ABSTRACT: PSE&G required the installation of a duct bank under the Hackensack River in Carlstadt, New Jersey, close to the Meadowlands Sports Complex. Designed cable sizes and ampacity requirements resulted in the need for a 15 duct bundle about 1,400 feet long: ten 6-inch ducts that would be used immediately after installation for two sets of three (3), 69 KV single phase 1500kCMIL cables as a station to station source under the river; one for the neutral; one to carry three 1-inch inner ducts for fiber for station to station communication; and two spare ducts in the case of a single phase failure. The final five (5) ducts were 5-inch, and were to be used for future 26/13/4kV crossings for the host Division. This was one of, if not the most densely populated duct arrangements ever attempted with a thermal grout heavily sanded to provide the required thermal capacity. The cross-sectional fill area was 49% that was occupied by the ducts leaving very tight spacing for the grout to flow.

A reliable thermal heat dissipation system was necessary to obtain the required cable system ampacity. Because of poor site soil stability and thermal characteristics, the ducts were designed to slip into a casing to permit a predictable installation and to optimize the thermal dissipation efficiency of the thermal grout. A 36-inch steel casing was selected and installed under the river via horizontal directional drilling methodology. The steel casing does have excellent thermal conductivity and the thermal grout can be designed to be effective however, duct material was not selected at the time. A plastic material is strongly desirable for electrical and constructability reasons but it is also an insulator. A thinner wall material is desirable to reduce the insulating effect and to optimize the grouting space for constructability. Eventually, Fusible PVC™ was chosen to meet the demands of the specialized thermal dissipation grout used on the project. Studies provided as part of the selection process included temperature profile of the grout during curing, duct buckling resistance during placement and grouting, and configuration of the casing and duct system with the required spacers.

This paper will focus on the issues associated with optimization of the project for thermal effectiveness, cost, and constructability. We will review the duct configuration, spacer design, and grouting design. It will explore the construction phase of the successful installation, and ultimately demonstrate why it is smarter to involve the grouting contractor in the design phase of an HDD (or jack & bore) project.

1. INTRODUCTION

Setting the stage, the original project design required installation of ten (10) 6-inch diameter and five (5) 5-inch diameter ducts under the Hackensack River in the area of the Meadowlands Sports Complex in New Jersey as
shown in Figure 1. Construction was specified to be by horizontal directional drilling (HDD) methods with the ducts to be placed inside a 36 inch diameter by ~1,400 feet long steel casing in a fixed configuration retained by spacers placed at 5 foot intervals. The designed ducts were HDPE DR13.5 based on Iron Pipe Size (IPS) criteria. As is often a concern of electric utilities, the designer also required the ducts be “UL electric” certified as per the National Electric Code. The spacers had been designed and pre-purchased based on the design DR13.5 HDPE duct sizes. Once installed, the annulus between the ducts and the steel casing needed to be filled with a Portland cement based thermal grout designed for a specified thermal conductance. The HDD construction included the installation of the steel casing. The ducts, duct and spacer installation, and grouting were constructed under a separate contract. The construction of the HDD had started before the involvement of the duct and grouting construction contractor. The maximum depth of the HDD profile was 50 feet below the entry with the entry approximately at the high tide elevation.

![Figure 1. Site Locus (Source: Google Earth©)](image1)

This was the given situation for the start of discussions presented in this paper. Work remaining included the duct selection, assembly, assembly installation, and grouting. A specialty grouting contractor became involved with the project at this time. Based on the specialty grouting contractor’s experience, Portland cement based thermal grouts require a high percentage of sand to achieve the required thermal conductance that also has a specific gradation range to prevent segregation or settlement of the placed mix. Past installations with field measurements using similar Portland based thermal grouts have shown pressures around the ducts in the range of 100 psi and temperatures in the area of 120 degrees F during the installation and curing of the grout. The vulnerable time for the duct package is during the pumping and initial set of the grout as there is minimal lateral support for the duct resulting in the dominant failure mode of unconfined compressive buckling. The first job of the specialty grouter is to assess constructability of the desired project and the buckling capacity of a plastic duct is a critical part of this assessment.
2. PROJECT ASSESSMENT

A contractor has a right to assume that the project is constructible as designed. However, a prudent contractor will make their own assessment based on their procedures and equipment planned for the project for achieving the required project performance outcome. The critical failure mechanism when plastic materials are used for these installations has been found to be unconstrained buckling. This failure mode is compounded by the reduction in pipe buckling resistance with increase in temperature. Unconstrained buckling occurs when the differential pressure between the inside and outside of the duct exceeds the critical pipe buckling pressure under conditions where there is no confinement such as would be provided by set grout or concrete. Confinement increases buckling resistance significantly, at least by a factor of 7, once confinement is applied.

The contractor’s assessment involves calculations of the installed duct at the worst case location, bottom of the hole, for unconstrained buckling during grouting and through initial grout set. For this project, the casing had been installed and could be either left dry or filled with water or other material as a part of the duct and grouting installation process. Similarly, the ducts could be installed dry or water filled though the ducts typically are preferred to be dry at the time of cable installation. The maximum differential pressure to the duct would be applied with air filled ducts placed in a water filled casing then grouting. If calculated differential pressure is too great for a selected duct then mitigation measures include: filling the ducts with water, and pressurizing the ducts.

The grout installation requires pressure to overcome the grout flow resistance to move the grout into and along the casing and around the spacers just like it requires pressure to push water through a water supply system. This pressure is applied by the grout pump through a tremie grouting process with discharges starting at the low point in a hole to provide some assurance that the grout fully encapsulates the ducts. The grout pumps typically used are constant displacement concrete pumps which can achieve the necessary volumes and pressures without by-passing however; these pumps can apply up to 1,100 psi pressure which can easily crush the ducts. This pressure capacity, along with tremie line loss pressure, must be incorporated in the grouting plan to determine the success of the construction means and methods. These pumps include a volume adjustment by changing the stroke rate but pressure must be managed by design.

Table 1 provides the results of this initial assessment. As the grout placement typically take hours, a 10 hour modulus for the plastic duct material was selected for the assessment. Two temperatures were considered to model the full range of construction conditions prior to the initial set of the grout. Two failure conditions were modeled: buckling for collapse of the duct when subjected to grout pressure and burst to assess the amount of mitigation internal pressure that can be applied inside the ducts to counter the grout pressure.

<table>
<thead>
<tr>
<th>DR13.5 HDPE Pipe</th>
<th>Modulus</th>
<th>Buckling Pressure</th>
<th>Burst Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temp. °F</td>
<td>Time</td>
<td>E</td>
</tr>
<tr>
<td>73</td>
<td>10 hours</td>
<td>57,500 psi</td>
<td>47.0 psi</td>
</tr>
<tr>
<td>120</td>
<td>10 hours</td>
<td>30,500 psi</td>
<td>24.9 psi</td>
</tr>
</tbody>
</table>

Table 1 - Initial assessment of HDPE DR13.5 Duct

<table>
<thead>
<tr>
<th>Condition</th>
<th>Temp. °F</th>
<th>P_u</th>
<th>P_w</th>
<th>P_surcharge</th>
<th>P_G</th>
<th>P_dynamic</th>
<th>FS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Filled Duct</td>
<td>73</td>
<td>47.0 psi</td>
<td>0.0 psi</td>
<td>0.0 psi</td>
<td>43.4 psi</td>
<td>100.0 psi</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>47.0 psi</td>
<td>0.0 psi</td>
<td>0.0 psi</td>
<td>43.4 psi</td>
<td>100.0 psi</td>
<td>0.2</td>
</tr>
<tr>
<td>Water Filled Duct</td>
<td>73</td>
<td>47.0 psi</td>
<td>21.7 psi</td>
<td>0.0 psi</td>
<td>43.4 psi</td>
<td>100.0 psi</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>47.0 psi</td>
<td>21.7 psi</td>
<td>0.0 psi</td>
<td>43.4 psi</td>
<td>100.0 psi</td>
<td>0.3</td>
</tr>
<tr>
<td>Water Filled Duct</td>
<td>73</td>
<td>47.0 psi</td>
<td>21.7 psi</td>
<td>128.0 psi</td>
<td>43.4 psi</td>
<td>100.0 psi</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>47.0 psi</td>
<td>21.7 psi</td>
<td>128.0 psi</td>
<td>43.4 psi</td>
<td>100.0 psi</td>
<td>1.2</td>
</tr>
</tbody>
</table>

\[ \text{Ultimate Factor of Safety against buckling, FS} = \frac{(P_u + P_w + P_{surcharge})}{(P_G + P_{dynamic})} \]
Assessment of the results indicate that air or water filled ducts may be installed safely in a dry casing but a water filled casing will require filling the ducts with water to prevent buckling failure. Once installed, water filled ducts will not withstand the static grout fill without adding a surcharge pressure to the duct water fill to reduce the differential pressure, even at 73 degrees F; assuming a grout density of 125pcf and a duct Ovality of 4%. The situation becomes significantly worse at higher temperatures. Mitigation in the form of water fill in the duct and surcharge pressure is required to offset the 100 psi grouting dynamic pressure. Selecting the maximum allowable pressure of 128 psi for this duct results in marginal but acceptable factors of safety against buckling during grouting. Adding higher internal pressure will exceed the allowable burst pressure which can be done but is not recommended without careful thought and planning. This is not considered to be a constructible situation.

Armed with this information, the specialty grouting contractor approached the Owner with the problem and alternatives for solutions. The problem was that the HDPE was simply not strong enough at the present wall thickness to withstand possible grout installation pressures with an adequate factor of safety. Solutions included thicker wall HDPE to provide the necessary increased strength or use of a stronger material like PVC. PVC has been used in electrical installations on other projects and does have a successful track history. The Owner was faced with the dilemma that any change in the project at this time would impact both cost and schedule. However, the project also needed to function within design parameters after construction for the project to be profitable thus successful.

3. DUCT SELECTION PROCESS

Both HDPE and PVC plastics are ethylene-based polymers with material properties that are temperature and time dependent. Both materials can be produced with the same outside diameter. However, the two materials are at different ends of the spectrum in terms of material behavior relative to one another. PVC is a plastic with high tensile strength and high elastic modulus, making it a stiff, high strength material, with less flexibility. HDPE is an impact resistant, low elastic modulus plastic, making it a flexible, tough material, with lower tensile strength. There are advantages and disadvantages to both materials and the way that they can be employed for specific pipeline projects. HDPE is not as strong as PVC in axial tension or in the hoop direction and thus it requires more care in design and handling to prevent overstress situations. In either case, “UL certified” pipe is not available with pressure-rated plastic resin, and therefore “UL certified” pipe does not have a reliable pressure-capacity and thus will not yield a grout-able system. Furthermore, “UL certification” is for ‘electric conduit’, not ‘power conduit’ which is the case of an HDD (or Jack & Bore).

Given conditions include the casing dimensions, casing geometry, pre-purchased spacers designed for the HDPE, and cable dimensions. The one component not yet discussed is the cable dimensions and its’ related impact to the design. Cables need to be pulled into position through the ducts after the installation and grouting. There is a required maximum clearance called fill percentage which is a ratio between the cable area and the duct inside area. If the fill percentage is exceeded then the cable installation may not be successful thus the project would not be successful. This is an important factor as the strength and rigidity of pipes like these ducts is a function of modulus of elasticity and pipe wall thickness and thicker walls on both PVC or HDPE plastic pipes results in a smaller inside dimension for the same size pipe. The pipe wall for the 6 inch DR13.5 HDPE is 0.491 inches. However, the preliminary assessment resulted in the rejection of this duct size as insufficient to withstand installation loads.

Analyses are needed to determine minimum acceptable duct. Results of the analyses must be acceptable to the grouting contractor to withstand grout placement, to the cable designer for ampacity, and to the cable installer for pulling loads and percentage fill for code compliance. Duct design criteria include: total package must fit in the 36 inch casing; inside area of ducts must be sufficiently large to accept cable installation; rigidity must be sufficient to withstand construction loads determined during the preliminary analyses. For this installation, the owner and cable engineer have determined that the ducts may be filled with water during installation as long as they may be cleared for the cable pull.

Duct selection uses the same analytical approach as in the initial assessment but looks at different strength ducts based on different duct wall thickness or dimension ratio (DR) and material properties, specifically modulus. The DR of a duct is defined as duct outside diameter divided by the minimum wall thickness, t. The use of DR permits
assessment of different size pipes that will have the same internal and external pressure capacity. Results of the analyses based on an applied pressure $P_{OD} = 121.73$ psi are shown in Table 2 and include 100 psi grout dynamic pressure and 100 psi internal pressure with water fill for mitigation.

Based on our experience, and on the procedures that we use during installation of the grout for monitoring the pressures and temperatures during construction for compliance with design assumptions, in our opinion a FS Ultimate = 1.2 for temperature conditions of 120 F is sufficient for duct selection. Results indicate that a DR11 dimensioned duct made of pressure rated PE 3608 HDPE material provides the minimum FS Ultimate required for the installation. This section will result in an approximate 8% decrease in the inside dimension of the duct. As the outside dimensions remain the same size for all wall thicknesses, the duct will fit in the 36 inch casing for both the 6 inch and 5 inch duct configuration.

Table 2 – Results of wall thickness calculations for HDPE IPS dimensioned pipe under 10 hour conditions.

<table>
<thead>
<tr>
<th>Temp. °F</th>
<th>Modulus E (psi)</th>
<th>Available DR</th>
<th>Wall, t</th>
<th>Avg. ID</th>
<th>Inside Area Reduction</th>
<th>Buckling Pressure</th>
<th>FS</th>
</tr>
</thead>
<tbody>
<tr>
<td>73</td>
<td>57,500</td>
<td>15.5</td>
<td>0.427 in</td>
<td>5.720 in</td>
<td>0.00%</td>
<td>30.1 psi</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13.5</td>
<td>0.491 in</td>
<td>5.584 in</td>
<td>-4.70%</td>
<td>47.0 psi</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11.0</td>
<td>0.602 in</td>
<td>5.349 in</td>
<td>-12.55%</td>
<td>91.7 psi</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.0</td>
<td>0.736 in</td>
<td>5.065 in</td>
<td>-21.59%</td>
<td>179.2 psi</td>
<td>2.3</td>
</tr>
<tr>
<td>120</td>
<td>57,500</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16.0 psi</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>24.9 psi</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>48.7 psi</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>95.0 psi</td>
<td>1.7</td>
</tr>
</tbody>
</table>

The result of this assessment was a recommendation to use DR11 HDPE PE3608 pipe for the ducts. This information was provided to the Owner and cable engineer for assessment. The conclusions of the cable designer and pull specialist was that the inside area reduction was not acceptable for installing the designed and already purchased cable. A solution was needed. The options were to use a larger diameter HDPE or change the material properties by using PVC. The next size larger HDPE duct was a special order 7 inch diameter or an 8 inch diameter to replace the 6 inch ducts. The same situation existed for the 5 inch ducts. However, the existing 36 inch diameter casing and pre-purchased spacers prevented the upsizing as the bundle would not fit inside the casing and the upsized conduits would not fit in the spacers. The resulting team solution was to use a PVC duct. The PVC material has a higher modulus thus is a more rigid pipe at similar wall thickness to the HDPE thus providing both the needed increased strength and the inside area needed for the cable installation. But a manufacturing problem now came to light. The 5-inch is not a standard production item, and a special order threatened project deadlines.

A similar assessment of properties and capacities was then completed for the PVC to determine size for the ducts. Table 3 contains the results of the PVC calculations. Results of the analyses indicated that 6 inch Sch. 80 and 5 inch DR17 ducts, both IPS standard sizing, would withstand the construction loads and still fit inside the 36 inch casing. Selection of these ducts also resulted in a reduction of the duct wall thickness. This is important from a thermal perspective as both PVC and HDPE are insulating materials when compared to the thermal grout, steel casing, and surrounding ground. Hence a thinner wall allows the heat to escape faster from the cables which is desirable even though the reduction is not large when compared to the original DR 13.5 HDPE used in the original cable design calculations.

Table 3 Buckling Capacity of PVC 10 hour condition

<table>
<thead>
<tr>
<th>Temp. °F</th>
<th>Modulus E (psi)</th>
<th>Available Size</th>
<th>Outside Diameter</th>
<th>Wall, t</th>
<th>Avg. ID</th>
<th>Buckling Pressure</th>
<th>FS</th>
</tr>
</thead>
<tbody>
<tr>
<td>73</td>
<td>400,000</td>
<td>17.0</td>
<td>5.563 in</td>
<td>0.327 in</td>
<td>4.906 in</td>
<td>164.3 psi</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sch 80</td>
<td>6.625 in</td>
<td>0.430 in</td>
<td>5.709 in</td>
<td>225.1 psi</td>
<td>2.6</td>
</tr>
<tr>
<td>120</td>
<td>312,000</td>
<td>17.0</td>
<td></td>
<td></td>
<td></td>
<td>128.2 psi</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sch 80</td>
<td></td>
<td></td>
<td></td>
<td>175.6 psi</td>
<td>2.3</td>
</tr>
</tbody>
</table>
The selection of the PVC now required assessment of how to couple and install the ducts. Glue joints have a proven record of failure both when being pulled into trenchless installation and during grouting. Glue joints are not a recommended solution for HDD installations as there is much less control during the pull in process and the loads are considerably higher than with typical jack and bore installations. There are many types of mechanical couplings that are successfully used for trenchless installations. However, each mechanical coupling requires an enlarged section at the coupling. There was not enough room in the 36 inch casing for this project to use the mechanical couplings. Additionally, the pre-purchased spacers did not have sufficient clearance for any form of belled or mechanical coupling. Even if possible; the bell ends jeopardized adequate grout flow through the exceptionally tight bundle (49% cross-sectional fill area occupied). The solution was to use UGSI’s Fusible PVC™ to eliminate the coupling and maintain a uniform inside and outside duct profile. The fusion process results in a relatively sharp internal bead. There are construction procedures that can remove this bead to prevent possible cable damage during cable installation. These debeading procedures would be implemented for construction to prevent the beads from damaging the cable. Another key factor in the selection was the ability of UGSI to meet the short delivery schedule required to maintain the project deadline.

4. INSTALLATION OF DUCTS

Installation of the PVC ducts into the casing requires planning and sequencing to assure a successful installation. The sequence had to consider several items including: the project site configuration, the fusion and internal bead removal operations, the assembly of the spacers, and finally the insertion into the installed steel casing pipe. Underground Solutions, Inc. (UGSI) performed all fusion and internal bead removal activities, along with providing specialized construction management to aid J. Fletcher Creamer in the overall assembly and pipe movement planning required for final installation.

There was only about 320 LF available for assembly of the ducts at the project site which did not afford the opportunity to fuse all of the ducts for the entire drill into a single ~1,400 LF length. It is normally preferred to fully assemble a bundle with spacers prior to installation to prevent impacts and risks associated with stopping the drill rig. However, the casing provided ground support thus permitting the extra time required to assemble the ducts in segments. To address this project restriction, the duct assembly and construction sequencing proceeded as follows:

1.) Assembled and fused an initial 320 foot string of 10 six inch and 5 five inch diameter ducts from ~40 foot pipe lengths resulting in 15 strings of individual ducts. After each fusion, the internal fusion bead was removed.
2.) Assembled the fifteen strings with the spacers to configure a duct assembly package for the final casing pipe insertion. The spacer assembly was done for the leading ~120 LF of the duct assembly package, and the remaining ~200 LF was left without spacers (see Figure 3).
3.) Install the initial 120 LF into the casing pipe. The remaining 200 LF was left as a loose duct bundle that could be separated enough to fuse on individual lengths (see Figure 4).
4.) From this point on, 120 LF lengths were fused and debeaded onto each duct string in the bundle. When this was completed, another 120 LF of loosely bundled duct strings would be fitted with spacers, and finally, after both of these actions were completed, another 120 LF of the duct assembly package would be inserted into the casing. Final insertion of the duct assembly package required 12 separate installation segments of ~120 LF each.
Internal removal of the fusion bead was required due to the obstruction and possible electric cable jacket damage that it could incur present when the cables were installed. Typical wastewater bead removal requires that most of the bead be removed if it is required to be removed at all. However, a raised area is usually left since it has little bearing on the hydraulic capabilities. Since for electric cable housings this bead removal process was much more critical, internal bead removal tooling was assembled to assure that a flush removal was possible, repeatable, and that it did not remove too much material that could compromise the pipe wall. A field check was performed on the bead removal tooling and method for the first fusion joint of the project. This joint was then removed and inspected. The process was repeated, with tooling adjustments, until a satisfactory internal bead removal surface was attained, which took a total of three trials. At this point, a mandrel was made to match this satisfactory profile, and was used to check clearance at each joint that went into the final ducts assembly. There were a total of 510 fusion joints, internal bead removals, and mandrel compliance checks performed for the project. Figures 5 and 6 shows the debeading tool and operations.

The bend radius of the bundle compared to the bend radius of the individual pipes was also a consideration for installation. The assembled bundles had an outer diameter of ~ 33 inches. It was initially assumed that the bundle would act as a single rigid pipe for the purposes of determining alignment and elevation for installation. However, in practice the spacers did not hold the conduits completely rigid. This allowed the bundle to behave as an equivalent to a smaller OD pipe resulting in somewhat smaller bend radii being accommodated for the pull-in transition.

UGSI utilized three to four fusion technicians at a time with four fusion machines, and were able to perform about 45 fusion joints in a single shift or day. UGSI performed all of the fusion joints and owned the risk not only for the product, but the assembly of the product, and the internal bead removal operation and workmanship until the ducts were installed and accepted.

Assembly of the ducts and installation into the casing took a total of three weeks and did not use the directional drill rig. A winch was used for the pull-in. Early in the process, a three day cycle was used with UGSI performing
fusion, then assembly of the casing spacers, and then insertion of the assembled and bundled section into the casing with each step occurring on a separate day. Working with the project team, the schedule was adjusted to be more time efficient overall. UGSI crews went to a night work schedule, completing the required fusion for 120 LF by first thing in the morning. Then J Fletcher Creamer crews added the spacers, assembled the complete bundled ducts, and pulled in 120 LF of the assembled bundle by 3 PM that same day. Then at night the fusion crews would begin again. This greatly reduced the overall time required for the assembly and insertion.

5. CONSTRUCTION DESIGN FOR GROUTING

Design Criteria: The project ampacity calculations were based on the thermal grout with design conductivity. Project designers wanted a cementations based grout to support the ducts during cable installation, protect adjacent ducts should an event occur, and to provide a stable long term installation package. Design parameters for meeting these requirements included the following:

- High sand content grout to meet the thermal requirements of less than 60°C-cm/W at set-hardened state.
- Pumpable grout properties that would allow pumping at relatively low pressures through very tight duct spacing (49% area blockage; Figures 7 & 8) over relatively long distances from the pump and for filling the approximate 1,400 foot long casing, maximum design pressure was 100 psi for the selected ducts.
- Sufficiently low cement content to prevent the heat of hydration from exceeding the design temperature of the PVC ducts for resisting the buckling pressure.
- Stable mix that would not bleed which could form ungrouted pockets at the top of the casing or around the spacers.
- Longevity in the fluid state to permit enough time for the grout to be placed and for mitigation actions should something occur that would stop the pumping and possibly destroy the installed bundle and casing.

Initial Mix For Thermal Requirements: The sand mineralogy and grain size distribution as well as other ingredients are critical to both thermal properties and pumpability. Sands and other ingredients were selected for this project by the specialty grout subcontractor, inTerra Innovation, Inc. (inTerra) who then conducted a preliminary evaluation of all potential aggregates for use in a mix design by adjusting the available grain size distributions using cement and other fines for thermal and pump-ability properties as well as maximum density. Once it was confirmed which component materials had the potential for producing a viable mix, these ingredients were sent to Geotherm to develop the thermal blend of the ingredients to obtain the specified thermal properties. The resulting mix consisted of about 300 pounds of cement per cubic yard and had a rho of 50°C-cm/W in the set-hardened condition.

Assessment of the cement content indicated that if the typical rule of thumb of 10 degrees increase in temperature per 100 pounds of cement per cubic yard above mix temperature was applied, then the cure temperature would be approximately 100°F. Because of concern of the elevated temperature during the cure process, an assessment was made of the impact of the cement heat production over time when placed in close proximity to water filled ducts that
could absorb some heat along with the surrounding ground that could absorb some heat. This study consisted of a heat of hydration test for the mix design and a thermal model to assess the temperature profile in section at the PVC ducts during the cure process. The results (Figure 9) indicated that the water in the ducts, as well as the set-retardation and other ingredients in the mix made a significant impact on the temperature field thus mitigating the actual temperature of the PVC ducts during the cure. The model predicted a grout temperature of about 70°F with a temperature range around the ducts during cure also of about 70°F.

**Adjusting the Mix for Pumpability:** The next design step is to adjust the mix so that it can be pumped through the tremie to fill the casing length. This is done by minimizing internal grout friction which reduces pumping pressure without permitting segregation of the grout aggregate that could jam the system. Pumping pressure in the casing must remain below the unconstrained buckling pressure of the ducts at the grout set temperature. Pumping pressures must also remain below the tremie burst pressure capacity. An additional consideration is to minimize the water to cement ratio to control the bleed of the mix and to keep the aggregate in suspension and mixed until the initial set. These conditions are impacted by the need to retard the mix set time sufficiently to permit placement. Typically, a set retard of about 24 to 48 hours is desirable. All of these factors are the responsibility of the grout contractor and is done by modifying the thermal blend while maintaining the thermal design density as a minimum value. Once modifications are completed, a specific retarder is added to the mix to retard the set time. Note that retarding the set time does not change the amount of heat produced during the cure process for this retarder, it will only delay the production interval however, some retarders can actually cause the heat to be released faster than a non-retarded mix resulting is much higher actual temperatures as the heat has less time to dissipate.

**Quality Control (QC) Measures:** Continuous observations and incremental measurements of grout density as it discharges from the mobile mixer provide reliable QC during grouting operations. Pump pressure is monitored and instrumentation installed throughout the casing length provides real-time temperature and pressure of the mix in in the casing to match up with design limits. The instrumentation also provides indication of when set has been achieved. Volume pumped is determined by calibration of the pump stroke counter to actual measured volumes pumped prior to grouting. Finally, grout emanating out of the vents is sampled and tested for density and for thermal resistivity.

**Installation Design:** Now that the mix is developed, the contractor must install the mix. Typical installation methods with a proven track record include the use of concrete pumps to move the sand mix and a multiple tremie system for inserting the grout at design locations to maximize the chances of full coverage in the casing before the tremie pipes renders them useless.

One key issue for this mix is that it is not a standard mix. Few thermal grout mixes can be economically blended in a timely manner at a central mix operation. Some of the mixes actually have materials that central mix operations do not want running through their equipment. To modify the mix design for central mix operations is to compromise the quality of the mix for placement thus increasing risk of problems. This issue is solved by the use of mobile continuous mixers used in a manner for which the mixers were originally developed: providing calibrated consistent fresh blending of special mix continuously ready for site use.

The tremie system is designed to reduce placement pressure in the casing. A 2 inch diameter DR11 HDPE by coil tremie pipe made of PE3608 pressure pipe material was used for this project so as to avoid having splices or internal beads in the tremie that often cause clogging.

The duct bundle instrumentation included pressure and temperature gauges for field verification during and after grouting operations. Gauges were installed during conduit PVC, tremie and spacer bundle assembly. After the duct bundle was pulled into place, the ducts were pressurized to verify integrity and help mitigate pump pressure. This pressurization system also acts like a pressure sensor and provides an early warning should pumping induced pressures in the casing exceed the design limit of 100 psi.
6. INSTALLATION OF GROUT

Standard procedure used over 20-years for mobile continuous mixing requires part of the fines content to be pre-blended in with the sand portions of the mix prior to grouting activities. These ingredient materials are mixed as per the dry-weight mix design with tests conducted on the pre-blend to ensure it meets design properties. Past 20-year history proved that this pre-blend could be stockpiled for months without issue. This pre-blend is loaded into the sand hopper of the mobile mixer with cement & other additives loaded into the cement hopper and water with additives into the water tank as shown in Figure 10.

The mix is blended through the pre-calibrated mobile mixer according to standards cited in this papers references. The quality control and quality assurance (QC/QA) program developed by inTerra covers the calibration of the mobile mixers to ensure they are manufacturing grout according to the dry-weight mix design.

During the Hackensack River project grout mix evaluations coming out of the mixer prior to placement in the grout pump, and thus not under pressure, showed the mix to meet design parameters for density, settlement, bleed, etc. However, upon pumping into the tremies the pressures soon began to rise to abnormal levels, and the tremie injection line quickly became clogged. inTerra’s pre-planned contingency measures were then immediately initiated to flush out the tremie line and create a worm-hole through the injected grout within the casing. This worked on one side of the bore, but not the other. On one side of the bore, the tremie could be flushed out but a worm-hole was not able to be created, so a mechanical splitter was used to re-open the clogged tremie at a specific location determined by instrumentation located within the casing. The set-delay properties of the mix provided adequate time to conduct these contingency methods.

The mix ingredients were then investigated to determine what was causing clogging problems when the mix was put under pressure during pumping. It was found that without informing its’ customers the manufacturer of one of the fines sources in the mix had begun adding an ingredient in an ad-hoc manner that adversely reacted chemically with other ingredients in the thermal grout mix. inTerra then used it’s extensive geotechnical and mix design experience to immediately source substitute fines ingredients to modify the mix. Field trials were quickly conducted, followed by implementation of full production activities as shown in Figure 11. The mix no longer balled or segregated under pressure, continuously met density target values, and was pump-able within reasonable pressures. After the entire bore was filled with grout, samples were taken from the vents at either end of the bore and submitted for thermal resistivity.

7. RESULTS

For the Hackensack River project, grout densities out of the mobile mixers stayed consistently over 120 PCF, denser than the original design which was good for thermal resistivity. The thermal resistivity of the grout emanating from the vents at the end of the pour was also over 120 pcf, and tested at 48°C-cm/W at set-hardened state, better than the

Figure 10. Diagram of Mobile Continuous Mixer

Figure 11. Grouting Operation
original design and 20% better than specifications. Maximum temperature inside the casing (grout & PVC temperature) was 90°F, or about 20°F higher than heat of hydration modeling predicted. However, we did not measure the initial mix temperature to assess the base temperature prior to adding the heat from hydration. This should be done in the future to permit accurate predictions. The maximum pressures in the casing reached 30 psi which was lower than predicted and lower than experienced on numerous similar other projects. Low pressures were likely due to the enhanced fluidity of the grout as well as the zero settlement and zero bleed qualities of this particular grout. Normal acceptable grouts will have slight bleed and settlement which is typically less than 2-percent.

8. CONCLUSIONS

The 1,400 LF long, 36-inch diameter HDD Hackensack River bore containing 16 Fusible PVC™ conduits was successfully grouted allowing the cables to be pulled through safely, and providing an excellent thermal environment for the 69 KV high voltage power cables for years to come. It must be emphasized that the technical issues generated and solved during grouting of this HDD are very specific to this particular project. Results for other sites may vary significantly, and the contractor needs to do its’ due diligence in evaluating each project to ensure a constructible system. It is the selection of the means and methods, the experience of the grouting contractor, and the careful planning with contingencies that are critical to ensuring a successful grouting operation. It should also be kept in mind that preliminary test data such as heat of hydration test results, predicted grout pressures, etc. developed in the design phase can only be used as an indication of what might happen during actual grouting activities, and experience from other projects and adequate factors of safety must be applied along with experience to generate reasonable engineering judgment allowing for an acceptable risk scenario.

The iterative team effort between the owner (PSE&G), general contractor (J. Fletcher-Creamer), grouting contractor (inTerra) and pipe manufacturer (UGSI) ultimately resulted in selection of conduits achieving the multiple objectives of the project, namely ducts that could provide satisfactory housing of high voltage electric cables, ducts that could be assembled to meet the project schedule, and ducts that could help create a groutable system with acceptable factors of safety. The grouting contractors’ engineered grouting contingency methods worked as designed to prevent loss of the conduits and bore when problems occurred, maintaining a groutable system for success. It is critical to always design the entire grouting system with an ability to mitigate problems, so that you do not go down a one way street. This is subsequently why it is smarter to involve the grouting contractor in the design phase of an HDD (or jack & bore) project.

The high risk of HDD thermal grouting jobs is why the pipe manufacture (UGSI) and grouting contractor (inTerra) become heavily involved upfront. Underground Solution’s heavy involvement providing its’ own engineering, field crews, and field technicians provide assurance of proper pipe material suited for the installation, proper fusion procedure and results, and proper debeading. UGSI’s trained personnel cover each of these critical aspects geared towards the success of the project – specifically those items critical to successful ducts installation.

inTerra Innovation’s heavy involvement of its engineering and field staff assures that all phases and all aspects of a grouting project result in success: from design of a groutable system to development a pumpable mix with good thermal properties to grouting of the bore.

9. REFERENCES

1. ASTM C685 “Standard Specification for Concrete Made by Volumetric Batching and Continuous Mixing” (written by C09 Ready-Mixed Concrete Subcommittee C09.40), Volumetric Mixer Manufacturer Bureau (VMMB)
2. MB 100-01 “Volumetric Mixer Standards of the Volumetric Mixer Manufacturers Bureau”
3. American Concrete Institute (ACI) 304.6R “Guide for Use of Volumetric-Measuring and Continuous-Mixing Concrete Equipment"