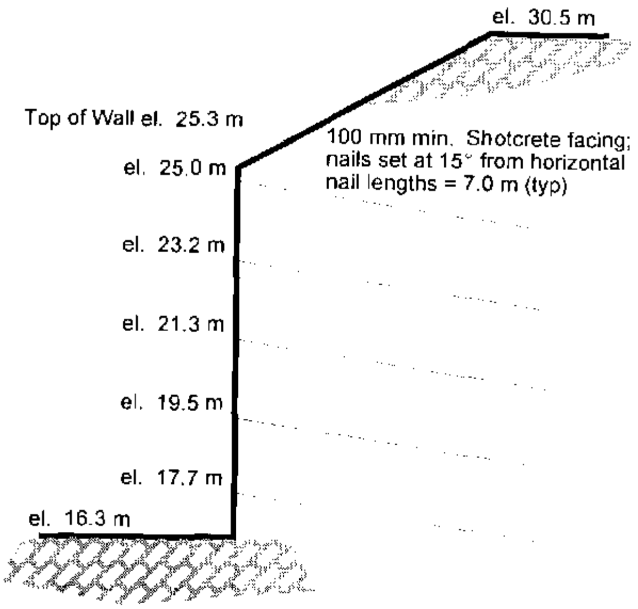

***Figure 5**: Typical cross-section for the soil-nail wall on the east side of the BYU library excavation.*

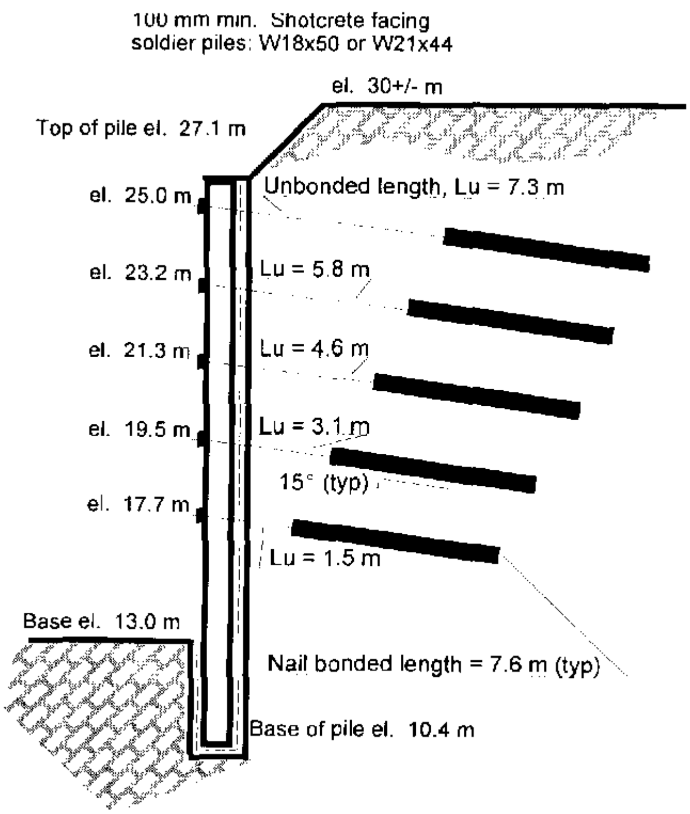

***Figure 6**: Typical cross-section for the soldier pile wall on the west side of the BYU library excavation.*

Construction History

The construction procedure employed for soil-nail walls was essentially the same as that used at the Brigham Apartments. Grout strength was specified to be 25.2 MPa (3500 psi) and typically exceed this value by at least 20%.

The soldier pile walls were constructed by drilling the 0.76 m diameter hole to a depth of 2.5 m below the base of the excavation, installing the steel section, and filling the holes with a lean concrete. As the excavation proceeded, the concrete was cut away to the flange and tie-back anchors were installed. The installation procedure for the tie-backs was identical to that used for the soil nails, however, a length of PVC pipe was placed around the nail at the excavation face to create an unbonded length of 1.5 to 7.3 m as required. About 72 hours after installation, the tie-backs were proof tested to 120% of the design load and then locked in at the design load.

The original design called for most of the excavation support to be provided by soil-nail walls, however, conditions at the site made it necessary to use soldier pile walls as the predominant wall type. Although the soil nailing procedure worked relatively well on the east side where the percentage of fines in the sand was relatively high (see Boring 11, Fig. 4) it was difficult to create a stable vertical face in the clean fine sand (Boring 12, Fig. 4) on the northwest side. In addition to the clean sand zone, some layers of loose fill were also encountered near the ground surface which caused problems.

Despite these difficulties, the soil-nail approach was initially attempted on the west side, but at a depth of about 5 m, a 45 m long section of the wall failed. Excessive raveling and caving of the face had been a problem in this location from the beginning of the excavation. At the time of the failure, the third row of nails had just been installed and the exposed soil face (about 2 m high) was about to be shotcreted. Before the shotcrete could be applied, sand began running out from behind the shotcrete facing creating a void behind the facing. As the sand continued to run out, small sections of the shotcrete facing began to fall away from the bottom up. Finally, several large sections of the wall fell away and the vertical face caved into the excavation. While the failed section was probably the worst section of the soil profile for soil-nailing, clean sand layers were located in an erratic fashion along the length of the wall. Because of the risks associated with unexpected caving, the decision was made to use soldier piles with tie-back anchors on the west side of the excavation. The soldier pile wall construction proceeded without incident and the failed section was repaired with flowable fill.

Testing and Performance

Pull-out load tests were performed on two test nails placed in a nearly vertical face at an angle of about 15°. The test nails were about 4 m long and had overburden depths of only 1.5 to 3 meters. The ultimate resistance for the two tests were 56.8 kN/m (3.9 k/ft) and 49.6 kN/m (3.4 k/ft). Ultimate resistance was obtained at an axial displacement of about 25 mm. These values are in reasonable agreement with ranges provided by Juran and Elias (1991) for nails with low-pressure grouting. The design for the soil nails used a somewhat liberal working load capacity of 43.7 kN/m (3.0 kip/ft) of length, with the idea that most of the nails would be subjected to higher overburden pressures and would thus have greater frictional resistance. Proof load tests to 120% of the design capacity were performed on all of the anchors and all but one reached the design load at deflections of 6 to 12 mm. Maximum design loads for a given bar were 333 kN (75 kips).

An inclinometer pipe and settlement monitors were installed behind the soldier pile wall to monitor horizontal and vertical movements during construction of the wall. The inclinometer

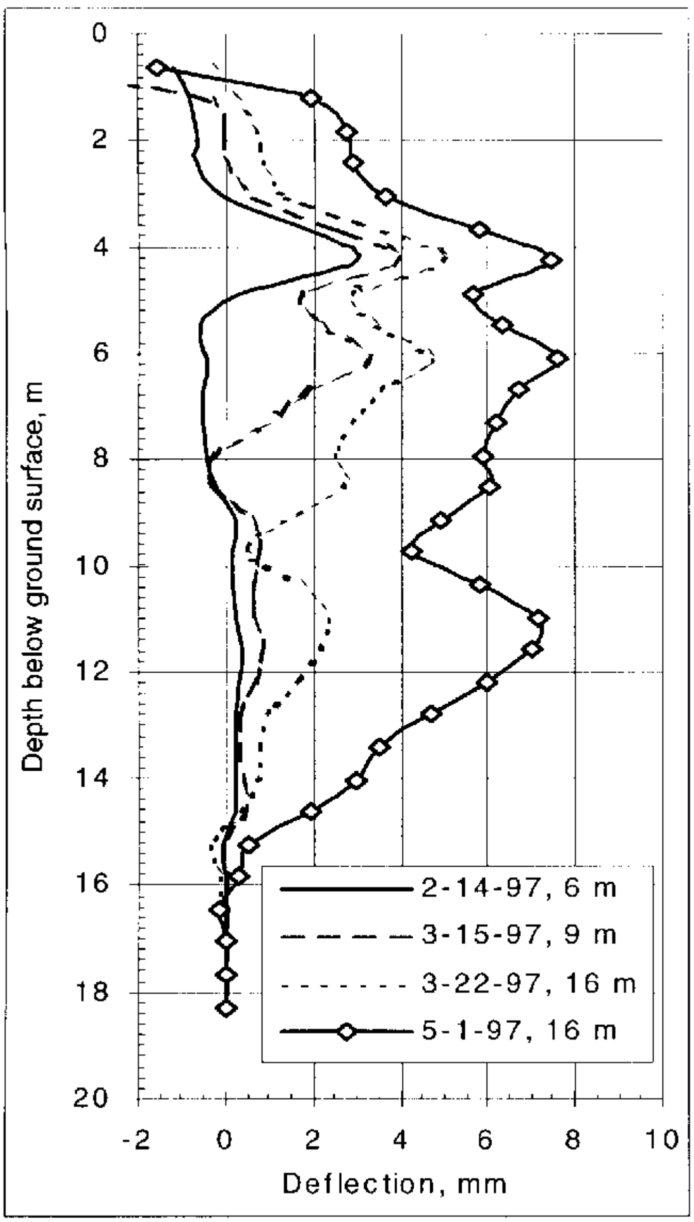

***Figure 7**: Horizontal deflection versus depth curves for various excavation depths behind soldier pile wall at BYU library.*

was located 0.3 m behind the wall face. Plots of horizontal deflections versus depth at 4 stages of excavation are shown in

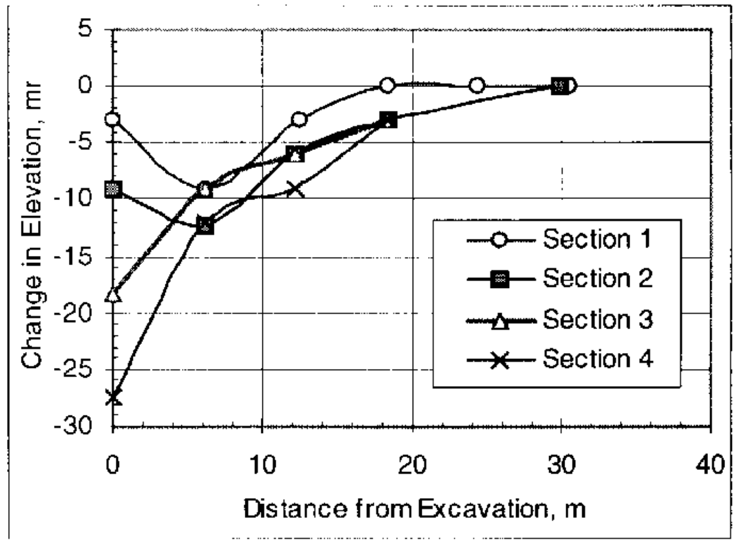

***Figure 8**: Settlement versus distance from the face at four sections behind the soldier pile wall at BYU library.*

Fig. 7. Maximum horizontal deflections were typically 0.05% of the wall height. Vertical settlement versus distance from the excavation face is shown for four sections (at 25 m spacing) along the west wall in Fig. 8. Maximum settlements were 18 to 27 mm near the failure section (<0.17% of wall height). However, at other sections maximum settlement was only 6 to 9 mm (<0.06 % of the wall height) and about the same as the maximum horizontal movement. These movements are relatively low considering observations made by Peck (1969).

Both the soil-nailed wall and the soldier pile walls have been in place since March 1997 and have been performing in a satisfactory manner. A photograph of the soil-nail wall on the east side of the excavation is shown in Fig. 9. Construction of the library addition is proceeding on schedule and should be completed by the end of 1998.

CONCLUSIONS

1. The hollow soil-nail installation procedure produced walls which performed successfully in both temporary and permanent applications for significant wall heights (≥14 m). The new method provides significant reductions in construction time and cost (about 25%) over conventional installation methods.

2. Typical ultimate pull-out resistance values for the 100 mm diameter soil nail installation were 58.3 to 65.6 kN/m (4 to 4.5 kips/ft) in the gravelly sands and 49.6 kN/m to 56.8 kN/m (3.4 to 3.9 kips/ft) in the silty sand (30% fines). These values are comparable to those measured using low-pressure grout installation procedures.

3. The constructability of soil-nail walls in sand is a function of fines content. Clean sands will generally not stand vertical long

enough to prevent raveling and sloughing prior to shotcreting while sands with higher fines contents (30%) or gravelly sands with slight cementation may be acceptable.

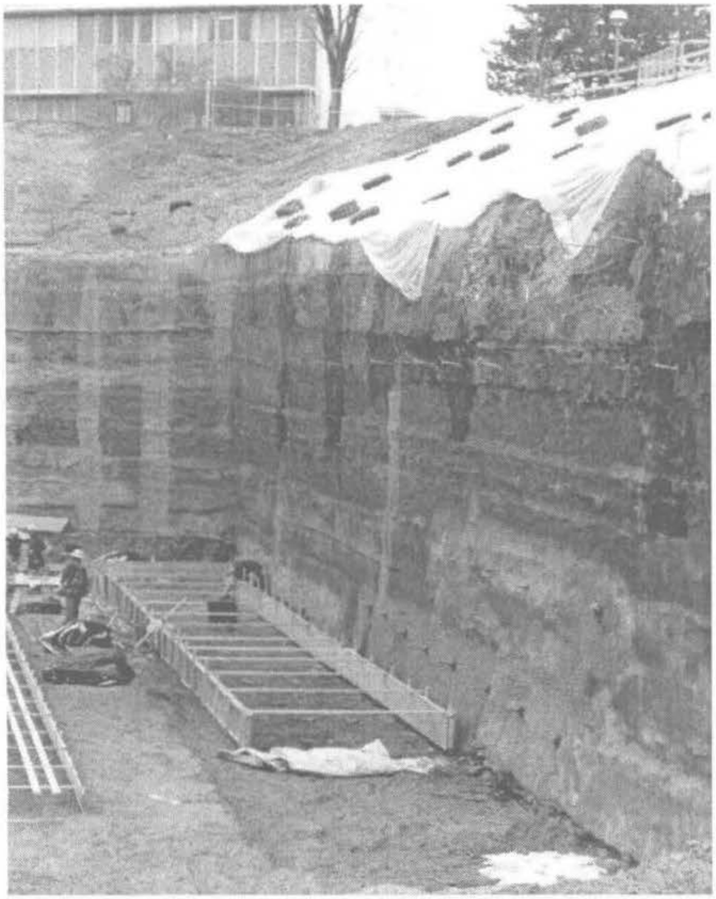

Figure 9: *Photograph of soil-nail wall on east side of excavation of BYU library.*

REFERENCES

Juran, I. and Elias, V. (1991) "Ground anchors and soil nails in retaining structures", in Foundation Engineering Handbook, 2nd Edition, Ed. Fang, H-Y, Van Nostrand-Reinhold, NY

Peck R.B. (1969) "Deep excavations and tunneling in soft ground, State of the Art Volume, 7th Intl. Conf. on Soil Mech. and Found. Engrg., Mexico, pp. 225-290.

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