CHAPTER 6 – CONCLUSIONS

The tests performed for this investigation provided valuable insight into the behavior of HBSNs, and constituted the first published concerted effort in establishing suitable installation procedures for test HBSNs.

Geotechnical failure was achieved in most of the tests performed during this investigation. However, at some sites, failure of the test nails did not take place in the granular soils. Therefore, the data given in this report includes maximum tested bond values and not ultimate values for some of the tests. It must be noted, however, that most of the test nails that did not achieve geotechnical failure were installed using Method C. It is likely that in these nails, the Doughnut Effect was significant and the maximum bond values reported are overestimated as discussed in the report.

The results of the tests performed on SBSNs installed in Silty Sand (SM) and Poorly Graded Sand (SP) showed values of average bond strength similar to the presumptive values given by FHWA (2003). However, the calculated bond strength values for SBSNs in Poorly Graded Sand with Gravel (SP with Gravel) and Poorly Graded Gravel with Sand (GP with Sand) were significantly higher than the FHWA presumptive values. Therefore, it may be concluded that the presumptive values given by FHWA for SBSNs in coarse granular soils may be conservative. This is consistent with the experience of the authors based on load testing of soil nails, tiebacks, and micropiles installed in coarse granular soils.

The tests showed that HBSNs generally develop larger bond strength values in granular soils than traditional SBSNs. This is due to the larger grout body created by undercutting and permeation of the soils by the grout, and to more pronounced roughness features in the surface of the grout body. Consequently, the FHWA presumptive values for SBSNs are likely very conservative in most cases.

In granular soils with a significant content of fines (SM and SC), the calculated average bond values for HBSNs installed using Methods B and D were similar to those for Method A nails, and to the presumptive values given by FHWA (2003). This suggests that undercutting and permeation of these soils by the grout are not as significant as in more predominantly granular soils.

Observation of exhumed HBSNs that were installed in predominantly granular soils reveals that the grout body along the bond zone is significantly larger than the nominal drill bit diameter. This is caused by undercutting of the soil by the jet of grout exiting the drill bit. Comparison of the exhumed HBSNs and SBSNs suggests that the grout body of the HBSN is larger and rougher than that of the SBSN installed in the same formation.

Also, in granular soils, exhumed HBSNs show an exterior zone of grout-permeated soil adhered to the bond zone, which further contributes to the capacity of the soil nail.

The Method B installation procedure (Hollow Bar Installed with Debonding Sheath and Water Flushing) provided efficient debonding of the soil nail along the intended unbonded length. However, this method requires equipment to install and remove the casing within the free length, which is not typically used for HBSN installation. In addition, if this method is used for production soil nails to be proof-tested, it would not be possible to provide a suitable grout cover along the unbonded length after testing. Therefore, this method would not be suitable for permanent soil nails used for proof testing.

Method D (Hollow Bar with Bondbreaker Installed by Re-drilling a Pre-grouted Hole) also provided efficient debonding of the soil nail along its intended unbonded length. However, the effectiveness of this method in debonding the soil nail may vary depending on the soils at the site, and the experience of the driller. Therefore, it is advisable to request that the contractor provide proof that the test loads are not being transferred to the free length of the soil nail. This can be accomplished using strain gauges near the top and bottom of the unbonded length.

Method, D can possibly be used for proof testing of production soil nails in long-term support applications. If the hole is stable after re-drilling, it may be possible to re-grout the unbonded zone after testing.

In HBSNs installed using Method C, significant debonding was achieved along the intended unbonded length. However, the efficiency of debonding was less than that achieved using Methods B and D. In addition, a significant Doughnut Effect was inferred from the test data from soil nails installed following Method C. The annular grout around the debonded zone of the nail may transfer significant loads from the bond zone below up along the unbonded length, thus biasing the test results and providing inaccurate, unconservative values of average bond strength.

Consequently, Method C is not recommended unless the tendon of the soil nail is fitted with a suitable number of strain gauges that allow determination of the bond stresses mobilized along the bond zone. In most cases, a minimum of four strain gauges would be necessary: two along the unbonded length, and two along the bonded length. It is also likely that the tendon of the soil nail needs to be oversized to allow sufficient load to mobilize the design ultimate bond stress along the bond zone.

The Doughnut Effect was not observed in Method C HBSNs installed at the Olympia Site, possibly because the annulus around the unbonded length was partially flushed. Flushing of Method C nails is not recommended as a standard test procedure.

The tests at the Olympia Site showed that it is possible to install a suitable number of strain gauges within hollow core bars for measurement of axial strain with depth. A suitable number and location of strain gauges may aid in the correct determination of bond strength values in Method C soil nails, and should be a requirement in any test nail where there is uncertainty about the efficiency of the debonding procedure used, or on the existence or not of a significant Doughnut Effect.

Interpretation of strain gauge data must consider the stiffness of the grout in tension when relatively small loads are applied to the soil nail.

In many soils, it is clear that there is a benefit to anchor design developed by the HBSN installation processes. The evaluation of testing methods is not complete at this time, and further data collection is warranted to finalize a testing protocol and establish preliminary design bond values or diameter magnification factors.