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CONSULTING ENGINEERS • GEOLOGISTS

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ADSC West Coast Chapter
1390 Broadway #B
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Reference: ***Caltrans / ADSC West Coast Chapter Joint Task Force***
Substructures and Geo-Support Committee

Subject: ***Overview of Standard CIDH Pile Anomaly Mitigation Plans***

Members of the Committee:

At the request of the ADSC West Coast Chapter (WCC), Holdrege & Kull (H&K) is providing two standard CIDH pile anomaly mitigation plans to facilitate the discussion of anomaly mitigation methods, and quality control in general for drilled shafts, amongst industry and Caltrans representatives. Standard mitigation plan "A" contains typical procedures for "basic repair" of anomalies, and standard mitigation plan "B" contains typical procedures for mitigation by replacement and/or permeation grouting methods. The recommendations are based on H&K's experience with pile mitigation and input from Caltrans and industry representatives. No warranty, expressed or implied, is included or intended by the standard plans. The user of the standard plans is solely responsible for determining the suitability of the plan for the intended mitigation.

To address the wide range of anomalies that may be candidates for grouting repair, standard mitigation plan "B" is broad in scope and contains provisions that will not be applicable to all anomalies. Although the generic nature of the plan may lead to some inefficiency in mitigation operations, the intention of the standard plan is to expedite the acceptance of typical mitigation plans by providing a template for formal submission to Caltrans. The submittal of an anomaly mitigation plan can be made job specific by the attachment of a cover letter which addresses the specific site conditions and contract requirements.

The standard mitigation plans do not address specific anomalies. Thus, the plans do not contain some of the components of a typical mitigation plan, such as a description of the subject anomalies and a review of project documents. The remainder of this letter provides an overview of the standard mitigation plan components.

The standard plans do not purport to address safety concerns associated with their use. It is the responsibility of the contractor to establish appropriate health and safety practices and to determine the applicability of regulatory limitations prior to performing the work.

OVERVIEW OF MITIGATION PLAN "A"

Standard mitigation plan "A" describes a typical procedure for basic repair. Basic repair involves the mechanical removal and replacement of concrete within an anomalous zone. Basic repair is typically performed by hand; thus, the anomalies to be repaired must be accessible, or the anomalies must be accessed by excavation. Basic repair performed near the top of a pile is also known as "simple" repair. Restoration of earthen materials may be required if the anomalies to be repaired are not immediately accessible.

OVERVIEW OF MITIGATION PLAN "B"

Standard mitigation plan "B" describes typical procedures for grouting repair. Pile design data, construction details, subsurface conditions, and the results of conformance testing are considered in the development of a grouting mitigation plan. The formation conditions and extent of communication often cannot be completely characterized by the results of water flow testing and thus may be largely unknown at the start of grouting. Thus, provisions for both replacement grouting and permeation grouting are presented in standard mitigation plan "B". If grouting is determined to be a potentially effective method of repair, anomaly mitigation typically consists of the following steps:

- high-pressure cutting of inspection tubes;
- high-pressure washing;
- water flow testing;
- flushing (high-volume, low-pressure washing);
- down-hole camera observation;
- grouting;
- conformance testing, if deemed necessary; and
- documentation.

The mitigation procedure should be performed by a contractor and crew who are experienced in grouting repair. The mitigation contractor and/or the engineer should keep records during pressure washing, pressure testing and grouting using the attached field report or a similar form.

Pressure washing and grouting are typically performed using existing PVC inspection tubes. The segment of the tube in the vicinity of the anomaly is removed with a high-pressure jet of water. As the anomaly may be discontinuous, each injection location is addressed individually during washing, pressure testing and grouting.

If needed, rotary-drilled holes extending to the anomaly may be drilled from the top of the pile to access a discontinuous portion of an anomaly. If additional ports are required, air-rotary equipment is typically employed. The drilled holes should be at least two inches in diameter. Care should be taken to avoid reinforcing steel. Due to potential difficulties associated with grouting the drilled holes below the anomalous zone, and if the vertical extent of the anomaly is easily detected during trial drilling, drilling typically extends only to the bottom of the anomaly.

If coring is required to assess the quality or compressive strength of concrete, the coring should be performed according to the special provisions of the construction contract. A double wall core barrel system utilizing a split tube type inner barrel is typically required. Rotary-drilled holes may be appropriate to provide access for coring.

Water flow testing is performed after pressure washing and often provides additional information regarding the appropriate mitigation method. Permeation grouting should be performed only if communication with the surrounding geomaterials is evidenced by sufficient flow during water flow testing. If communication is not evident, alternate methods of repair such as replacement grouting may be applicable. Video of the anomaly after pressure washing may also be useful for characterizing the nature of the anomaly and determining the mitigation method.

The grouting procedure is generally intended to increase compressive strength and/or frictional resistance and to reduce the chance of steel corrosion. Grouting generally does not adversely affect geotechnical design criteria. Restoration of earthen materials is typically not required as a result of grouting. Grout and wash water may daylight during repair of anomalies located at relatively shallow depth. Care should be taken so that the surrounding surface soil does not heave. Reduced grout pressures may need to be employed if ground heave is observed.

After completion of the repair procedures, post-mitigation non-destructive testing may be required. Post-mitigation non-destructive testing from the original inspection tubes can be problematic because of the relatively low density of the grout, as well as the difficulty in repairing the anomaly immediately around the tube

while preserving the tube's integrity. Coring may be used in some circumstances to recover samples of the grouted materials for visual inspection and strength testing. Typically, the success of grouting mitigation is addressed qualitatively based on observation of the mitigation procedure and review of information such as pressure test results and grout take. The mitigation is typically observed by an engineer, who prepares a mitigation report summarizing the mitigation procedure.

High-Pressure Cutting of Inspection Tubes

PVC inspection tubes may be removed from the anomalous zone using a high-pressure washing procedure. The tubes are cut by a stream of high-pressure water, directed laterally against the side of the hole, and rotated as it is slowly withdrawn. Pressure at the pump should be adjusted to account for pressure losses in the line. Excessive pressure loss in the line may result in pressures at the tip that are insufficient to remove the PVC inspection tubes.

Good results have been obtained using water pressure of 10,000 to 15,000 psi at 10 to 15 gpm. Higher pressure may cut the concrete around the tube, and lower flow rates may be less efficient for removal of the plastic. However, satisfactory results have been achieved with pressure between 7,000 and 30,000 psi. Inspection tube removal typically extends from two feet below to two feet above the anomaly.

High-Pressure Washing

The anomaly is pressure washed with high-pressure water concurrently with the tube removal process. The water jet used to cut the tubes also acts on the defective concrete as the plastic is removed. As a general rule, water pressure of 10,000 to 12,000 psi will not affect sound concrete, while higher pressure may remove sound concrete.

A high-pressure submerged jet may be effective at removing segregated concrete, honeycomb concrete and/or inclusions in the concrete. In addition, the jet may break through the concrete to the soil or rock outside of the drilled shaft. The nature of the material cut by the jet can often be determined by observation of the color and grain size of the cuttings returned to the surface. Concrete materials generally run grey to milky with few large pieces, while soil has a wide range of color and heavier suspended solids load.

The pressure washing procedure should be monitored to reduce the chance of disturbance of soil adjacent to the shaft while attempting to remove deleterious

material from the anomaly. Solids content in the wash return water should be monitored by periodically straining solids out of the effluent. If significant solids content is observed in the return water, the washing may be causing excessive disturbance of the surrounding formation. If native material is not observed in the return water, washing may be continued until the solids content of the return water is deemed insignificant. The contractor should keep a log of communication between holes, water color, type of solids, and estimated solids content.

Water Flow Testing

Water flow testing is performed for each inspection tube. Initially, all other ports are open. Water should be injected through the grout plant, and signs of communication to other holes or to the ground surface should be recorded. The contractor should record the pressure, injection rate and communicating tubes.

After all communicating ports are closed, water flow testing shall be continued to determine whether there is significant communication with the formation. An experienced grouting foreman or engineer can perform a qualitative evaluation of the water flow test based on injection rate and pressure. A water injection rate into the inspection tube of less than 2 gpm at a pressure of 10 to 20 psi (in addition to the existing hydrostatic pressure in the inspection tube) may be considered insufficient communication for permeation grouting. In the case of insufficient communication, replacement grouting should be considered.

A falling head water flow test may also be used to determine whether there is adequate communication to perform permeation grouting. The criterion for adequate communication is typically more stringent for the falling head test than for the water flow testing described above.

If the flow of groundwater into the inspection tubes is not rapid, the inspection tubes are typically cleared by air injection after water flow testing and prior to down-hole camera observation or grouting.

Flushing

Flushing (high-volume, low-pressure washing) should be performed if there is significant communication between inspection tubes. The purpose of flushing is to remove loose material after pressure washing and prior to grouting or down-hole camera observation. Flushing may involve pumping large amounts of water into an inspection tube and allowing it to return from another or washing material up around a tremie tube inserted into a single inspection tube. Air, water or alternating

injections of air and water may be used for flushing. Solids content in the wash return water should be monitored by periodically straining solids out of the effluent.

Down-Hole Camera Observation

Down-hole camera observation may be performed to verify that the PVC inspection tubes and deleterious materials were adequately removed from the anomalous zone. Dry conditions are typically preferable for camera observation. If camera observation is to be performed under water, flushing may be necessary to remove suspended materials from the water within the inspection tubes and scoured anomaly area.

Permeation Grouting

Typical permeation grouting repair involves high-pressure injection of a water-based, high-slump slurry of cement grout into the pore volume of soil, or contaminated concrete or sediment within a drilled shaft. Permeation grouting results in little disturbance of the material and is accompanied by displacement of pore water. Grain size for microfine cement grout typically ranges from 4 to 8 microns, whereas the grain size for typical Portland cement ranges from 20 to 50 microns. Permeation of the matrix decreases as voids are filled with cement solids.

Permeation grouting is generally effective when the pore aperture or fracture width in soil or rock is approximately five or more times as large as the effective grain size of the grout material. This is often expressed as the groutability ratio ($D_{15,SOIL}$ / $D_{85,GROUT} \geq 5$). However, there are enough exceptions to this rule that a grouting specialist should be consulted before starting a large or costly grouting program. The grouting contractor should typically assess and confirm the feasibility of permeation grouting based on the results of pressure testing.

In most permeation grouting scenarios, there is a pathway for the pore water to escape from the grout injection zone. In the case of grouting a defect in a drilled shaft, there may not be a pathway, or the path may be constricted. This is an inherent limitation on the ability to successfully permeate a concrete defect. Anomaly mitigation by permeation grouting is typically intended to address “soft tip” anomalies, to increase frictional side resistance and decrease corrosion, rather than to fill all potentially disconnected voids within an anomaly.

In a typical permeation grouting scenario, the grout flow is laminar and displaces most of the trapped pore fluid. If the grout is stable, it cures with less than a 10% separation of solids from the water fraction of the grout. Unstable grout “bleeds”, leaving a layer of solids in the bottom of the pores with a layer of mix water above.

Similarly, a macroscopic void may only be partially filled with solids if unstable grout mixes are used.

The cement solids used for grouting have a specific gravity in the range of 2.75 to 3.17 for ordinary Portland cement. Depending on the water/cement ratio needed to achieve the required viscosity of the grout, density of the grout mix varies but is usually much less than the structural mix used for drilled shaft construction.

Compressive strength results provided by Nittetsu Cement Company are attached. The reported 28-day compressive strengths for Nittetsu Superfine cement grout with water:cement ratios of 1:1, 0.8:1 and 0.6:1 were 23.6, 31.7 and 40.2 MPa, respectively. The grout mix included Mighty 150R dispersion admixture (Kao Corporation) at one percent of the cement content by weight. The compressive strength of materials permeated with these grout materials depends not only on the strength of the grout, but also on the strength of the solid matrix into which the grout is injected.

The relatively low density of microfine cement may not meet GGL density requirements. When the low-density material in the anomalous zones is permeated or replaced by the grout during the mitigation procedure, GGL post-mitigation non-destructive testing may not result in densities that meet the standard acceptance criterion, which is typically defined as the average surrounding concrete density minus three standard deviations.

Replacement Grouting

Replacement grouting is intended to fill voids with a relatively low-slump, mortar-type mix. Contaminated concrete and other deleterious material must be removed from an anomaly. This is typically accomplished by high-pressure washing as described earlier, prior to replacement grouting. Flushing may be employed if large voids are present that allow communication between ports. Grout typically consists of Type II cement mixed at the ratio of one sack of cement per five gallons of water and is pumped at a pressure of approximately 150 psi. Drilling of additional holes into the anomalous zone may be required to promote communication and to reduce the chance of air entrapment within isolated portions of the anomalous zone.

Prior to replacement grouting, the anomaly is cleared of water by injecting compressed air through the inspection tube at the base of the anomaly. Water and air typically return through an adjacent tube, if communication exists, or through the annular space in the tube around the air line.

Conformance Testing

Quantification of the success of permeation or replacement grouting may require conformance testing. Testing may include GGL, Cross-hole Sonic Logging (CSL), coring, or excavation. GGL and CSL confirmation testing is often inconclusive due, in part, to the difficulty of washing and grouting adjacent to the inspection tubes while preserving their integrity. The relatively low density of the grout solids also contributes to the difficulty in interpretation of test results. For these reasons, and due to the high cost of invasive confirmation testing procedures, the mitigation procedure is often evaluated qualitatively based on the results of pressure testing, communication and grout take.

Mitigation Report

Upon completion of the mitigation procedure, a post-mitigation report is to be submitted to Caltrans stating what repair work was performed and whether the repair work conformed with the mitigation plan. Any deviations from the mitigation plan must be stated in the report. Caltrans reviews the report and determines whether the mitigation efforts were successful.

H&K appreciates the opportunity to provide the enclosed mitigation plans. If you have any comments or questions regarding the mitigation plans, please contact us.

Sincerely,

HOLDREGE & KULL

Jason W. Muir, P.E.
Principal

attached:
- Standard Mitigation Plan A
- Standard Mitigation Plan B
- Table 1 – Grout Mix Table
- Chart 1 – Starting Mix for Permeation Grouting
- Chart 2 – Relationship Between Mix Number and Pressure for Permeation Grouting
- Flow Chart – Permeation Grouting Procedure for CIDH Pile Repair
- Example Summary Table
- Example Field Report
- Compressive Strength Results (Nittetsu Cement Co., Ltd.)

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