OBSERVATIONS OF INSITU TIEBACK GEOMETRY

OBSERVATIONS DE LA GEOMETRIE INSITU DES TIRANTS

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SYNOPSIS: Construction of a pair of bus tunnels beneath a main street in downtown Seattle, Washington provided an opportunity to observe insitu characteristics of tiebacks that had been installed up to 9 years previously for the construction of high-rise buildings along the street. The geometry of tiebacks that intersected the tunnel's alignment was observed and is compared here with both the design and as-built geometries. A simple statistical analysis is used to provide an indication of the amount of "wandering" of the augers used to construct the tiebacks. The wandering was observed to be significant in both the horizontal and vertical directions. Implications of auger wandering on tieback capacity and avoidance of buried obstructions are discussed.

INTRODUCTION

The use of ground anchors has proven to be an effective and economical means for support of temporary excavation bracing and are increasingly being used in permanent support applications. Tiebacks, which involve construction of anchors that are stressed by the application of tensile loads to a tie rod at the face of a wall, have been used successfully for many years. More recently, the use of soil nails, which consist of closely spaced, smaller diameter inclusions that are not stressed at the face of the wall, has increased. Both methods involve construction of grouted inclusions in holes augered in the soil that is to be retained. These inclusions are often installed at some relatively regular pattern and inclination, and their design assumes that they retain the same spacing and inclination over their entire length. This paper presents the results of field observations of the insitu geometry of previously installed tiebacks which were encountered below the ground surface during construction of the METRO bus tunnels in Seattle, Washington.

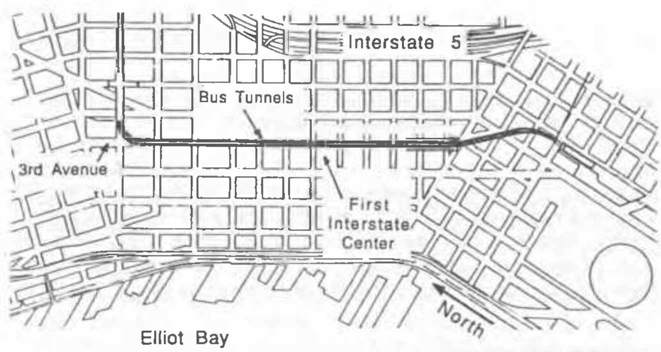

Fig. 1. Site plan showing location of 3rd Avenue, bus tunnels and First Interstate Center.

BACKGROUND

During 1987-88, Seattle METRO constructed two parallel bus tunnels as part of a downtown transit project. The main portion of the 6.1 m (20 ft) diameter tunnels runs in a north-south direction below 3rd Avenue as shown in the site plan in Figure 1. The 1982 construction of the First Interstate Center, a 44-story structure with six levels of underground parking located immediately west of 3rd Avenue between Madison and Marion streets, required temporary support of a 25.3 m (83-ft) deep excavation along 3rd Avenue. This excavation was supported by a soldier pile wall with tiebacks which ranged from approximately 15.3 m to 24.4 m (50 to 80 feet) in length. Between Madison and Marion streets, the METRO tunnel inverts are at a depth of approximately 20.7 m (68 ft), with the centerlines of the east and west tunnels located about 18.3 and 6.1 m (60 and 20 feet), respectively, from the edge of the First Interstate Center excavation. Therefore, the alignment of the both the east and west tunnels intersected the First Interstate Center tiebacks as shown in Figure 2.

SOIL CONDITIONS AND TIEBACKS

Much of downtown Seattle, including the general site area, is underlain by glacially overconsolidated soils. Subsurface investigations for the First Interstate Center and for the tunnel indicated that the soils at the site consisted of a glacio-lacustrine deposit of interbedded, very stiff to hard clays and silts with interbedded fine sand, and a highly variable glacio-marine drift containing clay, silt, sand, and gravel. Cobbles and boulders have been observed in these materials in previous construction in the area, but were not specifically noted to to have caused significant problems during tieback installation. A soil profile at the First Interstate Center site is shown in Figure 3.

The First Interstate Center tiebacks were installed at approximately 1.5 m (5 ft) intervals horizontally and 1.5 to 3.1 m (5- to 10-ft) intervals vertically. The boundary of the no-load zone was given by a 60 degree envelope passing through a point located one-fourth of the wall height behind the base of the wall. Anchor lengths beyond the no-load zone were generally between about 5.8 and 9.2 m (19 and 30 ft), producing tiebacks of total length up to about 24.4 m (80 ft). Of the 166 tiebacks projected to intersect the east tunnel on the basis of as-built inclination, 118 were to be

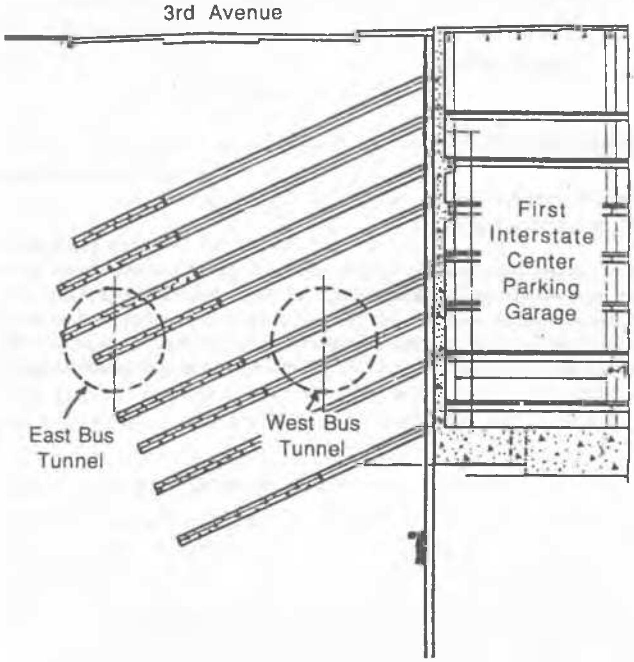

Fig. 2. Typical profile showing intersection of tiebacks with bus tunnels at First Interstate Center.

inclined at 15 degrees, 28 were to be inclined at 20 degrees, and 20 were to be inclined at 25 degrees from horizontal. A histogram of design tieback inclinations is shown in Figure 4. Tieback holes were drilled with a crane-supported, 45.7 cm diameter, continuous flight, hollow stem auger at the design inclinations of 15, 20, and 25

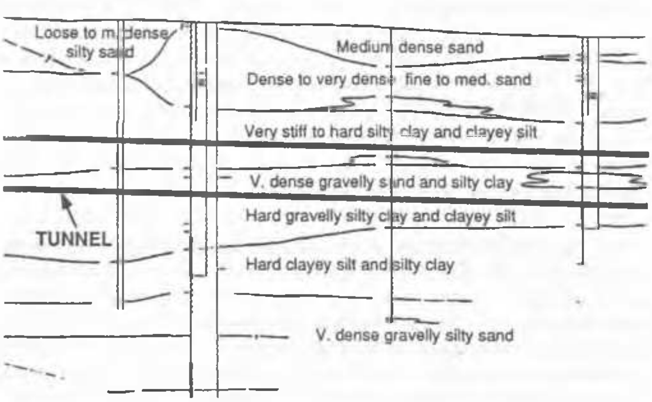

Fig. 3. Soil profile along tunnel alignment adjacent to First Interstate Center.

degrees. The anchors were constructed by placing 20.4 MPa (3,000 psi) grout around 2.54 cm (1 in) and 3.49 cm (1-3/8 in) Dywidag bars centered in the auger holes. Tieback installation was monitored during construction by the project geotechnical engineer. Each tieback was proof tested and those failing (10 out of more than 320 installed along the entire 3rd Avenue wall) were abandoned and replaced with new tiebacks installed nearby.

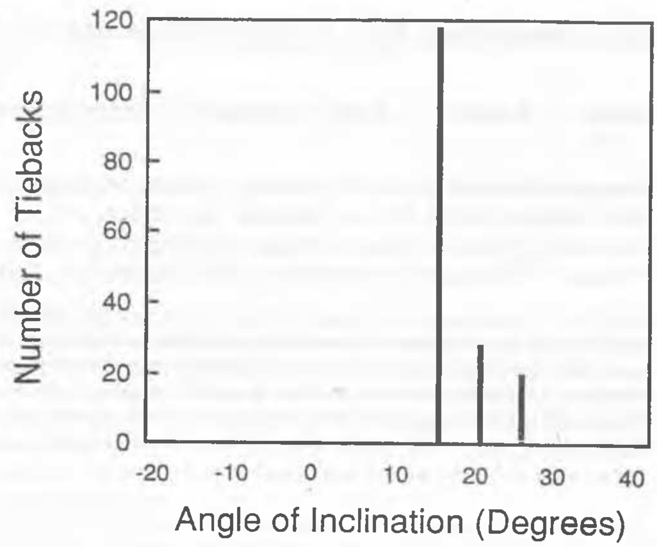

Fig. 4. Histogram of design tieback inclinations.

TIEBACK OBSERVATIONS

Detailed examination of the tiebacks could not be accomplished without impeding the tunnelling contractor's progress. Access to the working face of the tunnel was obtained during occasional pauses in the work cycle but, in general, tieback observations were made from the working platform of the tunnelling machine, approximately 6.1 m (20 ft) from the face.

The most accurate observations that could be made under these circumstances were those of tieback geometry, particularly of the inclinations of the tiebacks as they were encountered at the face of the tunnel. These observations were made by sketching the observed tieback orientation within a 3.1 cm (2 in) diameter circle (representing the face of the tunnel) on a data sheet and by taking photographs. Observed tieback inclinations were subsequently measured from these records. Comparison of tieback inclinations obtained from the data sheet sketches and photographs indicated very good agreement, and the recorded inclination data are considered to be within a few degrees of the actual tieback inclinations.

TIEBACK INCLINATIONS

During tieback installation, the actual, as-built inclinations of all tiebacks were measured with a Brunton compass at the face of the wall. These inclinations were observed to vary somewhat from the design inclination values. While the majority of the tiebacks were installed at their design inclinations, there was some variability in tieback inclination. Of those tiebacks not installed at their design inclination, more were installed steeper, rather than flatter, than their design inclinations. The design inclinations were generally changed to avoid utilities or other buried obstructions, or to extend the tieback into a stronger soil unit. A histogram of the as-built inclinations of the 166 tiebacks projected to intersect the east tunnel is shown in Figure 5. The three peaks of this histogram correspond to the three discrete design inclinations of 15, 20, and 25 degrees.

If the tiebacks had been installed by drilling perfectly straight holes, the distribution of observed tieback inclinations would have been identical to the distribution of as-built inclinations. Based on many years of visual observations, however, most drillers and field inspectors believe that augers have a tendency to "belly" or flatten in very dense soils, and in any soil will tend to wander upward and to the left because of auger rotation. The observed locations and inclinations of the tiebacks encountered in the east tunnel were so highly variable, however, that it was impossible to identify them on an individual basis. In fact, only 123 of the 166

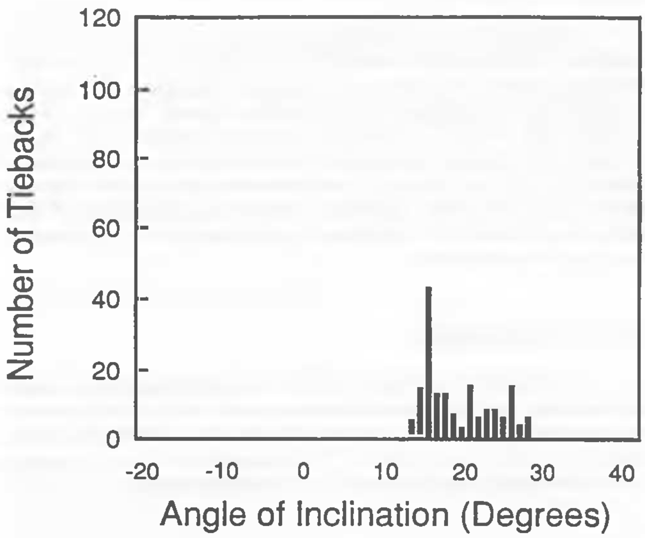

Fig. 5. Histogram of as-built tieback inclinations.

tiebacks projected to intersect the east tunnel on the basis of the as-built inclinations were actually encountered in the east tunnel. Consequently, the observed tieback inclinations could not be partitioned and were lumped together, regardless of design or as-built inclination. The observed tieback inclinations in the east tunnel are also shown in Figure 6. Some tiebacks actually had negative slopes (tieback elevations increasing with distance from the wall) and others plunged steeply at inclinations greater than 35 degrees. The observed inclinations are obviously considerably different than both the design inclinations and the as-built inclinations, indicating the inability of the tieback installation equipment to drill a straight hole in the soils at the First Interstate Center site.

INTERPRETATION

Interpretation of the results of the tieback inclination observations is difficult. Certainly, the data indicates considerable deviation from straightness. Some of the scatter in the observed tieback inclinations resulted from differences between design and as-built inclinations and some resulted from wandering of the auger during drilling. In an attempt to separate the as-built deviation from the wandering deviation, a simple Monte Carlo simulation model was developed. In this model, the shape of the tieback was assumed to be quadratic, hence, the slope of the tieback was assumed to vary linearly over its length according to

$$\tan(\theta) = \tan(\alpha) + bx \qquad (1)$$

where θ is the inclination of the tieback at a horizontal distance, x, from the face of the wall, α represents the inclination of the tieback at the face of the wall, and b reflects the rate of vertical wandering

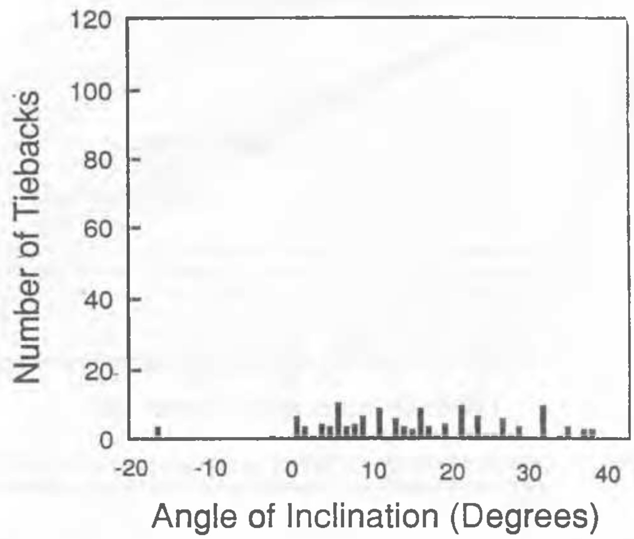

Fig. 6. Histogram of observed tieback inclinations.

deviation with horizontal distance from the wall. The variation in the values of a were considered to be represented by the histogram of as-built inclinations, and the variations in observed tieback inclination, $\theta(x = 18.3\ m)$ were considered to be represented by the histogram of observed tieback inclinations. A simulation was performed to estimate a simple distribution for b which, when combined with the known variation of as-built tieback inclination, would predict the variation of tieback inclination observed in the east tunnel. The simplest possible distribution capable of reasonably predicting the observed variation of tieback inclination was sought. The use of a uniform distribution for b ranging from $b_{min} = -0.00732$ to $b_{max} = 0.05410$ (when x is in m) was found to predict reasonably well the variation of observed tieback inclination. This distribution indicates that the tiebacks were more likely to wander up than down, which is consistent with the experience of most tieback contractors. It does not explain the extreme values of observed inclination, however, it does provide a rough indication of the tendency of tiebacks to wander vertically at the First Interstate Center site. On the basis of this distribution, tiebacks installed at design inclinations of 15, 20, and 25 degrees would be expected to lie with quadratic shape within the shaded zones of Figure 7. The variation of inclination can be seen to be smaller close to the wall as was subsequently observed qualitatively in the west tunnel.

SUMMARY

The results of field observations of the in-situ geometry of previously installed tiebacks indicated that the as-built tieback geometry differed somewhat from the design geometry, and that the insitu geometry was considerably different than both the design geometry or the geometry that would be inferred from measurements of as-built inclinations at the face of the wall. A

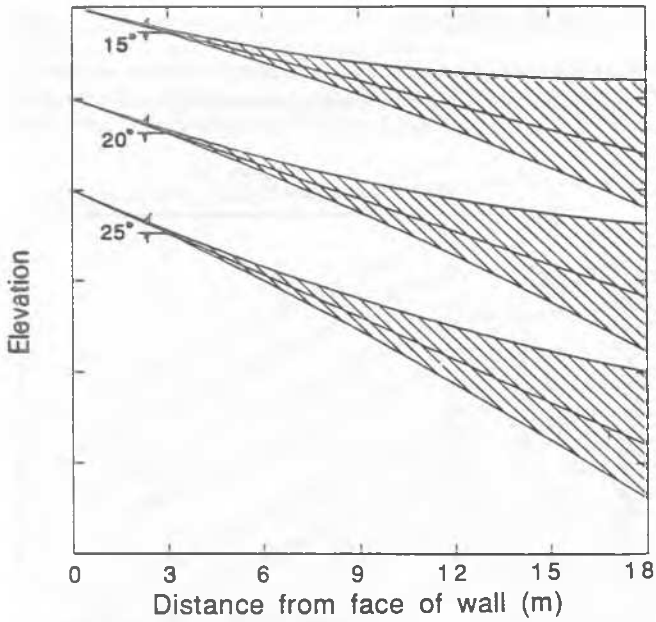

Fig. 7. Anticipated variation of tieback position due to wandering of auger during installation (elevation scale is identical to distance scale).

simple statistical simulation was used to separate the variation in tieback inclination due to wandering of the auger during installation from the variation of as-built tieback inclination. Considerable evidence of horizontal wandering was also observed qualitatively but its magnitude could not be estimated.

Designers of tiebacks often assume that the insitu configurations of tiebacks are as designed. Field evidence, however, suggests that the configuration of the tiebacks may differ considerably from the design configuration. Non-uniform spacing of tieback anchor zones may lead to undesirable interaction effects between closely spaced anchors. The soil between closely spaced anchors will be stressed by both anchors, and the resulting strains will be greater than if the anchors were spaced farther apart. These larger strains will produce larger displacements in the vicinity of the anchors and, ultimately, at the face of the wall. Also, when buried structures, foundations, utilities or other potential obstacles are present, careful consideration of the potential variability of tieback configuration may be very important to avoid damage during installation.

These results and conclusions should also be of interest to designers and builders of soil-nailed excavation support systems. Soil-nail anchors are generally of smaller diameter than tieback anchors and consequently require smaller diameter augers. Since the flexural stiffness of augers increases quickly with auger diameter, the augers used for soil-nails may be more flexible than those used for tieback construction, even at similar length/diameter ratios. Coupled with the closer spacing of soil nails, the potential for undesirable interaction between adjacent nails may be pronounced.

ACKNOWLEDGEMENTS

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