PROBLEMS ASSOCIATED WITH THE USE OF COMPACTION GROUT FOR SINKHOLE REMEDIATION IN WEST-CENTRAL FLORIDA

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Abstract

Compaction grouting is a widely used method for sinkhole remediation. It is generally less costly than other methods of remediation and provides a less intrusive method of repairing adverse subsurface conditions. However, we believe that many engineers in preparing specifications and contractors in construction practice have improperly applied compaction grouting as a method of remediation. In some cases, improper use of compaction grout has resulted in the deterioration of marginal subsurface conditions significantly increasing the cost of repair and inconvenience to the homeowner. Another consideration in the selection of compaction grout is the occurrence of subsurface conditions in which deep foundation support should be used rather than the seemingly less expensive compaction grout method. This manuscript discusses techniques in the proper use of compaction grouting and the precautions that should be taken before, during and after compaction grouting. It also discusses potential conditions when compaction grouting should be supplemented or replaced with deep foundations. Included in the manuscript are compaction grouting case studies and recommendations for the proper application of compaction grout.

Introduction

Compaction grouting is a common method used to remediate homes affected by sinkhole activity. It generally provides a relatively fast, effective and economical method of soil improvement. The compaction grouting process consists of injecting, under high pressure, a stiff mortar-like grout into the ground to displace, fill voids and compact the surrounding soil. The common practice is to apply compaction grout from the rock surface upward (upstage grouting) by building successive segments of grout such that one segment rests on the segment below until the grout reaches the desired depth. Fundamental to the success of the grouting procedure is deposition of the grout in a globular mass (typically either columnar or tear-shaped) at each injection location

(Warner, 2004). In theory, the volume of grout placed in the ground will cause an increase in density in loose sandy soils as the expanding grout displaces soil and thus compacts and increases the strength of soil between the successive grout columns. Although some benefit will be obtained from the compressive strength of the grout columns placed typically six to ten feet apart but terminated 10 to 15 feet (3.0 to 4.6 meters) below the ground surface; however, the primary use of this method is for soil densification through compaction. Another function of the grout is to seal any seepage paths that may exist at the rock soil interface.

Grout Application Problems

Detracting from the benefits of compaction grout are problems that occur when grout is placed at a high flow rate causing hydraulic fracturing of the soil. In this instance, high pore pressures develop that cause the soil to fail in an undrained state, remolding the soil into a liquefied mass that moves in response to the high pore pressures generated by the rapidly expanding grout front (see Figure1).

The hydraulic fracturing interferes with the orderly compaction process and can cause damage in the building under which grout is injected and in nearby buildings. Damage to overlying structures can be caused by the increase in overburden weight from the soil that has been intruded by lenses of grout as shown in Figure 1. The increase in soil weight can sometimes result in settlement of the building being remediated. Nearby buildings can also be damaged from the intrusion of grout into utilities and into the building.

Some assert that contactors monitor heave while pumping and pumping can be stopped when movement is seen. This sounds reasonable in theory but in practice there are a number of problems. First, there is a time lag from the time the inspector happens to notice movement till the time he communicates that to the pump operator.

Figure 1. Adverse effects of high flow rates.

Second, once movement starts it may continue for a period because of pressure in the formation. Third, when movement occurs, even if it stops when pumping is stopped, it may be too late, the building can be immediately damaged.

These problems, in many cases, pale relative to the greatest impetus to increase grout flow rates, to the highest possible rate. This is the increased cost for pumping grout at low flow rates. The lower flow rate increases the time required to complete the grouting hence labor and equipment costs increase for the grouting contractor and for inspection. Costs for supply of grout also increase because of the increased time to use the grout. Typically, most contracts adhere to ASTM C94 requirements for discharge of the concrete within a 1½ hour period from batch to placement. If this time is exceeded the concrete cannot be used. This means that instead of the grout supplier providing 10 cubic yard trucks they must deliver grout in 5 cubic yard trucks. This obviously decreases the supplier's efficiency and therefore increases cost.

A significant part of the grouting procedure is that no one actually sees the completed product—it is unseen below the ground surface. Only when something goes

wrong such as damage to the home, grout deposited in a neighboring property or settlement sometime after completion of remediation is the grouting procedure questioned. By that time it is too late to correct the problem; all that can be done is deal with the difficulty and conclude that this is one of the shortfalls of compaction grouting. The delay in determining if the grouting was successful is a concern for all and is minimized by the procedures discussed.

Recommended Methods of Resolving Grout Flow Problems

A solution to the dichotomy of cost versus compaction grout quality that considers both technical and economic factors is to determine the critical flow rate at which hydraulic fracturing occurs in soft soil areas. This is done by increasing the flow rate until a decrease in grouting pressure occurs (presumed to be the onset of hydraulic fracturing of the soil). The procedure is performed in known areas of soft soil found in existing borings or at the location of soft soil conditions found in the newly installed grout holes. The production flow rate is determined based on a value of 90% of the flow rate that causes a decrease in pressure or in any area where an increasing flow rate results in a decrease in pressure. In other areas, with different soil properties, a flow rate of 5 to 7 cubic feet per minute (0.142 to 0.198 cubic meters per minute) is used.

Variable Soil and Rock Conditions

It is important to use all subsurface information that is available to analyze the diverse conditions that occur in karst terrains. To determine potential areas where soft soil conditions may be present for use of the low flow rate, it is recommended that consideration be given to the depths to sound rock found in the grout drill holes. Figures 2 through 5 show two sites where grout hole information is known. The point in illustrating this data is to show the stark difference in the interpretation that occurs when additional information is available. Compare the differences in the depth to rock found from grout holes where rock information is on 10-foot (3.0 meter) centers as opposed to information obtained from SPT borings where distances between data points are very great. The grouting data points show the extreme variability in the rock surface that was not found in the SPT data. Therefore, the advantage in using grout hole data is that one can anticipate where soft soil conditions may occur—in karst areas this is common in locations of abrupt changes in depth to rock. The lower grout flow rates should be used in areas of abrupt changes in depth to limestone.

When Not to Use Compaction Grout

If more than several inches of settlement have occurred in a structure, lifting a building component should be accomplished through means other than compaction grouting such as by use of pin-piles (small diameter piles commonly referred to as mini-piles, micro-piles and pin-piles having a diameter from approximately 0.3 to 1 feet [0.1 to 0.3 meters]). Small adjustments for settlement can be accomplished by the use of chemical grout (polyurethane foam in low viscosity liquid form pumped at low pressure into cohesionless soils) where loads and the amount of lift are small. However, larger lifts may be accomplished with chemical grout on some slabs with moderate loads depending on geometry and loading.

As a side note, an often-overlooked property in the use of pin-piles is the quality of the rock material used to support the piles. The limestone rock surface tends to be highly solutioned and weathered resulting in a surface of questionable integrity to support a load. Unfortunately, the quality of the limestone rock used to support the pin-piles is often not properly investigated to determine its competency. Figure 6 provides an illustration of a typical limestone surface that may be encountered for support of pile loads. When these conditions are anticipated, an additional subsurface investigation should be performed to determine the integrity of the rock.

Figure 2. Depth (in meters) to sound rock from borings in Site 1 (no horizontal scale).

Figure 3. Depth (in meters) to sound rock from grout holes in Site 1 (no horizontal scale).

Figure 4. Depth (in meters) to sound rock from borings in site 2 (no horizontal scale).

Figure 5. Depth (in meters) to sound rock from grout holes in Site 2 (no horizontal scale).

Figure 6. Typical limestone surface.

When large thicknesses of very soft (weight of hammer/weight of rod, WH/WR) soil conditions are found in the order of greater than 20 feet (6.1 meters), a cost comparison should be performed to determine which method is economical. The analysis should include the cost for pumping grout at reduced flow rates and the cost for additional investigation of the quality of the rock surface to support a pile load.

Other Considerations

The use of compaction grouting is directed to remediating soft soil conditions; however, in doing so, areas of dense soil will inadvertently be subjected to compaction grout. The net result is that the grouting process may loosen these areas. When large areas of dense soil are known to be present on a site, the extent of the grouting program should be re-evaluated after grout hole data is available to determine the grouting effort to be used in the various grout holes.

Conclusions

It has been discussed that:

1. The use of high grout flow rates results in unacceptable lateral displacement of the grout extending in lens-like fashion to substantial distances beyond the point of placement. This causes remolding of the soil greatly adding to the weight of the composite grout-intruded soil (Figure 1).
2. A production flow rate should be determined based on a value of 90% of the flow rate that causes a decrease in pressure in soft soil areas or in any area where a decrease in pressure is found. In other areas a flow rate of 5 to 7 cubic feet per minute (0.142 to 0.198 cubic meters per minute) is used.

3. The net increase in soil weight, due to a high flow rate injection, can cause settlement of the underlying soil and the building foundation supported by the soil (Warner).
4. Compaction grout is not a process where the weight of the building is supported on a column of grout; it is a process where compaction of the soil occurs from the inclusion of a volume of grout between successive grout columns compacting the soil and increasing soil strength. The strength of compaction grout is only required to meet or exceed the in situ soil.

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