To Replace or Reuse: National Grid's Large-Scale Substation Foundation Remediation

As National Grid embarked on a large-scale upgrade of its more than 40-year-old Bear Swamp substation, the utility considered reusing the existing foundations to significantly reduce planned outages and capital costs. The project involved over 150 isolated equipment column support locations with associated drilled shaft foundations. The project required a full investigation of existing foundations to test their ability to support the new equipment. National Grid selected Leidos to provide the substation design engineering for the project.

BACKGROUND

Ranked the number one utility on Newsweek's Top Green Companies in the World two years in a row, National Grid is one of the largest and most environmentally sustainable investor-owned energy companies in the world. Its electric and gas service territories in the United States cover much of New England and New York.

National Grid's Bear Swamp substation located in northwestern Massachusetts is a critical location for the utility. Typical of a large substation, Bear Swamp serves a variety of roles including:

> A point of protection for operable transmission and distribution lines
> A location where the power can be switched, regulated, and stepped-up or stepped-down to different voltage levels
> A critical interconnect point between utilities

In addition, Bear Swamp services the adjacent 600 MW pumped storage hydroelectric facility, which balances the peak load demands on the regional bulk power grid.

Projects at existing facilities present challenges that do not exist at greenfield sites. The decisions surrounding what to replace versus what to reuse present challenging technical assessments, but can also offer significant savings to project costs. For the Bear Swamp upgrade, National Grid wanted to minimize planned outages, adhere to a tight schedule, and minimize costs by keeping construction to a minimum. Therefore, the civil/structural scope called for an analysis of both the existing rigid bus systems and the existing structures/foundations for reuse to accommodate a retrofit design of the substation.

CHALLENGE: TESTING THE EXISTING FOUNDATIONS' STRENGTH

The investigation of the existing pier foundations included reviewing and analyzing the historic plans and legacy drawings. The drawings showed a minimum embedment or socketed rock condition for each of the existing piers. Under the proposed design loads and using the minimum embedment depths, the Leidos team found the existing pier foundations would not meet the serviceability criteria for the project.

To further pursue the reuse concept, National Grid and Leidos agreed that the initial analysis using minimum depths might be overly conservative if the actual embedment depths installed in the field were deeper than on the drawings. The drawings lacked field redlines to determine what the actual installed pier depths were, so the team moved forward with a new field investigation.

To perform the field investigation, National Grid retained GZA as the geotechnical engineering firm to provide non-invasive confirmation of below-grade pier geometry using low strain impact Pile Integrity Testing (PIT). The PIT measures dynamic acceleration and velocity as a compressive stress wave propagates through the test pier. Fortunately, there was enough space adjacent to the base plates to impart a hammer-induced compression wave at the tops of the piers and record the impact. Variations in the pile impedance would produce return wave reflections recorded by an accelerometer mounted on the pier surface. The last, or deepest, reflection was interpreted to be the pier toe.

GZA analyzed 24 representative piers using PIT, and a number of piers showed a deeper embedment than was originally assumed based on the drawings. However, an equal number of piers showed approximately the same embedment depth shown on the drawings. Due to the large number of piers present in the yard that were set to support new equipment replacements, the data from the PIT did not warrant further analysis at an extended embedment depth. Instead, it was clear the team needed a new approach to reuse these existing piers.

AN INNOVATIVE SOLUTION: SOIL STRENGTHENING

Further evaluation of technically feasible options led to the consideration and eventual application of soil strengthening techniques to qualify the existing foundations for reuse. The team considered several remedial alternatives, including increasing the shaft dimensions with a concrete collar and replacing the upper soil with stiffer fill material, including either compacted dense-graded gravel or controlled low-strength material (CLSM).

To determine the best solution, multiple iterations of lateral deflection analysis were conducted under the controlling design load combinations. The results showed that either fill material could strengthen the soil

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to the required serviceability levels. With further analysis factoring volume, labor, and equipment, the team concluded that CLSM was a more cost-effective solution.

CLSM is a cementitious material, with a typical compressive strength range between approximately 50 and 1,000 pounds per square inch (psi). The team selected a CLSM with moderate strength that could be modelled as a cohesive soil rather than a soft rock to account for future weakening from local excavations and freezing weather. Through close coordination and iterative foundation analysis, Leidos determined a depth of CLSM that would satisfy the required design criteria for reuse of the existing foundations. Foundation repairs and remediation occurred with the structures still supported on the foundation anchor bolts, with the equipment remaining energized and in service.

RESULTS: MORE THAN $200,000 IN SAVINGS

At the conclusion of the project, a total of 155 existing foundations were reused. If National Grid had been required to replace the foundations, the existing structures and electrical bus work that did not require upgrades would need to be removed, which could have presented major challenges to keep the station energized during construction. Avoiding these planned outages saved substantial costs associated with taking assets offline, rerouting power to serve customers, planning with all stakeholders, and increased schedule complexity.

Based on a comparison of the two alternatives, the project foundation work was completed at an overall construction cost savings of over $200,000. The capital costs savings came from eliminating excavation, demolition, disposal, localized rock removal, new foundation construction and backfill. This net cost savings was offset by the additional engineering, testing, and placement of CLSM required to reuse the foundations. Additional soft costs saved by reducing the planned outages is estimated to double or triple the capital cost savings.

Reuse of existing foundations with the application of CLSM proved to be a manageable technical solution, with the added benefits of simplifying construction, reducing construction cost and carbon footprint, minimizing electrical outages, and reducing expense to utility customers within the constraints of a complex project in a remote location.

As the world adapts to greater demands for more sustainable and reliable energy, regulated utilities strive to identify means of reducing costs to customers. The Bear Swamp reconstruction project shows how utilities can reduce capital costs and meet the performance needs of the project, while also reducing the project's carbon footprint by reusing existing foundations and utilizing locally available resources.

More details on this project can be found in the American Society of Civil Engineers paper "Large Scale Substation Foundation Remediation" presented at the 2019 Geo-Congress.

CLSM Placement around Existing Drilled Piers (Structure Upgraded)

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