SPECIFICATIONS FOR
CEMENT DEEP SOIL MIXING (CDSM)

DESCRIPTION and DEFINITIONS

CEMENT DEEP SOIL MIXING (CDSM) is a soil improvement technique used to provide support to load-bearing foundations, mitigate liquefaction potential, offer temporary excavation support, or increase slope stability and/or seismic lateral spreading. The stabilized soil columns are formed by a mixing shaft and paddle configuration rotated by a drill motor mounted on a specialty built rig. As the mixing shaft is advanced into the soil, grout is pumped through the hollow stem of the shaft and injected into the soil at the tip. The mixing blades on the shaft blend the soil with the grout in a pugmill fashion. The mixing shaft produces individual columns that can be used independently or which can be overlapped to form a wall or underground buttress. Mixing is performed as a "top down" procedure. When the design depth or refusal is reached, the tool is withdrawn in a counter rotating manner on the way to the surface. The "wet" CDSM column hardens over time, gaining most of its strength and permeability properties within 28 to 365 days.

GROUT is a stable mixture of water and Portland cement. Additional materials such as bentonite clay, attapulgite clay, fly ash, or other additives may be added with the approval of the Engineer.

1.1 SCOPE and DESIGN BASIS

The Contractor shall install the CDSM columns in accordance with GeoDesign, Inc.'s design package, the Drawings, and these Specifications. The work consists of furnishing all batch plant, labor, equipment, and materials and performing all operations required to perform the soil mixing, except for the removal of obstructions that may be encountered and which are larger than 12 inches in nominal diameter or length. The work also consists of testing the CDSM columns to verify that design strengths and adequate mixing are being achieved.

The CDSM shall have a minimum 28-day unconfined compressive strength (UCS) of 150 pounds per square inch.

1.2 CDSM INSTALLATION PLAN

The Contractor shall submit a CDSM Installation Plan that includes the following items:

- Evidence of Contractor's previous experience in performing similar types of work.
- A detailed description of the equipment and procedures to be used during construction; methods of monitoring the specified Quality Control parameters; and methods of obtaining, storing, and transporting samples for laboratory testing. Provide a description of the equipment that will be used to monitor mixing systems, delivery systems, alignment systems, and shaft rotation and penetration speeds. Submit equipment calibration results.
- Working drawings showing the CDSM column layout and column numbering system.
- Construction schedule that includes mobilization, start of production, end of production, verification testing, and demobilization. Include the assumptions used to develop the schedule, including estimated rig production rates, the number of rigs to be used, the number of rig shifts per day, and any known pauses in production.
- Grout mix design, including materials and quantities. Include information on admixtures.

Provide the anticipated cement dosage that will be necessary to achieve the specified CDSM strength.

- Spoils Management Plan that identifies spoil stockpile location and anticipated stockpile volumes as well as outlines waste containment methods.
- Attach a copy of the project Temporary Erosion and Sediment Control Plans. Include procedures to be used to prevent high pH stormwater or dewatering water from being discharged from the project site.
- Proposed drilling subcontractor(s) and equipment that will be used to perform the full-depth Quality Control cone penetration testing and/or coring of CDSM columns.
- An example Daily Quality Control Report form.
- A description of the Quality Control program. Include the names of testing agencies. Describe how wet and cored samples will be collected, stored, and transported to the testing agency.

1.3 PRE-CONSTRUCTION MEETING

A pre-construction meeting shall be held at least five working days before the Subcontractor begins any CDSM-related work at the site to discuss construction procedures, personnel, equipment to be used, Quality Control, and other elements of the CDSM Installation Plan. The meeting attendees shall include the following:

1. Representing the Contractor:
    a. General contractor project manager
    b. CDSM subcontractor project manager
    c. CDSM subcontractor Quality Control manager
    d. CDSM subcontractor superintendent/foreman in charge of CDSM construction
    e. Contractor responsible for site work, spoils removal, and stormwater runoff collection and treatment
    f. Manager/supervisor from the independent testing laboratory
2. Representing the Owner:
    a. Owner’s representative
    b. Project geotechnical engineer
    c. Special inspector

1.4 SOIL MIXING

Soil Mixing shall be performed to the lines, grades, and cross sections indicated on the Drawings. The columns shall be essentially vertical and shall be at least the minimum lengths shown on the plans. The completed CDSM columns shall be a homogenous blended mixture of grout and the in situ soils. Mixing is to be controlled by mixing shaft speed, penetration rate, and grout injection rate. The soil profile through which the CDSM columns are to be constructed is indicated by boring logs included in the project Geotechnical Report. Contractor shall immediately notify the Engineer if changes are to be made to the grout mix, installation methods, or Quality Control program. The Contractor will not be compensated for CDSM columns that do not comply with the requirements

of these Specifications. The Contractor will not be compensated for CDSM columns that are constructed above the top elevation or below the bottom elevation specified on the project Drawings, unless approved by the Engineer.

Before construction, a proposed mix design shall be generated by the Contractor. The mix design may be prepared based on site soils and laboratory testing or, alternatively, based on the Contractor's experience with similar soil conditions and strength requirements. The mix design is intended to specify the mix ingredients, sequence of mixing, grout properties, and soil mix properties. The basic guiding principal for the laboratory mix program is to strive to accurately model expected field conditions.

1.5 MATERIALS

1.5.1 Grout: The material added to the soil will be water-based grout. The purpose of the grout is to assist in loosening the soil for penetration and mixing, and to aid in structural support. The grout will be premixed in batch plants, which combine materials in predetermined proportions or via continuous mixing with its quality controlled by specific gravity. Ready mix grout is also acceptable with the approval of the Engineer.

1.5.2 Water: Fresh water, free of excessive amounts of deleterious substances that adversely affect the properties of the grout, shall be used to manufacture grout. It is the Contractor's responsibility that the grout resulting from the water shall always meet the standard of this Specification.

1.5.3 Additives: Admixtures of softening agents, dispersions, retarders, or plugging or bridging agents may be added to the water or the grout to permit efficient use of materials and proper workability of the grout. However, no additives shall be used except as approved by the Engineer.

1.5.4 Cement: Cement used in preparing a grout shall conform to ASTM Designation C-150 Requirements for Portland Type I/II Cement. Type V cement may need to be used depending on sulfate concentration test results. The cement shall be adequately protected from moisture and contamination while in transit to and in storage at the job site. Reclaimed cement or cement containing lumps or deleterious matter shall not be used.

1.6 EQUIPMENT

1.6.1 Batching Equipment: The batch plant shall consist of purpose-built mixers, volumetric screw feeders, and flow controllers. Dry materials shall be stored in silos and fed by screw feeders to the mixers for agitation and circulation. Dry materials may also be stored in bags tailored for this specific purpose. The resulting grout will be transferred to the soil mixing rig.

Dry ingredient proportions shall be batch mixed by weight or continuously mixed by means of a jet valve to a predetermined final density. A minimum mixing time of three minutes and a maximum holding time of three hours will be enforced for the grout. The grout hold time shall be calculated

from the beginning of the initial mixing. Notwithstanding this requirement, the maximum holding

time does not relieve the Contractor from its responsibility to produce a pumpable and stable grout mix adequate for the CDSM process.

The precise arrangement and sequence of mixing shall be based on the results of field calibrations at the beginning of the treatment program that are performed during the installation of a "sacrificial" column. Calibration of mixing components shall be done at the beginning of the project and monthly thereafter. The screw feeders shall be calibrated against time to deliver a predetermined weight, unless a Jet Valve mixing system is used. Water shall be controlled by flow meter and/or by volume level indicators in the mixer. The specific gravity of the grout shall be determined at least daily during the CDSM installation program to double check grout proportions.

1.6.2 Soil Mixing Equipment: The Soil Mixing rig shall consist of a mixing shaft capable of creating a column with nominal diameters as indicated on the Drawings. The mixing shaft and mixing blades shall be configured in such a manner so that they are capable of blending the in situ soils and grout. The range of expected drilling conditions is indicated in the project Geotechnical Report. The shaft is to have a bottom discharge capability for grout.

Unless obstructions are encountered, the power source for driving the mixing shaft shall be sufficient to maintain a minimum shaft rotation speed of 20 rotations per minute (RPMs) and a penetration rate of greater than 1 inch of penetration per revolution.

1.7 CONSTRUCTION

1.7.1 Horizontal Alignment: The Soil Mixed Columns shall be carefully staked out before construction begins. The columns shall be constructed within 4 inches of the locations shown on the Drawings.

1.7.2 Vertical Alignment: Vertical alignment of the auger stroke will be controlled by the equipment operator. The columns shall have a tolerance of 1:50.

1.7.3 Mixing Shaft Speed: The mixing shaft speed (RPMs) shall be adjusted to accommodate a constant rate of mixing shaft penetration based on the degree of drilling difficulty.

1.7.4 Penetration Rate: In order to ensure adequate mixing, the penetration rate of the mixing shaft shall be maintained in the range of 1 to 8 vertical feet/minute during both penetration and withdrawal. The bottom of the columns shall be double mixed by raising the mixing shaft 5 feet off the bottom and then reinserting it for remixing. The penetration rate and maximum depth of each stroke shall be recorded on the Daily Quality Control Report form.

1.7.5 Grout Take: The grout take (or injection rate) per vertical foot of column will be adjusted to the requirements of the design mix. Positive displacement pumps will be used to transfer the grout from the batch plant to the CDSM rig. A flow monitoring device will be installed in the grout line to detect any line blockage.

The rate of application may be controlled and monitored by adjusting the pump output to the penetration rate so that a preset grout take can be achieved. Typically, the application rate can be

successfully controlled by experienced operators once the pattern of operation is established.

Inevitably some variations of the grout take will occasionally occur due to field conditions. However, the overall application rate to each stroke can be monitored, calculated, and controlled. Additional mixing is to be used when necessary to evenly distribute the grout through the entire column. The injection of grout to each stroke will be monitored, checked by calculation, and recorded. If the volume of grout injected per vertical foot of column is less than the amount required to meet the CDSM mix design, the column shall be remixed and additional grout injected at the design rate to a depth of at least 3 feet above or below the deficient zone and at no cost or schedule impact to the Owner.

Each column shall be installed continuously without interruption. If an interruption of more than one hour occurs, remix the entire column while injecting new grout at the design rate at no cost or schedule impacts to the Owner.

Recently installed CDSM columns will have low strength and are susceptible to damage from equipment traffic. Only track-mounted equipment shall be allowed to drive over CDSM columns within the first 3 days of installation. Contractor shall wait approximately 24 hours to install adjacent columns spaced closer than two column diameters apart (center-to-center spacing) so that the CDSM material has begun to harden and the risk of negatively impacting an adjacent fresh column is reduced.

1.7.6 Column Depth: Unless otherwise directed, the CDSM columns shall be extended to elevation -30.0 feet (COP datum) or below. The final depth and penetration of the columns shall be measured from shaft penetration and checked by the Contractor and approved by the Engineer immediately following penetration.

1.7.7 Obstructions/Mixing Shaft Refusal: If obstructions are encountered that reduce the rate of penetration to 1 foot per minute for 5 minutes, the stroke shall be completed in accordance with the Specifications and remedial measures will be taken. If the obstruction is less than 6 inches, the Contractor will attempt to remove the obstruction using an auger. If the obstruction is larger than 6 inches or cannot be penetrated with the auger, the location may be abandoned and a new column may be installed adjacent to the abandoned location or the obstruction may be removed by others using excavation equipment. In cases where refusal is encountered due to obstructions, the Contractor is to be additionally compensated. Pre-augering or trenching operations may be necessary to remove shallow debris. Pre-trenching is to be done with a nominal 24- to 36-inch-wide bucket. Although it is anticipated that trench walls will be temporarily stable, the Contractor shall be prepared to backfill the excavation with loose or broken-down soil to a depth of 4 feet below the working surface. The Contractor shall also be prepared to use other means of temporary trench stabilization such as building a water pressure head, if necessary. No trench that is deeper than 4 feet shall be left open overnight or at any time when the Contractor is not actively working on site.

1.7.8 Vibration and Noise: Soil mixing operations shall not cause excessive vibration at adjacent facilities or noise exceeding permit limits beyond property lines.

1.7.9 Contaminated Soils: If contaminated media is encountered, the excavated soils are to be screened, separated, and removed (by others) per the project Contaminated Media Management Plan (CMMP). The Contractor can re-use the part of the soils that are free of contaminants and debris to refill part of excavated trenches and/or CDSM hole locations. On-site handling or stockpiling of excavated soil, covering of stockpiling with plastic, or other measures to prevent cross contamination, etc., as required by the CMMP are the responsibility of others as covered in other sections of the contract documents.

1.8 QUALITY CONTROL PROGRAM

The Quality Control program shall be the responsibility of the Contractor. The Contractor shall provide all equipment and personnel necessary to implement the Quality Control program. The Quality Control program shall include field monitoring of construction parameters, wet sample collection, cone penetration testing and/or full-depth coring with core sample collection, and laboratory strength testing. Some of the samples shall be retained by the Contractor for potential Quality Assurance testing by the Engineer. The as-built locations of CDSM columns shall be located in the field by a licensed surveyor.

The design UCS strength requirement applies to a curing time of 28 days. For evaluation and acceptance of the work, 28-day strengths will be used based on the 3-day and 7-day correlations below, unless superseded by a site-specific correlation and the approval of the Engineer.

$$q_{u28} = q_{u3} * 2.5$$
$$q_{u28} = q_{u7} * 1.5$$

Field correlations can be developed, in coordination with the Engineer, for verification testing at other time intervals.

1.8.1 Quality Control Field Monitoring and Documentation: The Contractor shall submit Daily Quality Control Reports to the Engineer by the end of the next working day. The Daily Quality Control Reports shall document the progress of the CDSM installation, present the results of the quality control parameter monitoring, present the results of strength testing, and clearly indicate where the columns have not met the acceptance criteria. At a minimum, the Daily Quality Control Reports shall contain the following information for each column:

- Project name
- Column ID number
- Column diameter
- Start time
- Time bottom of column is reached
- Finish time
- Mixing depth
- Depth vs. time

- Grout volume vs. depth
- Shaft rotation speed vs. depth
- Shaft penetration vs. depth
- Column tilt
- Grout mix design designation
- Grout specific gravity
- Notes regarding drilling conditions, interruptions, or other difficulties

1.8.2 Grout Monitoring: The proposed grout mix design shall be submitted to the Engineer for approval as part of the CDSM Installation Plan. Grout control shall be performed by unit weight or specific gravity testing, determined using the mud balance method, hydrometer testing, or a mass-density flow meter. At least one grout Quality Control test shall be performed and recorded per day. The specific gravity of the grout measured in the field shall not deviate by more than 3 percent of the calculated specific gravity for the mix design. Calculations of mix proportions will be by the absolute volume method. Proportion calculations will be based on the weight of the water proportion of the grout (i.e., water/cement ratio).

1.8.3 Wet Sample Collection: Once per shift, or at the rate of one location per 400 cubic yards of soil-cement column volume, whichever is more frequent, samples will be retrieved from a random column determined by the Engineer's inspector for testing each day's work. These samples shall be taken by a special sampling tool at the depth selected by the Engineer's inspector of the column immediately following installation. The soil mix obtained shall be placed in suitable molds, rodded to remove trapped air pockets, and then sealed in accordance with ASTM D1632. Inclusions of unmixed soil are allowed provided their nominal diameter is less than 15 percent of the sampler diameter (½-inch screen for a 3-inch-diameter cylinder) and the inclusion is completely surrounded by cemented material. The samples shall be stored in a damp environment for curing until initial set has been achieved, in accordance with ASTM D1632. After initial set, a dead weight load may be imposed on the sample to model the stress from earth pressures.

Six cylinders (3 inches by 6 inches) shall be cast from each sampled column. One half of the cylinder samples are to be stored and tested by the Contractor for Quality Control testing, while the other one half of the samples are to be stored on behalf of the Engineer for potential Quality Assurance testing.

1.8.4 Wet Sample Testing: The prepared wet samples are to be transported to an independent geotechnical laboratory for testing once they have sufficient strength gain so that transporting will not adversely affect the properties. Samples are to be stored in accordance with ASTM D1632 until they are tested. UCS testing shall be performed in accordance with ASTM D1633 at intervals of 3, 7, and 28 days after casting. The test results shall be promptly provided to the Engineer.

1.8.5 In Situ Testing: To evaluate the CDSM column mixing continuity and further assess strength, cone penetration tests and/or full-depth cores shall be performed on 5 percent of the CDSM columns. Testing shall be performed at additional CDSM columns if anomalies are observed during the initial evaluation. For cone penetration testing, tip resistance, sleeve friction, pore pressure, temperature, and inclination data shall be collected. For full-depth coring, the coring

shall be performed using a double- or triple-tube barrel with wireline drilling techniques. The minimum internal diameter of the core barrel shall be 2 3/8 inches (NQ). The core bit used should direct the drilling water sideways and outward, away from the sample to prevent erosion of the sample. Coring shall be retrieved at a distance of one-fourth the column diameter from the column center. Core drilling operators shall have experience successfully coring soft, rock-like quality materials. Extracted cores shall be logged by the Engineer's inspector for continuity, uniformity of soil-binder mixing, and strength. Care should be taken in logging, wrapping samples in plastic, and transporting cores from the field to the laboratory. Coring shall be performed after a minimum curing period of 21 days after installation to confirm 28-day design strength. The Contractor shall notify the Engineer at least one business day (24 hours) before beginning cone penetration test or coring operations. All cone penetration test and core holes shall be filled with grout having 28-day strength equal to or greater than the specified strength of the treated soil.

If gravel is present in the CDSM, it may cause cracks and other damage during coring and thereby reduce core recovery. During the coring process, gravel inside the soil-binder mixture tends to break or grind the core samples. In cases of poor core recovery, an optical televiewer may be used to supplement assessment of uniformity. Worn or inadequately maintained cutting heads, core rods, and other coring devices tend to reduce the recovery and quality. If the Contractor is unable to obtain adequate core recovery, an optical televiewer shall be used at the Contractor's expense.

Upon retrieval, the full-depth samples should be provided to the Engineer for logging, selecting test specimens, and assessing whether mixing uniformity and recovery criteria have been satisfied. Following logging, the Engineer selects specimens for strength testing. Three test specimens shall be collected from each full-depth continuous core for UCS testing. Test specimens should have a length-to-diameter ratio of 2 or greater.

Engineering judgment must be used to select test specimens to minimize the potential for biasing the data. Samples should be selected carefully to represent the deep mixed element rather than focusing on samples that appear to be unusually weak or that contain inclusions of unmixed soil that are not proportionately representative of the entire column.

Immediately following logging and test specimen selection by the Engineer, the entire full-depth core sample, including the designated test specimens, must be sealed in plastic wrap to prevent drying and transported to the laboratory by the Contractor.

Obtaining good core recovery in treated ground with gravel or cobbles can be difficult or impossible. When coarse-grained soils prevent core recovery even with high-quality triple-tube coring methods, acceptance will be permitted based on the strengths from wet grab samples combined with optical logging to verify thoroughness of mixing.

If a strength specimen falls below the specified strength due to an obviously unrepresentative lump of unmixed soil in the specimen, the Engineer shall test another specimen from the same core run. Only one such retest will be allowed per core run. The objective of this provision is to avoid incorporation of test results from specimens that contain lumps of unmixed soil that, if scaled to the full element size, would be unrepresentative of the actual size of unmixed soil that observations of core and spoils indicate could exist in the element. Mixed soil strengths below the specified

strength should not be permitted within 10 feet of the same elevation in more than two nearby cored elements. Nearby cored elements refer to cored elements without an intervening cored element that has a passing test result in the suspect elevation zone.

Core recovery (expressed as a percentage) should be reported and is equal to the total length of recovered core divided by the total core run length. Length of recovered core includes lengths of treated and untreated soil. Minimum required recovery shall be 80 percent. Core runs that do not satisfy the minimum core recovery should be verified using optical logging.

Percent treatment is calculated as the total length of recovered core minus the sum of the lengths of unmixed, unrecovered core length, or poorly mixed soil regions or lumps that extend across the entire diameter of the core divided by the total core run length expressed as a percentage. Percent treatment must be at least 80 percent for every 5-foot (1.5-meter) core run. If 80 percent treatment cannot be confirmed by coring, optical televiewer logs can be used to confirm uniformity.

1.8.6 Core Sample Testing: The core samples are to be transported to an independent geotechnical laboratory for testing once they have been cored. The samples must be stored in a moist room in accordance with ASTM C192 until the test date. UCS testing of core samples shall be performed 28 days after the CDSM column installation, in accordance with ASTM D2166. The test results shall be promptly provided to the Engineer.

1.8.7 Acceptance Criteria: Acceptance of the CDSMs shall be based on column geometry, mixing continuity, and strength. The geometry shall be evaluated based on column diameter, depth, embedment, location, and inclination. The mixing continuity shall be evaluated using cone penetration testing, recovered core samples, and/or an optical televiewer. The evaluation shall confirm that a relatively uniform and homogenous mixture of soil and grout is being achieved. The strength shall be evaluated based on wet samples of CDSM that are collected and tested, as well as in situ testing.

UCS tests should be considered passing where they meet or exceed project strength requirements. Tests should be considered passing if they are within 10 percent of the requirement, provided that no more than 10 percent of all tests fall below the requirement and the overall average strength exceeds that requirement.

1.8.8 Failure to Meet Acceptance Criteria: If the acceptance criteria provided in this Specification is not achieved, the limits of the deficient areas will be determined by the Engineer. If UCS tests fail to meet the strength requirements, the Contractor may conduct additional sampling and testing to better define the limits of the failed area at no cost or schedule impact to the Owner. For failed sections, the Contractor will be given the opportunity to remix or repair the failed section at no cost or schedule impact to the Owner. The Contractor shall submit a proposal plan for repair of the failed section for review and approval by the Engineer.