Guidance for Drafting Specifications for Ground Improvement

Abstract
As ground improvement becomes more widely implemented, practitioners in both geotechnical construction and consulting have realized that the content of current project specifications is inadequate to consistently promote the selection of the best-fit ground improvement solution. As an example, the specifications often require the use of a single ground improvement technique instead of defining performance criteria that allow the use of several techniques. Further, the specifications frequently do not define the parameters or methods to be used in design and evaluation of ground improvement. As a consequence, the ground improvement bidders often propose scopes and pricing that may not be consistent or directly comparable with each other. These realities prompted the DFI Ground Improvement Committee to prepare this guidance document to improve the consistency of specifications for ground improvement work. The purpose of this document is to help owners prepare specifications that provide broad performance criteria and design details so that contractors can offer bids that reflect the best-fit ground improvement technique for each project’s needs.

Introduction
A wide array of ground improvement techniques is increasingly being applied on projects to enhance the economy and performance of foundations and earth structures. Despite significant advancement in the analysis, design and implementation of the ground improvement technologies themselves, consistent and comprehensive specifications for ground improvement have not advanced accordingly. The guidance herein has been developed to provide owners, agencies, designers and specifiers with a minimum framework for preparing specifications for ground improvement work. The framework is intended to be technology-neutral to allow for the best application of technology to the project needs. Not all recommendations are applicable to all projects or every type of ground improvement, but this document presents a consistent structure for preparing specifications.

The drafter of ground improvement specifications should carefully consider, and address, each of the context and content items, and also incorporate the recommendations and commentary described herein for each unique project. The geotechnical engineer of record, structural engineer of record, and Owner should all be consulted for input on the requirements. Due to the specialized nature of the techniques, the author of the specifications should also consider consulting with two or more specialty contractors during preparation of the document. Contractor input may be helpful in addressing items related to constructability and cost-effectiveness.

The goal of this guidance document is to ensure that contract documents have:
- a consistent approach to the responsibility for characterizing the soil parameters;
- a clear, consistent, and complete set of reference information and performance requirements; and,
- current and appropriate design and verification methods that may impact design and installation.

Contract documents that employ this type of specification should facilitate the preparation of a set of proposals that provide the Owner with the same minimum level of performance and that are derived using soil properties and design methods that are acceptable to the Owner and which are consistent with current practice.

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**Relationships and Responsibilities**

Frequently, projects for which ground improvement may be applicable are structured to take advantage of the specialized engineering and design knowledge of Ground Improvement Contractors. To take advantage of the specialty contractor’s knowledge, the ground improvement scope of work is engineered and designed by the specialty contractor. This “design-build” framework blurs the boundaries of design responsibility between the Owner’s engineer/designer and the Contractor. Consequently, a well-written ground improvement specification will clearly establish these boundaries.

Of particular importance is defining who is responsible for selecting/determining the soil properties at bid time. Will data be provided in the form of a data report or will contractually-defined soil properties to be used by all ground improvement designers be specified?

If soil parameters are not explicitly provided in the specification, the characterization of the soil properties and the assessment of the likelihood of a design event (e.g., earthquake, flood, etc.) by bidders may result in substantially different approaches, different levels of ground improvement to be performed, and associated variation in costs. It is important that the drafter of the specification clearly appreciate that these parameters characterize the subsurface conditions of the Owner’s property and will be used to develop ground improvement programs to improve the Owner’s property, for the Owner’s benefit. If soil properties and parameters are not explicitly provided, the author of the specification must ensure the Owner is comfortable in accepting a design based on less conservative parameters and/or design conditions in the interest of saving time or money.

The specification should define if the Ground Improvement Contractor’s preliminary design is to be submitted with the bids. This may allow the Owner and his/her engineering team to determine the extent to which the low bidder has or has not met the minimum specified design requirements. If the preliminary ground improvement design is to be submitted as part of a bid package, it must be established how the Ground Improvement Contractor’s exclusive design will be protected during scope reviews/comparisons, in the event all bids are rejected, or if all bids are made public. The intellectual property of each of the specialty contractors is valuable and must be recognized and protected.

The specification must define who is responsible for the review and acceptance of the final design. The Owner has three possible roles:

1. The Owner makes no technical review of the Contractor’s design and the contractor is responsible for code compliance and relevant agency reviews and approvals.
2. The Owner reviews the contractor’s design for compliance with the requirements of the specifications but the contractor is responsible for code compliance and relevant agency reviews and approvals.
3. The Owner is responsible for review for specification compliance and design intent and is responsible for agency review, approval and issuance of permits.

In all cases, the Ground Improvement Contractor is to provide a design that intends to meet the requirements of the specifications and/or the requirements of the permitting Agency. The author of the specification and the Owner should determine if a peer review of the Contractor’s design is required, depending on the complexity of the design and the nature of the project.

Finally, the specification should address the relationship not only between the Ground Improvement Contractor and the Owner/Designer, but also between the Ground Improvement Contractor and the Prime Contractor/Construction Manager and other parties to the project.

**Geotechnical Information**

The specification must adequately convey all available project information to be used for preparation of proposals and for ground improvement design. It must also define the form in which the information will be provided. For example, will samples be stored and made available for inspection by the bidders along with the exploration logs? Will digital files for CPT soundings (as an example) be made available to the bidders? Additionally, is a site visit planned or required? Do opportunities exist for the contractor to conduct independent investigations?

At a minimum, the information provided to potential Ground Improvement Contractors must include:

1) The geotechnical report.
2) Exploration logs.
3) Available laboratory and in situ testing results.
4) The project datum elevation and coordinate system.
5) Existing and planned grades and slope geometries.
6) Existing and planned utilities.
7) Available information on the groundwater regime, along with existing and planned surface drainage features.
8) Available information on the site history:
   a) What grade changes have been made and when?
   b) Has the site experienced quarrying, surface mining or underground mining?
   c) Is there history or documentation of karstic activity or solution features or pinnacled rock?
   d) What structures existed, where and when?
   e) Did previous structures experience any distress associated with geotechnical conditions (e.g., excessive settlement, differential settlement, etc.)?
9) Existing and/or potential sources of contamination (soil, groundwater, etc.).
10) The planned construction sequence.

Operational Constraints

For all site- and foundation-related construction, communicating the constraints of each project site and its environment to the potential contractors is essential for the development of competitive and realistic proposals and for safe and productive execution of the work. This is critically important to ground improvement projects for which specialized techniques may influence or be influenced by these constraints to a greater extent than conventional construction.

The specification should clearly define existing agreements, covenants, etc. that exist between the Owner and third parties, or are attached to the project site, which may influence the conduct of the ground improvement work. The specification must also define:

1) Any schedule or shift limitations, e.g. no equipment noise before 0700 hours; no work between “rush hours” of xx to yy; etc.
2) The preliminary construction schedule as anticipated by the Owner/Designer. Is adequate time available to consider pre-loading or staged construction options?
3) Limitations on noise, dust, movement and vibrations. This must define not only threshold values, but also how and at what locations the threshold values are to be measured.
   a) Specific sensitive receptors should be identified, e.g., hospitals, schools, precision machinery, etc.
   b) Requirements for monitoring of noise, vibration, movements, etc. during ground improvement work.
      i) The type, frequency and reporting format should all be clearly defined, along with the parties responsible for collecting and distributing the data.
4) Available sources of water: available volume per day, maximum draw rate, available pressure, etc.
5) Limitations on discharge of wastewaters, including volume, rate and locations.
6) Requirements or limitations for handling/disposing of by-products resulting from ground improvement work.
7) Any known or anticipated environmental restrictions or concerns: wetlands, protected habitats, contamination, etc.
8) The nature, location (position and elevation), construction and condition of existing structures and utilities (on and near the project site), along with criteria for allowable vibrations, settlement, heave, lateral movement, etc.
   a) Requirements for pre- and post-construction condition surveys.
9) Access limitations/restrictions and defined routes of allowed access. This would include defining overhead structures, road and bridge ratings and utilities existing in the work areas or along available access routes.
10) Limitations on available laydown and storage areas.

In addition, the specification should address the obligations, among the parties, for construction, design and certification of a stable working platform for safe operation of ground improvement equipment.

Performance Requirements

An effective specification for ground improvement should explicitly define the performance expectations and requirements for the improved ground based on clearly defined loading and service conditions. It must define the conditions under which the criteria are to be applied, the location at which the criteria are to be assessed and the time frame for evaluation. The specification should be explicit in defining the structures and work limits for which the ground improvement is intended. Appropriate references to project drawings and sketches are recommended.
**Bearing Pressures and Loads**

The ground improvement specification should be clear on the requirements for design bearing pressures. The specification should define:

1) How the design bearing pressure is to be computed.
   a) Is the controlling criterion based on a minimum Factor of Safety or on a serviceability/settlement requirement?
   b) At what location is the target bearing pressure to be computed?
      i) Average across foundation/earth structure
      ii) At extreme foundation edge
2) Are there distinct requirements for footings (isolated or continuous), grade beams, mats, slabs, mechanically-stabilized earth, retaining walls, etc.?
3) Specific loading conditions for each distinct loaded element.

**Settlement**

Settlement performance specifications should define:

1) The magnitude of acceptable settlement, including displacements during construction and post-construction.
   a) Settlement criteria should be defined for static conditions, service dynamic conditions (i.e., machine/equipment loading/traffic) and seismic conditions.
   b) Criteria are likely to vary by structure and foundation type and may be different for different project components:
      i) Continuous footings
      ii) Isolated footings and/or mat foundations
      iii) Slabs-on-grade
      iv) Pavements
   v) Utilities
   vi) Tanks
   vii) Embankments
   viii) Retaining walls, etc.
   ix) Bridges, culverts
2) The conditions for which settlement computations are to be performed:
   a) Provide and describe Dead Loads, Sustained Live Loads, Transient Live Loads and Extreme Service Loads.
   b) Specify the design loading condition(s). Do not expect the Ground Improvement Contractor to “interpret” the critical load case(s) from code tabulations, etc.
   c) Define the acceptable levels in relation to both magnitude and time.
      i) Immediate / during construction settlement
      ii) Primary consolidation settlement
      iii) Secondary compression/creep settlement
3) Define where and how settlement is to be measured.
   a) What devices and precision are required?
      i) Monuments, PK nails, settlement plates, vibrating wire devices, robotic monitoring, LiDAR, etc.
   b) What is the reference baseline?
4) When is monitoring/measurement to occur?
   a) During construction.
   b) Post-construction.
      i) Following ground improvement
      ii) Following substantial completion of structure
   c) Define frequency and duration.
5) Who is responsible for collecting the data?
   a) What is the reporting format?
   b) To whom is the data distributed and when?
   c) Who is responsible for interpreting the data and confirming compliance with the project requirements?
6) What are acceptable corrective actions?
   a) When do corrective actions need to be taken?

**Seismic Considerations**

Among the most critical elements to be addressed by the ground improvement specification are the requirements for seismic design. These considerations can also be the most difficult to define with the current state of practice.

At a minimum, the specification must communicate the following items:

1) A thorough description of the design earthquake criteria and input ground motion:
   a) The reference/source of the ground motion should be identified.
   b) Provide design ground water level.
   c) Provide the maximum depth and horizontal limits of required liquefaction mitigation.
   d) Provide the minimum thickness of significant liquefiable layers.
   e) Provide criteria to be used to differentiate sand-like from clay-like behavior.
2) Note if a site-specific hazard analyses is included or will be provided.
3) Identify analytical method(s) that is/are acceptable for determining liquefaction potential and seismic settlements.
   a) Recognize that different analytical methods can yield significantly different predicted settlement values with the same input motion.
4) Define the maximum tolerable liquefaction-induced settlement.
5) Clarify if dry-sand dynamic settlement is to be assessed and, if so, what the cumulative seismic settlement criterion will be.
6) Identify analytical method(s) that is/are acceptable for estimating lateral spread.
7) Define the tolerance for acceptable lateral spread.
8) What are allowable improvement techniques (all, some or none of the following):
   a) Densification.
   b) Reinforcement.
   c) Accelerated drainage.
9) Specify acceptable improvement criteria and/or performance requirements. These may vary with the allowable improvement techniques.
10) Identify post-treatment verification testing requirements.

Additional information may be found in DFI Journal No. 7, August 2013. Specifically, the articles Commentary on the Selection, Design and Specification of Ground Improvement for Mitigation of Earthquake-Induced Liquefaction by the Ground Improvement Committee and Liquefaction Mitigation Synthesis Report by Timothy C. Siegel are particularly relevant.

**Slope Stabilization**

Ground improvement is frequently used for slope/embankment stabilization. An adequate specification should include:
1) Acceptable analysis methods.
2) Appropriate soil strength parameters.
3) Required minimum static FS and seismic FS.
4) Allowable temporary FS (less than the design FS) if acceptable for a stated time period of days, months, etc. following construction while excess pore pressure dissipates.
5) What, if any, monitoring is required?
   a) Inclinometers, pore pressure transducers, tiltmeters, etc.
   b) What is the reference baseline?
6) When is monitoring/measurement to occur?
   a) During construction.
   b) Post-construction.
   c) Define frequency and duration.
7) Who is responsible for collecting the data?
   a) What is the reporting format?
   b) To whom is the data distributed and when?
   c) Who is responsible for interpreting the data and confirming compliance with the project requirements?
8) What are acceptable corrective actions?
   a) When do corrective actions need to be taken?
9) What seismic conditions are to be analyzed and what seismic method is appropriate: pseudo-static, FEM, etc.?
10) Applicable codes requirements.

**Groundwater Control Applications**

If groundwater control is an objective of the ground improvement work, the groundwater regime may be impacted by the ground improvement work, or the groundwater regime needs to be controlled to perform the ground improvement several key items should be addressed by the specification:
1) What is the acceptable flow rate of water into/out of the work area/through the improved ground?
2) How is the flow rate to be measured? At what locations is the flow rate to be measured? When are flow rates to be measured?
3) Define any threshold drawdown levels in adjacent aquifers or other water bodies.
   a) Can recharge wells be considered in design to mitigate drawdown?
4) Define post-construction limits on impacts to site features if the hydro-geologic regime is expected to be altered by the ground improvement.
5) Define limits on impacts to existing plumes or other underground environmental conditions.

**Verification**

Not only are the project baseline references and performance requirements important to a well-conceived ground improvement specification, but also the means and methods for verification of improvement are essential. These verification tools must be consistent with the specified analytical and design methods, ground improvement technology and soil conditions. Therefore, the specification should clearly define:
1) Acceptable methods for verification testing.
   a) In-situ testing.
      i) Penetration tests
      ii) Load-deformation tests
      iii) Geophysical methods
   b) Acceptable methods for field sampling and laboratory testing.
      i) Sampling
      ii) Handling, storage, curing, etc.
2) Quality control measurements during installation.
   a) Data acquisition requirements.
   b) Field reporting requirements.
3) Field instrumentation requirements.
4) The frequency and schedule for any such testing.
   a) Is/are pre-production test element(s)/section(s) appropriate or required?
5) Minimum or maximum verification requirements or requirements for average values and acceptable ranges/variation.
   a) Will a statistical approach be utilized, e.g., the average value must meet or exceed the requirement but no individual value may be less than 10% lower than the requirement?
6) Parties responsible for verification testing.
Special Circumstances

Many projects include special site characteristics that may not be apparent to the potential contractors unless they are specifically addressed in the specifications. These characteristics or conditions can dramatically affect the safe and productive execution of the ground improvement work. Special considerations that must be addressed include:

1. Obstructions: Many ground improvement tools are ill-suited to penetrate or bypass significant buried masses. Likewise, anticipated natural obstructions should also receive comment. A concrete block and a granite boulder each represent similar challenges to ground improvement equipment. The document should comment on the existence or potential for man-made, underground obstructions to be present.

2. Flowing and artesian water conditions: Often overlooked is the potential for artesian pressure or significant subsurface gradients/groundwater velocity to negatively impact ground improvement methods, specifically grouting and ground freezing techniques. The specification and data report should identify the potential for these conditions.

3. Hazardous materials: The presence or potential presence of hazardous materials or gases (e.g., methane, hydrogen sulfide, etc.) must be disclosed in the contract documents. Under many circumstances, ground improvement techniques are the appropriate solution to mitigate risks associated with such conditions, but the potential bidders must fully understand the project environment to prepare a responsive proposal.

4. Locale-specific considerations: The specification should identify any special, local conditions that could influence the work. These could include:
   a. Road or bridge weight restrictions.
   b. Frost laws which could adversely affect delivery of equipment and materials during the late winter and spring.
   c. Readily available local materials (e.g., gravel pits, quarries, etc.).
   d. Project Labor Agreements or local labor/wage/work rule requirements.

Conclusions

The specialized nature of ground improvement does not always lend itself to standardized specifications. In fact, the best value for Owners can often be achieved by allowing specialist Ground Improvement Contractors to select among several available techniques to offer the best combination of performance and economy. Accordingly, establishing a framework for the preparation of ground improvement performance specifications that allows for maximum flexibility in potential technologies, while explicitly defining the performance requirements has great value to project sponsors.

The preceding discussion presents important considerations to be addressed, and the minimum content that should be included, in a ground improvement specification, such that Owners should receive proposals that reflect the delivery of equivalent project performance and competitive pricing.