CHAPTER 5

WHAT ARE QA/QC REQUIREMENTS FOR IMPROVED GROUND?

Verifying that the level of improvement required has been obtained is a difficult but extremely important aspect of ground improvement. Quality assurance and quality control consist of two phases: observation during construction and geotechnical verification testing after construction is completed. During construction, observations should be made and recorded at each improvement location, including ground surface movements, the volume of backfill material used, grout take, and the amount of energy or pressure expended. After construction, in-situ methods such as SPT, CPT and/or shear wave velocity testing can be performed to verify that the level of improvement required is achieved. Laboratory testing can also be used to evaluate some types of improvement.

Construction Observations

Construction observations provide an initial indication of the effectiveness of the method. While they cannot be used as the sole indicator that ground improvement has been successful, they give a general idea of where the treatment has succeeded or failed. In-situ testing can then be performed in areas where the observations indicate the minimum degree of improvement achieved. Such selective testing will give conservative results regarding the overall level of improvement achieved.

Different types of ground improvement require different types of construction observations and sampling. Some of the necessary observations for different methods are described below.

Admixture-Stabilized Soils. During stabilization of soils with admixtures, the most important observations are the amount of admixture and water mixed into the soil, the amount of mixing performed, and the amount of compactive effort used on the fill. The moisture content and density of the fill can be determined in the field. The curing time and conditions should also be recorded. Samples should be taken for laboratory testing.

Roller Compacted Concrete. One of the most important factors in satisfactory performance of RCC is bonding between layers. Therefore, it is important to observe that bedrock is cleaned thoroughly prior to placement of the RCC or bedding concrete. Bonding between successive lifts of RCC depends on the time between placement of successive lifts, temperature and humidity. If lifts are not placed continuously, "cold joints" consisting of bedding concrete may be required. The time between mixing and placement of the RCC, as well as the time between placement of successive lifts should be recorded. In addition, the weather conditions, lift thickness, degree of compactive effort placed on the RCC, wet density and water content of the RCC, and location of cold joints should be observed and noted. The lift surface and haul road should be kept clean to prevent the inclusion of soil and other debris in the RCC. Samples should be taken for laboratory testing.

Deep Dynamic Compaction. Observations during deep dynamic compaction include the height of the drop, the location of the drop points, the number of drops at each location, and the crater depth for each drop. The type of backfill and degree of compactive effort used in the crater should be noted. Based on the average surface settlement and the volume of backfill added, the average change in relative density in the improved zone can be calculated. If necessary, vibrations should be measured in nearby structures.

Vibro Methods. For vibro methods, it is important to record the location of the treatment points, the volume and depth distribution of material used to backfill the probe holes, and the vibroflot energy and time spent densifying the backfill at each location and depth. The settlement of the ground surface should be monitored. These observations give a general indication of the overall effectiveness of the treatment and the level of densification achieved. As with DDC, the average change in relative density can be calculated based on surface settlement and the amount of backfill added.

Explosive Compaction. When explosive compaction is used, the location of the boreholes and the depths of the charges should be recorded. After blasting, the surface settlements should be noted. If water erupts from the boreholes after blasting, it should be noted. If necessary, vibrations should be measured in nearby structures.

Penetration and Compaction Grouting. For grouting, the following observations should be made: the location of the injection points; the volume and location of each type of grout injected; depth, pressure, duration of grout injection; and, ground surface elevations before, during, after construction to check for settlement or heave of the ground or structure. Grout mix samples should be taken for strength testing. These observations provide information on where the grout is going in the soil mass and the overall effectiveness of the treatment.

Jet Grouting. Most jet grouting projects require test sections prior to construction to determine the geometry and quality of treated material that can be obtained. During construction, it is important to note if the grouting parameters and materials are consistent with the approved test section. As discussed in Chapter 3, the ability to erode the soil with the jets is an important factor in successful jet grouting. There should be a continuous flow of spoils to the ground surface during jetting. If there is no spoil return, it is possible that hydrofracturing is occurring. The rate of rotation and removal of the grout pipe and the rate of material consumption should be monitored. Preliminary assessments of the geometry of the treated ground can be made by measuring the unit weight of the waste return, however, the best methods for assessing the geometry are excavation or coring (ASCE, 1997). Wet grab samples should be taken for strength and permeability testing. If piezometers are installed for later hydraulic conductivity measurements, the construction details of the piezometers should be recorded.

Micro-piles, Soil Nailing, and Deep Soil Mixing. During construction, the material quantities used in construction should be compared to the design quantities. If the material quantities used are much less than design quantities, it is possible that the ground has "squeezed" into the hole and the pile or wall integrity could be compromised. In addition, the lengths of the piles or nails and the depths of the deep-mixed elements should be recorded. The drilling time and difficulty, as well as the type and quantity of spoils should be observed for each element.

PV Drains. Prior to installation of the PV drains, a gravel drainage blanket is typically placed. The thickness of the drainage layer and the type of gravel used should be recorded. The installation of monitoring devices such as piezometers, settlement platforms and gauges, and/or inclinometers should be observed. Details such as type of instrument, location, and elevation should be recorded. During drain installation, the length and location of each drain should be recorded.

Biotechnical Stabilization and Soil Bioengineering. The USDA Soil Conservation Service has a chapter in its Engineering Fieldbook (USDA, 1992) that discusses the use of biotechnical stabilization and soil engineering for slope protection and erosion control. The chapter contains guidelines and directions for use of biotechnical stabilization. Field observations for planting should include the type and quantity of seed or vegetation being planted, the location of the materials being planted, and soil, watering and weather conditions. For structural elements, the location and type of elements should be recorded, as well as fill placement and compaction procedures behind the structural elements.

Verification Testing

General. The most common methods used for in-situ verification of ground improvement are SPT and CPT testing. Other methods that may be used include Becker penetration testing (BPT) for soils with high gravel or cobble contents, shear wave velocity testing and vane shear testing. The tests are usually performed midway between treatment locations to determine the properties at the locations that are expected to have the smallest degree of improvement. When determining post-treatment properties, it is preferable to use the same test that was used to determine pre-treatment properties. On some projects, the lack of comprehensive data on pre-treatment conditions has made it difficult to evaluate the properties of the treated ground. It is also important to consider the time after treatment at which the tests will be performed, since properties of improved ground often continue to show an increase over time.

Shear wave velocity testing can be used to verify the overall improvement obtained from compaction grouting or vibro methods; however, the results can be difficult to interpret due to the heterogeneity of the improved ground. Load testing can be used to verify the capacity of stone columns and axially- or laterally-loaded micro-piles. Inclinometers or movement gauges can be used to monitor the performance of reticulated micro-pile installations or soil nailed walls. Coring and excavation are the best techniques for verification of the geometry and quality of jet grouting and deep soil mixing construction.

Liquefaction Resistance. The properties of the improved ground can be compared with standard liquefaction potential curves (Figure 44) to assess if the degree of improvement achieved is satisfactory. As discussed in Chapters 4 and 6, use of SPT $(N_1)_{60cs}$ values obtained in improved ground in conjunction with liquefaction potential curves was generally successful in predicting the performance of improved sites subjected to the 1989 Loma Prieta and 1995 Kobe earthquakes.

The use of shear wave velocity testing to verify ground improvement for mitigation of liquefaction risk is becoming more common. While the available data from liquefaction sites is somewhat limited at this time, shear wave velocity testing offers advantages in that it can be performed in soils where it is difficult to perform CPT and SPT testing and there are several techniques available for measurement. The most recent correlations between shear wave velocity and cyclic stress ratio causing liquefaction presented in Andrus and Stokoe (1997) in NCEER (1997) appear to give reliable results. As these correlations have not been tested as extensively as the CPT and SPT correlations, they should be used with caution or be used as a secondary method supporting results obtained using the CPT or SPT.

Hydraulic conductivity. Ground improvement methods are used both for increasing the overall permeability of a soil layer (e.g., gravel drains for liquefiable layers) and decreasing the permeability of a layer (e.g., seepage cutoff). In both cases, the permeability needs to be evaluated to determine the overall effectiveness of the treatment method.

Pump tests can be used to measure the resultant permeability when jet or penetration grouting is used for seepage control applications. For jet grouting, pump tests using cast-in-place piezometers are preferred because they are non-destructive and have shown reasonable correlations with measurements from wet grab samples (ASCE, 1997). Results from Packer testing have not correlated well with results from wet grab samples. Permeability values determined using cores taken from cemented materials are usually too high owing to the stress release and micro-cracking that accompanies the sampling process.

Pump tests are not recommended to determine the permeability of stone columns for mitigation of liquefaction risk (ASCE, 1997). According to a study conducted by Baez and Martin (1995), field pump tests resulted in permeability values up to two orders of magnitude lower than obtained from empirical correlations and laboratory tests performed on extracted samples. This result could possibly be due to the large difference in permeabilities between the native material and the stone columns and the small column diameter (Baez and Martin, 1995). Therefore, the preferred method is to perform laboratory tests on extracted samples. Empirical correlations can also be used.

Laboratory Testing

Laboratory testing can be used to evaluate the density, strength and stiffness properties of improved soils, especially when admixtures or grouts are used. Grab samples of the stabilized soil can be obtained during construction, cured in the laboratory and tested to give an overall indication of the effectiveness of the treatment. The unconfined compressive strength is a good indicator of properties in admixture-stabilized soils. For example, lime stabilization can be considered satisfactory if the compressive strength increases at least 50 psi after curing 28 days at 73 F. If the soil is reactive and this strength increase is obtained, good results can be expected with respect to other property values. Strength increases greater than this can be expected if Portland cement is used as the stabilizer.

Laboratory testing is more expensive and difficult if "undisturbed" samples are required after construction. The samples can be difficult to obtain, the effects of disturbance can be significant, and the sampling can destroy the integrity of the installation. Therefore, in-situ verification tests are the preferred method when possible.