Chapter 14 - Ground Improvement

Chapter Contents

14.1 General

Ground improvement is used to address a wide range of geotechnical engineering problems, including, but not limited to, the following:

- Improvement of soft or loose soil to reduce settlement, increase bearing resistance, and/or to improve overall stability of bridge foundations, retaining walls, and/or for embankments,
- To mitigate liquefiable soils,
- To improve slope stability for landslide mitigation,
- To retain otherwise unstable soils,
- To improve workability and usability of fill materials,
- To accelerate settlement and soil shear strength gain.

Types of ground improvement techniques include the following:

- Vibrocompaction techniques such as stone columns and vibroflotation, and other techniques that use vibratory probes that may or may not include compaction of gravel in the hole created to help densify the soil,
- Deep dynamic compaction,
- Blast densification,
- Geosynthetic base reinforcement for embankments on poor foundations,
- Wick drains, sand columns, and similar methods that improve the drainage characteristics of the subsoil and thereby help to remove excess pore water pressure that can develop when loads are applied to the soil,
- Grout injection techniques and replacement of soil with grout, such as compaction grouting, and jet grouting,
- Deep mixing methods,
- Lime or cement treatment of soils to improve their shear strength and workability characteristics,
- Permeation grouting and ground freezing (temporary applications only).

Each of these methods has its own technology, effectiveness and suitability for different soil types and also limitations regarding their applicability and the degree of potential soil improvement.

14.2 Design Considerations

In general, the geotechnical investigation conducted to design the cut, fill, structure foundation, retaining wall, etc., that the improved ground is intended to support will be adequate for the design of the soil improvement technique proposed. However, specific soil information may need to be emphasized depending on the ground improvement technique selected.

For example, for Vibrocompaction techniques, deep dynamic compaction, and blast densification, detailed soil gradation information is critical to the design of such methods, as minor changes in soil gradation characteristics could affect method feasibility. Furthermore, the in-situ soil testing method used during the investigation stage (e.g., SPT testing, cone testing, etc.) needs to be the same as the method specified in the contract to verify performance of the ground improvement technique. The in-situ soil test data obtained during the site investigation will be the baseline for comparison to the test data taken in the improved ground.

Specific feasibility issues need to be addressed if these types of techniques are used. Ground vibrations caused by the improvement technique may have critical impacts on adjacent structures. Investigation of the foundation and soil conditions beneath adjacent structures and utilities may be needed, (in addition to standard precondition surveys of the structures) to enable evaluation of the risk of damage caused by the ground improvement technique.

Environmental regulations may also restrict the use of specific ground improvement methods in some areas and must be assessed. For example, the use of stone columns in environmentally sensitive areas such as wetlands may be restricted or not allowed.

At sites where contaminated soils are present, any ground improvement method considered for mitigation should not result in a potential for transfer of subsurface contamination, either horizontally or vertically, through the substrate to uncontaminated soils or groundwater. For wick drains, the ability of the wick drain mandrel to penetrate the soil to the desired design depth must be assessed. The subsurface investigation should identify very dense soil layers, cobbles, boulders or other obstructions that may restrict mandrel penetration.

Grout injection techniques (not including permeation grouting) can be used in a fairly wide range of soils, provided the equipment used to install the grout could penetrate the soil. The key is to assess the ability of the equipment to penetrate the soil, assign soil density and identify potential obstructions. Permeation grouting is more limited in its application, and its feasibility is strongly dependent on the ability of the grout to penetrate the soil matrix under pressure. To evaluate the feasibility of these two grouting techniques, detailed grain size characterization and permeability assessment must be conducted, as well as the effect groundwater may have on these techniques. An environmental assessment of such techniques may also be needed, especially if there is potential to contaminate groundwater supplies.

Similarly, ground freezing is a highly specialized technique that is dependent on the soil characteristics and groundwater flow rates present.

14.3 Design Standards

The following design manuals and references should be reviewed in the design development of specific ground improvement applications:

- **General Ground Improvement Design Requirements:**

  The reference manuals for the NHI Course "*Ground Modification Methods*," (FHWA-NHI-16-027 & FHWA-NHI-16-028, Schaefer, et al., 2017) should be referenced for the design of ground improvement methods, supplemented as described below.

- **Stone Column Design:**

FHWA Report FHWA/RD-83/O26, *"Design and Construction of Stone Columns,"* (Barksdale and Bachus, 1983).

The following ODOT/OTREC research report, and the associated reference papers by Rayamajhi , et. al., (2013) and Nyguyn, et. al., (2013), provides additional information regarding the effectiveness of using stone columns to reduce shear stress in surrounding soils subjected to earthquake shaking. The assumption of strain compatibility between the stone column material and the surrounding improved soil may not be applicable and the reinforcing effect of stone columns to mitigate liquefaction effects is likely very small. Therefore, the shear stress reduction and soil reinforcement mechanism of stone columns should not be used for mitigation of liquefiable soils.

ODOT Research Report OR-RD-13-09*, "Reducing Seismic Risk to Highway Mobility: Assessment and Design of Pile Foundations Affected by Lateral Spreading*", (Ashford, S., A., et al., 2013), Oregon State University.

- **<u>Deep Dynamic Compaction:</u>**

  FHWA manual FHWA-SA-95-037, Geotechnical Engineering Circular No. 1, "Dynamic Compaction," (Lukas, 1995)

- **<u>Deep Mixing Methods:</u>**
  FHWA manual FHWA-HRT-13-046, *"Federal Highway Administration Design Manual: Deep Mixing for Embankment and Foundation Support"*, (Bruce, M.C., et. al., 2013). This report provides background on deep mixing for U.S. transportation projects and provides further information on design and construction aspects. This report also includes guidelines required for U.S. transportation engineers to plan, design, construct, and monitor deep mixing projects for embankment and foundation support applications. Considerations for secondary associated applications such as excavation support and liquefaction mitigation are also discussed.

- **<u>Wick Drain Design:</u>**

  FHWA manual FHWA/RD-86/168, "Prefabricated Vertical Drains –Volume 1, Engineering Guidelines," (Rixner, J.J., et al., 1986)

- **<u>Blast Densification:</u>**

  WSDOT Research Report WA-RD 348.1, "Blast Densification for Mitigation of Dynamic Settlement and Liquefaction," (Kimmerling, R. E., 1994).

  Proceedings of the 10th International Conference on Soil Mechanics and Foundation Engineering, "Soil Improvement: State-of-the-Art Report", (Mitchell, J. K., 1981), Stockholm, Sweden, pp. 509-565.

- **<u>Lime and Cement Soil Treatment:</u>**

  Alaska DOT/FHWA Report FHWA-AK-RD-01-6B, *"Alaska Soil Stabilization Design Guide"*, (Hicks, R.G., 2002).

14.4 References

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