



# Guidelines for the Application of Ground Modification Methods for Highway Structures, NCHRP 10-121 Workshop

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## Introduction: Research Team

- Allen Cadden, PE, BC GE, Principal Investigator
- Majid Khabbazian, PhD, PE, M.ASCE – Administrative Officer
- Jie Han, PE, Ph.D., BC GE - CO-Principal Investigator
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The objective of this project is to provide performance-based guidelines for the selection, design, construction, and acceptance of appropriate ground modification methods for transportation applications.

Can this be done w/ Ground Modification so we can

- define the site conditions and project needs
- suitably provide contractor flexibility,
- achieve the desired results,
- and meet Title 23 of the US Code of Federal Regulations, Part 637 (23 CFR 637) requirements

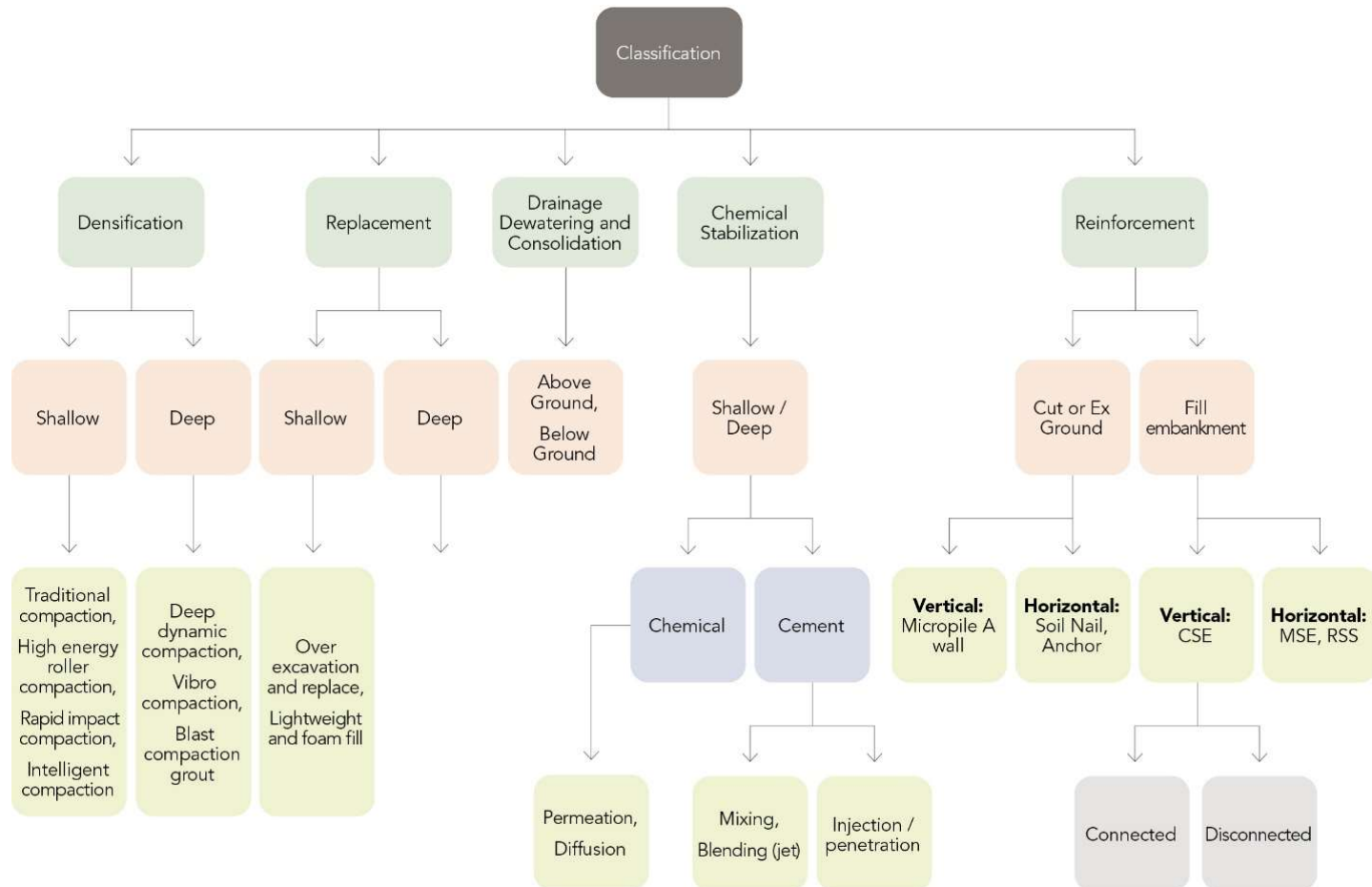


## Statement of the problem

- Traditional method specifications (**prescriptive specifications**) rely on explicit materials and construction requirements to ensure satisfactory results.
- **Performance specifications** shift focus toward:
  - Performance parameters
  - Measurement and verification strategies
  - Payment and incentive mechanisms
- This approach encourages innovation and performance excellence from the contractor.
- Performance specifications should be developed from the owner's expectations down, not based on assumptions of contractor capabilities up.



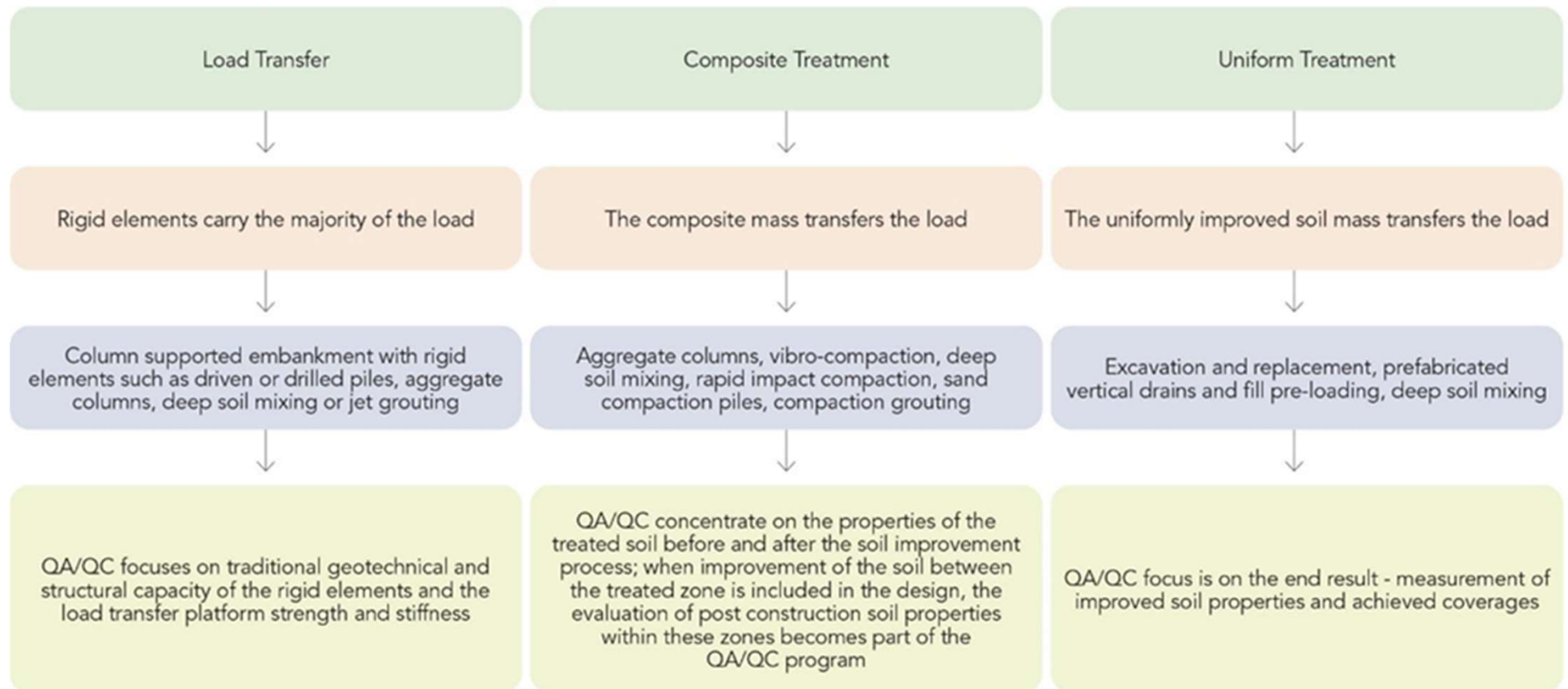
# Ground Improvement Classifications







## Proposed Ground Modification Classification





## Guide Specification - Overview

- **Objective of Specification:** Guidance for developing a performance-based specifications for ground modification (GM) methods used in transportation projects.
- **Agency's Responsibility:** Determine the need for GM, define the extent and performance metrics, work with the contractor to ensure concurrence/understanding, maintain an oversight role.
- **Contractor Responsibility:** The performance-based specification transfers design, construction, and performance responsibility to the contractor, while the Agency clarifies expectations and reviews plans for reasonableness.
  - Contractors choose GM technologies from an “approved” list. They assume the risk if proposing unapproved technologies.
- **Applicable Delivery Methods:** The specification applies to both design-bid-build (DBB) and design-build (DB) delivery, though GM portions are design-build.



## Determining the Appropriate Level of Design

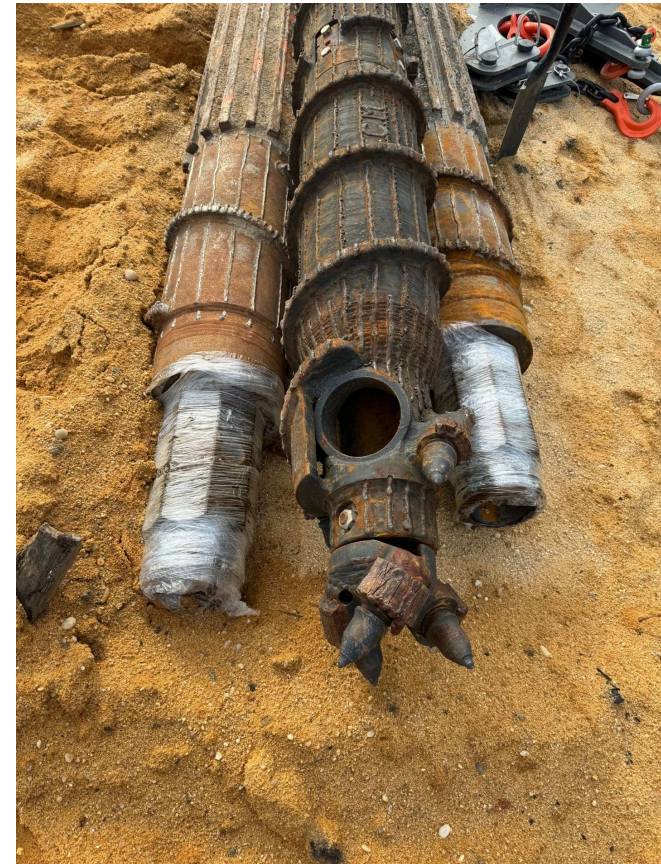
**Agency's Responsibility:** Develop a clear understanding of site conditions and limitations.

- **Issue Identification:** Define concerns with appropriate calculations and soil properties.
- **Baseline Standard:** The agency's exploration and analysis sets the minimum standard for the contractor's GM design, aimed at improving site conditions and addressing the owner's concerns.

**Collaborative Review:** Agency and contractor work together to ensure a full understanding of site conditions and concerns before construction begins.

**Agency's Role in Design Review:** Ensure the design adequately addresses site issues and accurately reflects the intended behavior of the GM system.

**Contractor's Responsibility:** Verify design assumptions, field conditions, and quality metrics during construction to meet performance goals.



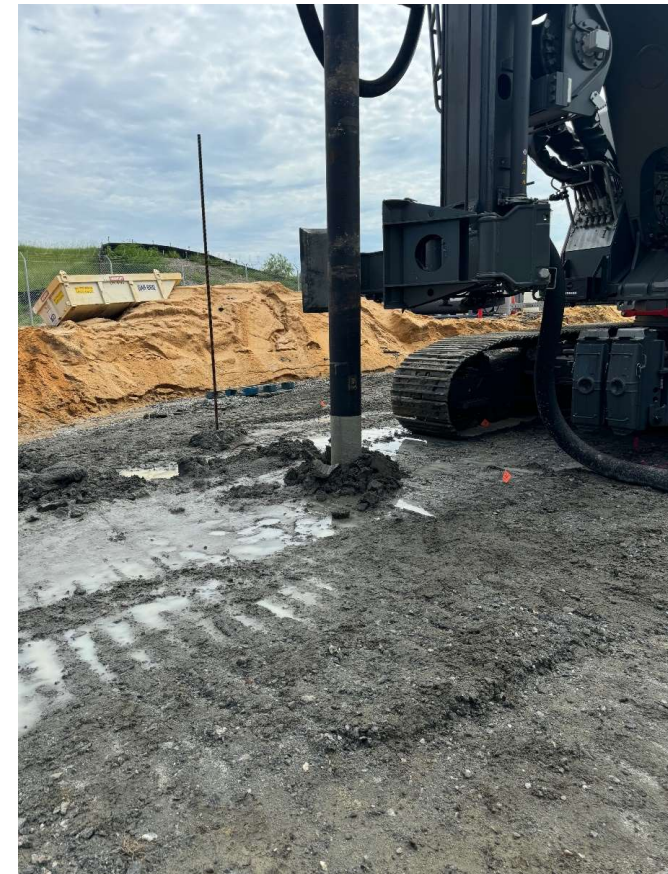




## Site Model - Owner and Contractor Roles

**Key to Success:** Clear understanding and agreement on site conditions or soil model is critical for performance-based GM contracting.

- **Data Collection:** Agency gathers site data based on site variability, construction plans, and risk tolerance.
- **Site Model:** Baseline interpretation of stratification, lateral extent, and material properties defines unsuitable conditions for contractor's GM design.
- **Data Collection Balance:** Limited data increases risk; excessive data may offer diminishing returns.
- **Contractor Reliance:** Site model informs contractor's selection of construction methods and equipment and is used to compare encountered conditions to baseline.
- **Accuracy of Model:** Must avoid overly conservative, ambiguous, or optimistic interpretations not supported by data.
- **Differing Site Condition Clause:** Allows for fair risk allocation and efficient dispute resolution when actual conditions differ materially from the model. Preferably handled during the design review.





## Ground Modification Guidance Table

Ground Modification Category	Ground Modification Technique	Guidance
Load Transfer	<p>Column supported embankment with rigid inclusions.</p> <p>List of acceptable rigid inclusion elements:</p> <ul style="list-style-type: none"><li>• Continuous Flight Auger Piles</li><li>• Steel H-Pile</li><li>• Steel Pipe Pile</li><li>• Timber Pile</li><li>• Vibro-concrete column</li><li>• Pre-cast concrete columns</li><li>• Cast-in-place concrete shell (mandrel driven)</li><li>• Shells driven without mandrel</li><li>• Grouted aggregate column</li><li>• Vibro-cast in situ pile</li></ul>	<ul style="list-style-type: none"><li>• Rigid elements transfer the majority of embankment or structure vertical loads through the compressible layer to the bearing layer.</li><li>• A load transfer platform (LTP), with or without geosynthetic layers, is typically used to improve the efficiency of load transfer from the embankment or structure to the rigid elements. When implemented, the LTP should be designed to ensure effective load distribution to the rigid elements. Key design considerations for the LTP include selecting suitable well-graded aggregates; determining the required thickness of the LTP; and specifying the stiffness, strength, and number of geosynthetic layers.</li><li>• Caps may be added to the top of rigid elements to enhance load transfer.</li><li>• Design analyses should be deformation based, consider the nature of load transfer, and encompass both geotechnical and structural aspects of the rigid elements.</li><li>• Structural analysis of rigid elements should consider shear and bending moments due to the embankment edge/slope-induced static lateral soil load, seismic lateral loads, and soil liquefaction-induced lateral spreading.</li><li>• The design of rigid elements (i.e., geotechnical and structural) follows the allowable stress design method. Where relevant, design considerations, such as downdrag, as outlined in AASHTO for deep foundations, should also be applied to rigid elements.</li><li>• For overall stability analyses, two-dimensional geotechnical global stability analyses should account for the rigid elements via a stress reduction that is compatible with load transfer into the rigid</li></ul>



## Organization of Specifications

- Geotechnical Documents
- Requirements & Selection of GM System
- Design Considerations
- Design & Construction Submittals
- Quality Control & Quality Assurance
- Long-Term Performance Criteria and Verification & Measurement/Payment



# Geotechnical Documents



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## Owners Thought Process cont.

- The owner/designer determines that a portion of the site cannot support the embankment/structure
  - Without excessive settlement
  - Within the allotted schedule
  - Maintain adequate slope stability
  - Poses a seismic risk
- The owner could....
  - Evaluate technical merits of several remedial methods
  - Evaluate cost, schedule, and risk of each
  - Select a solution
  - Develop a detailed design and construction documents for bidding
- Or the owner could...







## The Owner could...

- Develop expectations for the work
  - Area to be improved
  - Describe ground conditions of concern
  - Define engineering concerns that require ground modification
    - Settlement, bearing, stability, liquefaction...
  - Define expectations
- And let the contractors at bid time decide what is the best way to achieve this goal given:
  - Scheduling of the project
  - Available specialty contractor and their resources
  - Budget



## Results

- The results are compiled into a
  - Geotechnical Data Report
  - Geotechnical Engineering Report
  - Geotechnical Baseline Report -
- What should be included in the contract?
  - All of the Data
  - And the critical analysis

“Geotechnical Documents”





## Section 3.0 Owner's Preliminary Site Evaluation

### Section 3.1 Geotechnical Report

#### Specification

- The geotechnical document (information) is provided for reference and to establish the **baseline site model and design methods** used by the Agency to determine the need for and requirements of the GM program. This document serves as the baseline for the Contractor's site model assumptions and minimum design requirements.
- The Contractor shall review the available subsurface information provided and notify the Agency of all subsurface conditions materially different from those visible at the time of bidding or shown on the plans and in the GD which they may discover during design development or construction that may make a difference in the selection, design, and installation of the ground modification.
- Notification shall be provided with the design package or within 7 days of encountering the change during construction.

#### Commentary

The **design methods and criteria will be contractual items** and must be clearly defined in the contract documents through a GBR or similar report that defines the analysis methods used by the Agency to assess the need for GM. This may best be handled by developing a Geotechnical Design Report (GDR) and/ or a Geotechnical Baseline Report (GBR) as contract documents. The means of sharing geotechnical data and analysis requirements shall be determined by the Agency. These document(s) will be referred to herein as **geotechnical documents (GD)**.

The GD must **provide a reasonable level of detail** regarding the site model that includes subsurface stratigraphy and soil, and rock design parameters based on data and statistical information as outlined in GEC5. This definition of the subsurface conditions will be relied upon by the Contractor as a basis for design. Although the Contractor may collect and analyze additional data and develop a revised site model, the data and site model defined in the document(s) will be the baseline for comparison of existing conditions to final ground modified conditions.

*Agency shall modify this wording to be consistent with General Conditions and Definitions used for this project.*

The geotechnical document(s) (GD) shall include analysis of the existing ground conditions that require GM. This may include settlement analysis, global stability analysis, liquefaction analysis, etc. The **report shall include the parameters used in the above listed analyses** (i.e., short- and long-term strengths) and moduli of the subsurface layers, groundwater, etc. The method of analysis shall also be included in the geotechnical document(s).



## 3.2 Existing Conditions (i.e., Underground Utilities, Old Foundations, Geologic Features, etc.)

### Specification

- The existing site conditions are depicted on the project drawings and include known buried structures such as underground utilities, foundation elements, etc., and known geologic features such as old rivers, ponds, faults, etc. The Contractor shall consider all depicted conditions in their GM design and construction plan. No additional compensation will be provided for dealing with these and reasonably foreseeable ancillary conditions.
- The Contractor shall review the available information and visit the site to assess site geometry and equipment access conditions, and to verify the location of existing structures and above ground utilities and facilities. The Contractor shall provide a summary narrative of their understanding of the site conditions that may impact their GM design and installation (Site Model) and present this to the owner for concurrence in conjunction with design review. Once agreed upon with the Agency, this Site Model will become the baseline conditions for the project.

### Commentary

Careful consideration of the presence and location of all utilities, underground obstructions, and geologic features is required. The location of both active and abandoned buried utilities and geologic features at the site can have a significant impact on the selection, design, and construction of the ground modification.

Site access, existing features, need for working platforms, and conditions that may impact access or phasing shall be evaluated by the Contractor and considered in their GM technology. Conditions that are reasonably inferred from visible site conditions shall not be cause for future claims.

**Conditions materially different that impact the extent of the GM will be paid for per the unit rate. Conditions that impact the depth of treatment may require cost adjustment.**

This step **provides the Contractor the ability to revise the site model** based on data that may be collected during design and facilitate a discussion about impact to the “as known” conditions at bid time. Once the revised model is accepted and reasonable adjustments to the contract are made as a result, if needed, **this becomes the baseline for evaluation of changes that may occur later on during construction.**

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**AC0**

I thought we had the word material in here already? Same w slide before? Did I cut from wrong doc?

Allen Cadden, 2025-04-30T14:58:48.718





## Silence is NOT Golden

- If this [contractor/agency agreed upon] revised site model is silent on factors that are later found to have impacted the construction, such claims would not have a basis for comparison and should not be considered.
- The goal of this is to require the contractor to be clear on all assumptions such as rig and tooling capabilities and what might impact the installation.
  - If boulders are an issue for the auger and none are shown on the logs... then there should be a statement in the contractors site model that says “Boulders do not exist on this site”





# Requirements & Selection of GM System



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## Specification Section 4: Requirements vs. Selection

- Owner sets requirements while contractor selects GM system to meet requirements.
- System Level Performance Requirements
  - Geometry requirements (e.g., final elevation, area)
  - Structural requirements (e.g., loads)
  - Geotechnical requirements (e.g., deformations – settlement and lateral spreading, stability, liquefaction)
  - Utilities and environmental constraints (e.g., vibration)
  - Cost
  - Schedule
- Technology Selection
  - Load transfer, Composite, and Uniform
- Qualifications Requirements

### 4.0 Requirements and Selection of GM System

#### 4.1 System Level Performance Criteria

Specification	Commentary
Design and construct the GM to achieve the following	A more general statement could be

#### 4.2 Technology Selection

Specification	Commentary
The Contractor shall select the GM in accordance with Section 3.3. Selection of the RI solution must to fa trans emb satisf 4.1 a 5.0.	

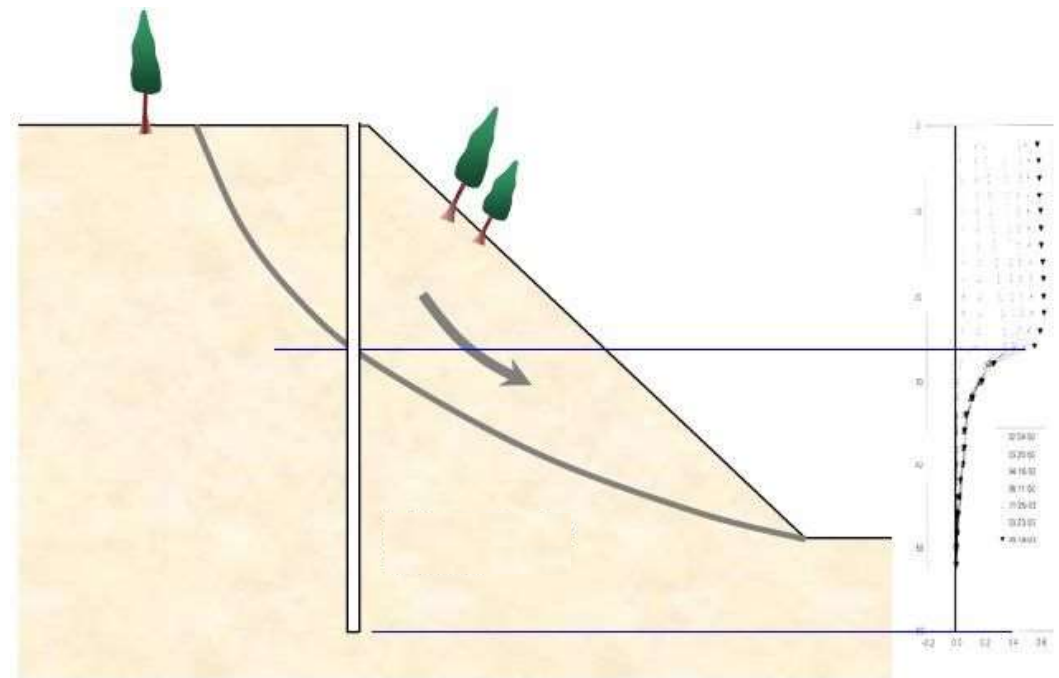
#### 4.3 Qualifications

Specification	Commentary
Submit the following to the Agency for review and approval at least 90 days prior to the start of the work: <ul style="list-style-type: none"><li>Documentation of the Contractor's qualifications showing that the Contractor has been engaged in the successful design and installation of column-supported embankments for at least five years and has</li></ul>	The term "Similar" referring to size and scope of a project should be evaluated in a broad sense of the underlying technology and general size of the project. If specific requirement criteria are to be evaluated,



## System Level Performance Requirements

- Post construction settlement limit
  - not more than XX inches in XX yrs
- Slope Stability
  - Factor of safety greater than XX
- Lateral spreading
  - Factor of safety greater than XX
  - Lateral movement
- Liquefaction
  - Liquefaction potential
  - Liquefaction-induced settlement
  - Lateral spreading





## How Do We Pick the Method?

- How does the contractor go about selecting the GM method?
  - Load Transfer: Rigid inclusion and load transform platform (LTP) type
  - Composite: Column type
  - Uniform: Function (densification, drainage, replacement, chemical)
- Contractor Considerations (partial list)
  - Equipment available
  - Schedule
  - Cost
  - Available site data to support evaluation
  - Other constraints
  - Reliability- confidence in method
  - Proven success





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- This is the Industry developed and maintained list of acceptable technologies
- The Agency is free to specifically preclude the use of a technology or a category if desired. (Will usually be based in past experiences)



# Design Considerations



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Purpose: Provide design guidelines so that both the Owner and Contractor know the minimum requirements for the GM

- Modes of failure that must be analyzed
- Factor of Safety Requirements
- LRFD Requirements



# Guide Specification

## 5.0 Design

### 5.1 Stability

### 5.2 Settlement

### 5.3 Lateral Spreading

### 5.4 Liquefaction

### 5.5 Design and Construction Submittals

### 5.6 Pre-Production Verification Testing (i.e., RI Load Test)

Specification	Commentary
The QC Plan and design drawings shall include the installation of a minimum of [ ] demonstration RI elements of which at least [ ] will be static (dynamic) load tested.	The purpose of the demonstration elements is to demonstrate the adequacy of Contractor's design and proposed methods and equipment for installation of

## Slide 26

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5.0 change to say Geotechnical Documents

Allen Cadden, 2025-09-08T17:49:26.685





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Again

- This table is a living document that provides guidance related to state of the practice design requirements.

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# Design & Construction Submittals



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Seems like we need a little more here.

Allen Cadden, 2025-09-08T18:05:31.431



## Submittals

- Qualifications
- Design
- Quality Control
- Construction
- Performance Verification



## Section 5.5: Submittals

### 5.5 Submittals

Specification	Commentary
All submittals shall be reviewed and accepted by the Agency prior to moving to the next stage of the project except as noted below.  Submittals shall be presented to the Agency	Stages of the project shall include, but not be limited to, <u>Design, Pre-Production Testing, Production Installation, and Post GM Monitoring</u> . Additional stages (stopping points) can be defined by the Agency as needed.

- Milestone Submittal Process



## Submittals

- Calculations demonstrating that the proposed vertical elements and LTP meet the design and performance criteria specified herein.
- Load Transfer GM drawings indicating the diameter, spacing, location, number,...
- Sample of RI installation and daily production report, including itemized work tasks (i.e., actual and theoretical concrete volumes, material quantities,...
- A quality control plan (QC Plan) with detailed criteria, to be followed during the GM installation,..
  - materials testing, installation
  - monitoring of performance
  - load testing,
  - Details of corrective measured ...
- Timely construction progress reports
- A complete and accurate final record



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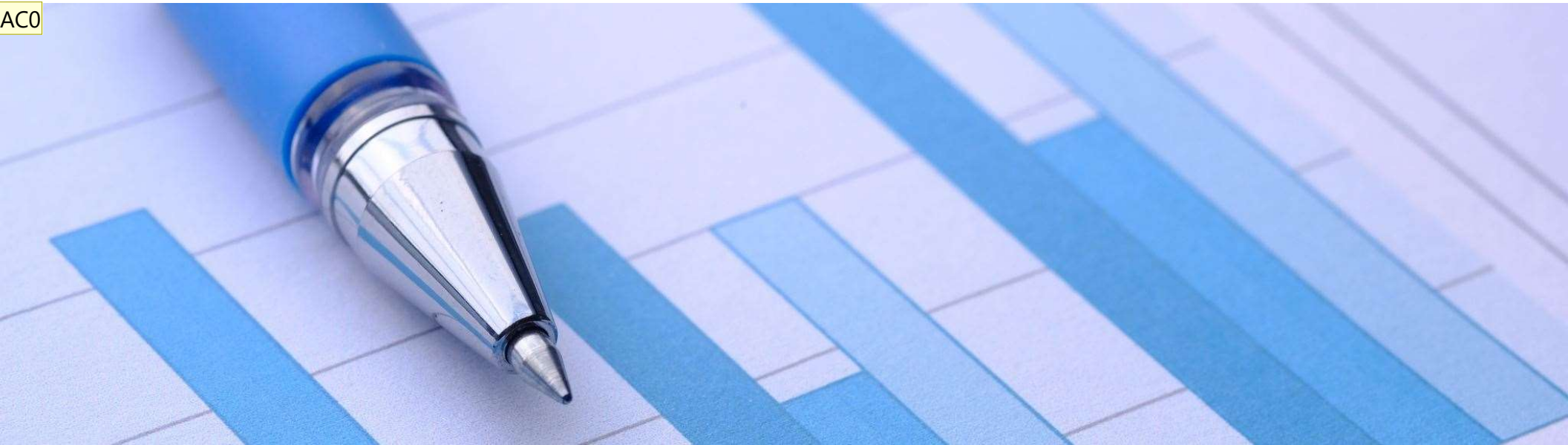
**AC0**      ??? The individual or total proecjt question?  
Allen Cadden, 2025-05-06T14:27:44.789

**AC1**      Most of this seems to fit QC next section.  
Allen Cadden, 2025-09-08T17:52:00.151



## Design Review by Agency

- Design review of required analysis is to confirm that the basic design elements are completed in accordance with the Agency requirements.
- Additional design analysis performed to optimize the design of the GM method shall be checked for reasonableness and consistency with the site model. Not detailed review and acceptance.



# Quality Control & Quality Assurance



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We can reduce this section

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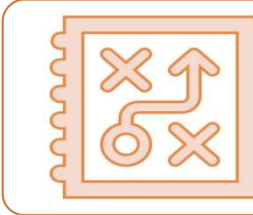


## Agency Role – QA



### Conduct limited independent QA testing:

- Separate sampling/testing.
- Random audits of contractor QC.



Rely primarily on contractor's QC Plan and records.



## 5.6 Pre-Production Verification Testing (i.e., RI Load Test)

- The QC Plan and design drawings shall include the installation of a minimum of [ ] demonstration RI elements of which at least [ ] will be static (dynamic) load tested.
  - *The purpose of the demonstration elements is to demonstrate the adequacy of Contractor's design and proposed methods and equipment for installation of the intended elements. Selecting a limited number of these demonstration elements for load testing (in accordance with the project key loading demands) is intended to verify the element design capacity and estimated depth. Selection of the test elements should be by the Contractor with **consensus of the Agency** and should be selected **based on the variable conditions observed** in the demonstration element installation.*
  - *Recognize that load testing traditionally is a way for the Agency to verify assumptions in design because the Agency is taking a risk that the design will meet expectations. **In this case, the Contractor is taking the risk**, so it is in their interest as well as the Agency's to know if the elements will carry load and help optimize the layout or number of elements. The test should verify the load carrying capacity and associated settlement of the RI is in accordance with the Contractor's design assumptions. **The Agency should look at this test program as a component of the review role as Independent Assessment** or QA of the design and installation methods.*
- The Contractor shall produce an **Installation Criteria Memo** describing required measurable installation criteria for the elements that will be used for installation acceptance of each element and become a component of the Contractor's QC Plan.





## Long-Term Performance Criteria and Verification & Measurement/Payment



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## System Level Performance Criteria

- Maximum immediate and/or total settlement (and rate) of [ ] inches ([ ] inches/ month) as measured at [location] prior to placement of pavement/structure and not more than [ ] inches [ ] years after completion of construction.
- Maximum differential settlement of [ ] inches over a distance of [ ] as measured along [location] prior to placement of pavement/structure and not more than [ ] inches [ ] years after completion of construction.
- Maximum lateral displacement of the rigid inclusions of [ ] inches measured at [ ] inches at the end of construction, and [ ] inches [ ] months after completion of construction.
- Minimum resistance factor against slope instability of [ ].
- Minimum factor of safety against liquefaction [ ].
- The liquefaction-induced settlement shall be less than [ ] inches under the design earthquake.
- Lateral displacement due to Extreme Events shall be less than [ ] inches, with vertical displacements less than [ ] inches at the crest under the design earthquake.

When discussing settlement or lateral displacement, consider whether this is **during construction** or **post construction** and the duration of the project and **reasonable time of measurement post construction**. It may be prudent to have a maximum criterion at end of construction (with a decreasing rate criteria) and post-construction settlement and differential settlement as measured in 12- or 24- months following project completion.

Also, be specific about **where deformations are to be measured**. At subgrade level, at the structure foundation, below grade (for lateral), on top of final pavement. For differential, where or what spacing is required for measurement.



## Performance Measurement: Settlement

- Settlement shall be measured with an acceptable and redundant system of points, including [ ] points evenly distributed beneath the [ ] and installed on the subgrade before addition of the structure or embankment. Point location distribution shall be representative of the variable site subsurface conditions and above ground loading to adequately provide data to verify the Agency performance criteria.
  1. Baseline readings shall be established consisting of at least [ ] independent readings separated by at least one day that demonstrate consistent and repeatable readings to an accuracy of less than  $\pm$  [ ].
  2. Readings shall be taken at a frequency of not less than [ ] per week during structure loading above the subgrade.
  3. Readings shall be taken weekly for three months following completion of the structure or embankment.
  4. Readings shall be taken at least monthly until measurement criteria or specified date, whichever is longer, is reached.
  5. A measure of the approximate load or fill height shall be documented when readings are being taken (daily is acceptable if readings are taken more frequently).

**Redundant monitoring system is required.**

**Points distributed beneath structure or embankment, aligned with site variability and loading.**

**Reading protocol: baseline, frequency, record fill height/load at each reading**



## Successful Measurement Program is the Contractors Responsibility

Damaged instrumentation that do not clearly demonstrate reliable data for verification of the Agency performance criteria shall be replaced by the Contractor at no additional cost to the owner.

- Instrument replacement is required until the performance criteria is met.

Means of assessing GM system performance must be clear and agreed upon.

Full alignment between Agency and Contractor on acceptance requirements is critical prior to start of work.



## Measurement

### Load Transfer

- GM will be measured by **the square feet of the area** where RI and LTP, if applicable, are installed, as measured to the centerline of the outermost rows of RI. Overhangs, overlapping steps, and transitions are incidental to this item. A separate pay item should be included for mobilization.



## Questions???

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