CHAPTER 2 – BACKGROUND

FACTORS AFFECTING BOND STRENGTH OF SOIL NAILS

HBSNs have been used in practice for over 15 years for both temporary and long-term excavation support. A description of the application, materials, installation methods, and design for HBSNs is provided in the Hollow-Core Soil Nails State-of-Practice (SOP) Report issued by the Federal Highway Administration (FHWA, 2006). In addition, the general design methods for local failure mechanisms and global stability for soil nail walls are provided in the Geotechnical Engineering Circular No. 7 (GEC 7), Soil Nail Walls (FHWA, 2003).

The bond strength at a given point along a soil nail corresponds to the shear strength along the interface between the grout and the ground at that same point. Typically, the interface strength between flat structural fascia and the ground depends on the following factors (Gómez et al., 2000, 2003, and 2008):

- Effective and total strength parameters of the soil or rock.
- Roughness of the grout-ground interface.
- Confining stresses.
- Rate of loading and soil permeability.

In the case of soil nails, other factors that may influence the average bond strength along a soil nail include:

- Stiffness of the soil or rock.
- Diameter of the soil nail, including permeated zone.
- Length and axial stiffness of the nail transferring the nail load to the ground.

As the soil nail tends to slide past the soil, the roughness of the interface between the soil nail and the ground may cause radial expansion of the soil at the nail interface. The normal stresses acting on the interface may increase, thus increasing the available bond strength under drained conditions. The magnitude of the normal stress would depend on the bond zone roughness and on the stiffness of the soil or rock around the nail. The average bond strength also depends on the interface shear stress level reached at different points along the bond zone. Shorter and stiffer soil nails will likely favor simultaneous mobilization of bond strength along their entire length; whereas longer, more flexible nails would favor mobilization of shear strength along their length at different times and present somewhat lower average bond strength in identical formations.

The current document governing soil nail design and construction, GEC 7, includes a table of estimated bond strength values for gravity grouted SBSNs installed in soil and rock. The table was originally compiled by Elias and Juran in 1991 (FHWA, 2003), and is reproduced here as Table 1. The influence of the ground characteristics and drilling method on the estimated bond strength is evident as shown in Table 1. Although this table does not reflect all the factors that affect the bond strength of soil nails, it does provide a useful range of bond values for preliminary design and is of frequent use in practical design applications. From the authors' experience and as noted in the SOP (FHWA, 2006), HBSNs are initially classified as rotary drilled when referring to Table 1. As an alternative, jet grouted SBSNs may be similar to HBSNs; however, the relatively low pressures used in the installation of HBSNs may not result in an increase of the hole diameter as significant as that typically seen in high pressure jet grouted SBSNs (FHWA, 2006). The differences in installation and bond strength of SBSNs and HBSNs will be presented and discussed in a subsequent section of this report.

Table 1. Estimated bond strength of soil nails in soil and rock.

Material	Construction Method	Soil/Rock Type	Ultimate Bond Strength, qu (kPa)
Rock	Rotary Drilled	Marl/limestone	300 - 400
		Phyllite	100 - 300
		Chalk	500 - 600
		Soft dolomite	400 - 600
		Fissured dolomite	600 - 1000
		Weathered sandstone	200 - 300
		Weathered shale	100 - 150
		Weathered schist	100 - 175
		Basalt	500 - 600
		Slate/Hard shale	300 - 400
Cohesionless Soils	Rotary Drilled	Sand/gravel	100 - 180
		Silty sand	100 - 150
		Silt	60 - 75
		Piedmont residual	40 - 120
		Fine colluvium	75 - 150
	Driven Casing	Sand/gravel	
		low overburden	190 - 240
		high overburden	280 - 430
		Dense Moraine	380 - 480
		Colluvium	100 - 180
	Augered	Silty sand fill	20 - 40
		Silty fine sand	55 - 90
		Silty clayey sand	60 - 140
	Jet Grouted	Sand	380
		Sand/gravel	700
Fine-Grained Soils	Rotary Drilled	Silty clay	35 - 50
	Driven Casing	Clayey silt	90 - 140
	Augered	Loess	25 - 75
		Soft clay	20 - 30
		Stiff clay	40 - 60
		Stiff clayey silt	40 - 100
		Calcareous sandy clay	90 - 140

From Elias and Juran, 1991 and reproduced in Geotechnical Engineering Circular No. 7 (GEC 7), Soil Nail Walls (FHWA, 2003).

Notes: Convert values in kPa to psf by multiplying by 20.9
Convert values in kPa to psi by multiplying by 0.145

HBSN BOND STRENGTH AND ITS MEASUREMENT

In response to the first objective of this research, we reviewed the factors that affect the bond strength of the grout to soil or rock as it relates to HBSNs. The higher grout injection pressures used for installation of HBSNs may lead to either undercutting and permeation of grout in granular soils or to undercutting of fine-grained soils. It is widely believed that results of higher grout injection pressures have a positive impact on the grout-to-ground bond strength. The increase in bond strength will depend on the soil characteristics and on the installation process. Some of the installation features affecting bond strength include grout mix properties at time of drilling, injection pressure of the grout, drill bit size and type, and drilling feed rate. Another important variable would likely be whether a leaner grout (higher water to cement ratio) is used for drilling, as this may promote more intense permeation of grout in granular soils.

One suggested technique to summarize the factors that promote increased bond strength in HBSNs during design is to multiply the drill bit diameter by a summary parameter or factor to account for undercutting and grout permeation (Con-Tech 2009). This factor is dependent on the soil type being penetrated with the HBSN. The results of the tests performed for this investigation provide some insight into the suitability of using factored diameter values for the design of HBSNs.

Extrapolation of bond strength values for typical SBSNs for use in the design of HBSNs can be difficult. Current soil nail testing includes verification tests and proof tests as part of the testing program. During installation of a solid bar test nail, the pre-drilled hole is filled with grout only to a predetermined bond length, leaving an upper unbonded length free of grout. The position and length of the bond zone in a test nail are selected to test the bond strength in a specific stratum. Results of the tests enable back calculation of the *in situ* bond strength of the grout-ground interface and verification of the design assumptions critical to internal and global stability of a soil nail wall. For traditional SBSNs, the installation and testing procedures are as defined in current FHWA documents (for example, FHWA, 2003).

Conversely, the concurrent injection of grout during the drilling of an HBSN results in a complete column of grout. There are no universally established and accepted installation procedures to allow consistent creation of bonded and unbonded zones within a test HBSN for selective bond strength verification. Based on the authors' experience and as reported in the SOP (FHWA 2006), the unbonded zone of test HBSNs has been developed by flushing grout, or through isolation by using a pre-installed smooth casing bondbreaker, or both. Each contractor develops a different procedure depending on the peculiarities of each job site, the required unbonded length, the available equipment and materials, and their own preferences. Thus, reported values of bond strength from differing contractors can vary greatly. Therefore, development of a suitable installation and testing protocol for HBSNs is a significant need at this time.