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Innovative Stabilization of Peat Soils for Railroad Foundation Using Rammed Aggregate Piers

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Abstract

The Freight Rail Improvement Project (FRIP) involves the construction of a third line adjacent to two existing Amtrak lines that will accommodate a new freight rail service. Due to the existence of a layer of peat below the boat section, the original design called for the use of piles for foundation support. Through value engineering, the costly deep foundations were eliminated and replaced with Rammed Aggregate Piers designed to stabilize the organic soils and allow for the use of slab-on-grade construction. Results from the modulus test and inclinometer measurements demonstrate that the piers were sufficiently strong to withstand the applied loads without bulging and adequately stiff to achieve the required pier modulus value for settlement control. The piezometer readings indicated that excess pore pressure build-up within the organic layer during pier installation quickly dissipates. The testing results demonstrate that Rammed Aggregate Piers are a cost-effective system for stabilizing organic soils to allow the use of shallow foundations and limit post-construction settlements.

Introduction

The Freight Rail Improvement Project (FRIP) involves the construction of a third line adjacent to the two existing Amtrak lines to accommodate freight rail service. In order accommodate freight rail traffic below existing highway overpasses, the tracks had to be constructed at a level approximately 1.5 to 2.4 meters (5 to 8 feet) below existing grade. This lowering of grade placed the tracks below the groundwater table, necessitating the construction of a concrete "boat" section to support the rails and

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keep the rail bed dry. The base of the structure is a 0.9-meter (3-foot) thick by 7-meter (23-foot) wide cast-in-place slab constructed within an excavation that ranges between 2.4 meters and 3.4 meters (8 and 11 feet) below grade. Cast-in-place sidewalls form the rest of the culvert.

The subsurface conditions consisted of up to 2.1-meter (7-foot) thick peat layer sandwiched between relatively clean sandy fill and a deep underlying medium dense glacial outwash sand deposit. The top of the peat layer is typically located between approximately 1.2 meters and 2.1 meters (4 and 7 feet) below the bottom of the culvert.

The presence of the peat deposit led the original design team to choose a deep foundation in lieu of slab-on-grade construction because of the concern with the potential for excessive settlement. The original design called for installing a combination of Pressure Injected Footings (Franki Piles) between the overpasses and low-overhead mini-piles beneath the overpasses, to support the concrete boat section.

To reduce the project costs, the design team accepted a value engineering proposal consisting of installing Rammed Aggregate Piers to stabilize the peat soils and reduce the potential for excessive settlement. Figure 1 depicts a typical cross-section of the boat section showing the Rammed Aggregate Piers extending through the peat layer. This solution required that the piers limit post construction settlements and resist the applied vertical loads without bulging into the surrounding peat.

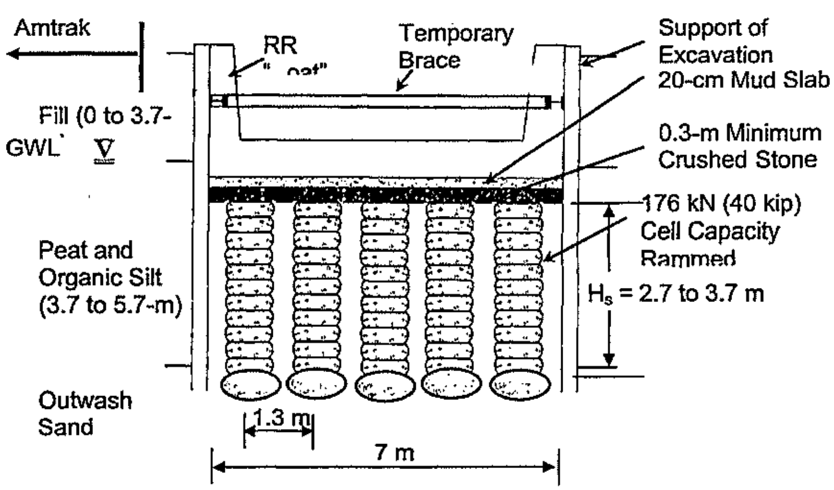


Figure 1. Typical Boat Cross-Section

To address the design issues, the Rammed Aggregate Pier installation contractor performed sophisticated modulus tests equipped with telltales to assess the performance of the piers during axial loading. Inclinometers and piezometers were

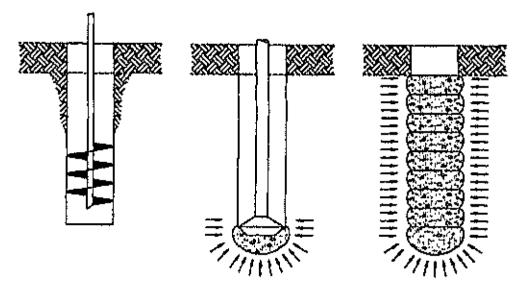
installed adjacent to the test piers to measure the lateral bulging and to measure excess pore water pressures generated during construction and during axial loading.

Design and Construction

Rammed Aggregate Piers increase the bearing capacity of the reinforced soil matrix, significantly reducing foundation settlements. Settlements are calculated by summing the compression of the reinforced soil (upper zone) with the compression of the zone of soil that is located below the tips of the piers (lower zone).

Upper zone calculation procedures are based on a spring analogy described in the literature (Lawton and Fox 1994, Lawton et al. 1994, Wissmann et al. 2000). Estimates of settlement in the lower zone materials, below the bottom of the aggregate pier bulbs, are computed using conventional geotechnical settlement analysis approaches. The analysis includes the assumption that the lower zone stress distribution induced by the footing may be estimated using solutions for a footing supported by an elastic half-space, ignoring the presence of the stiff aggregate pier elements.

The procedure used to install Rammed Aggregate Piers is shown in Figure 2. The Rammed Aggregate Piers were installed by drilling 760-millimeter (30-inch) diameter holes to depths ranging between 2.7 meters and 3.7 meters (9 to 12 feet) below the bottom of the culvert, placing controlled lifts of aggregate stone within the cavities, and compacting the aggregate using a specially designed high-energy beveled impact tamper. The first lift consists of clean stone and is rammed into the soil to form a bottom bulb below the excavated shaft. The bottom bulb effectively extends the design length of the aggregate pier element by approximately one pier diameter.



(1) (2) (3)

Figure 2. Rammed Aggregate Piers Installation Procedure

The piers are completed by placing subsequent 0.3-meter (1-foot) thick lifts of aggregate and ramming the aggregate with the beveled tamper. During densification, the beveled shape of the tamper forces stone laterally into the sidewall of the excavated cavity. This tamping action increases the lateral stress in the matrix soil around the pier thus providing increased stiffness of the surrounding soil and increased normal stress perpendicular to the perimeter shearing surface.

Because the subsurface conditions consisted of interbedded peat and granular soils, a temporary casing was used to stabilize the sidewalls of the hole during drilling and tamping. The steel casing followed the drilling tool into the hole during drilling and was lifted during each tamping cycle to ensure that the tamping energy was applied below the bottom lip of the casing.

Performance Verification

To verify the assumed modulus values used for aggregate pier design and to demonstrate pier resistance to bulging into the peat soils, a full-scale Rammed Aggregate Pier modulus test was conducted prior to the installation of production piers. The test pier was monitored during installation and throughout the modulus test with a suite of instrumentation including inclinometers, vibrating wire piezometers, and telltales. Figure 3 shows the configuration of the instrumentation.

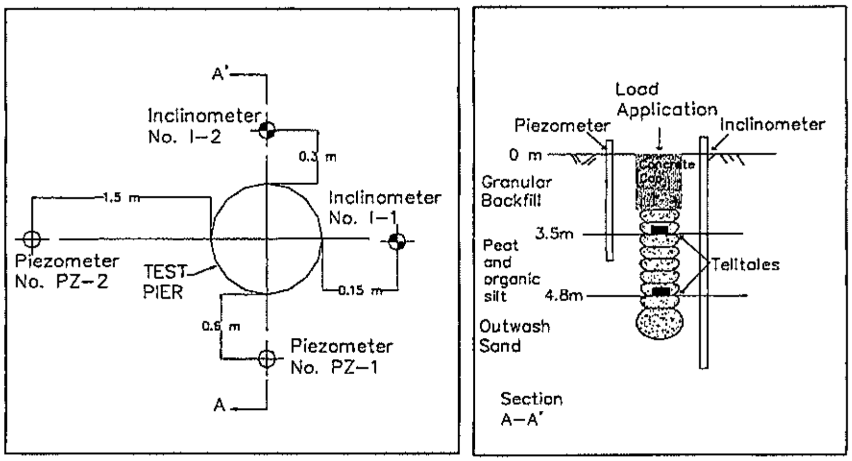


Figure 3. Instrumentation Location Plan

Modulus Test Procedures. The test pier had a shaft length of 2.9 meters (9.5 feet), extending from the bottom elevation of the culvert slab through the peat layer to 0.5 meter (1.5 feet) into the underlying sand layer. Telltales were installed in the pier to just above and just below the peat layer so that vertical movement within the peat layer could be measured. The pier was tested 6 days after installation to allow any excess pore pressure that developed during pier installation to fully dissipate. The test was performed by placing a circular steel plate over the full cross-sectional area of the installed pier and then applying pressure in increments of 10% to 15% of the design top-of-pier stress of 360 kPa (7,500 psf), to up to 3 times the design stress. A pipe sleeve was installed to isolate the telltales from the existing overburden soil.

Modulus Test Results. The results of the modulus test are shown in Figure 4. The test results indicate that the pier behaved with a near linear stress-deflection response from the start of loading to the design pier stress of 360 kPa (7,500 psf) with a total top of pier deflection of approximately 2 millimeters (0.1-inch). Net settlement of the top of pier after unloading from 150% of the design stress was less than 3 millimeters (0.12-inch). Movements for both telltales were also negligible over this stress range, indicating that a very small amount of pier bulging into the peat took place.

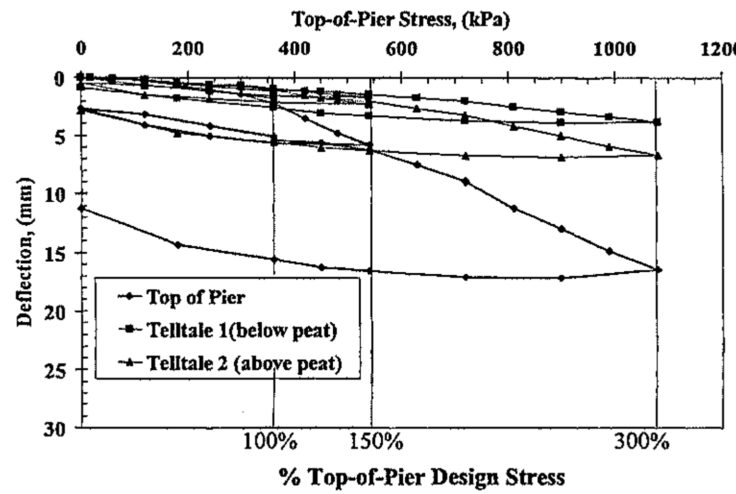


Figure 4. Modulus Test Results

Inclinometer Readings. Two inclinometers were installed at radial distances of 15 and 30 cm (6 and 12 in) from the edge of the test pier. The inclinometer readings showed up to 2 cm (0.8 in) of lateral deflection occurred during the construction of the pier (Figure 5). This is evidence of the lateral prestraining that occurs during pier construction (Fox and Cowell 1998) and the consequent reduction in the compressibility of the soils surrounding the piers (Handy 2001, Schmertmann 2005). Negligible additional lateral displacement occurred during the loading of the test pier up to 200% of the design stress, again indicating that significant pier bulging due to axial loading did not occur.

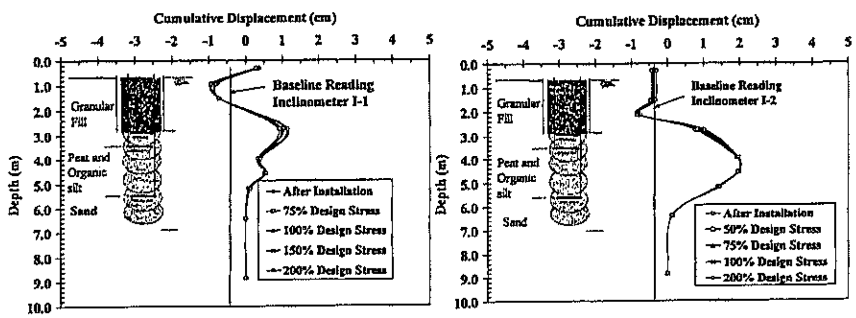


Figure 5. Inclinometer Results

Vibrating Wire Piezometer Readings. Two Vibrating Wire Piezometers were installed within the peat layer prior to pier installation. Figure 6 shows the variation in piezometric head with time. The data measured in both piezometers indicate minimal increase in pore pressure as a result of pier installation and test loading, after which rapid excess pore pressure dissipation occurred. Additional excess pore pressures developed during the installation of the adjacent production piers. Again, the pore pressures quickly dissipated due to the aggregate piers acting as drainage paths.

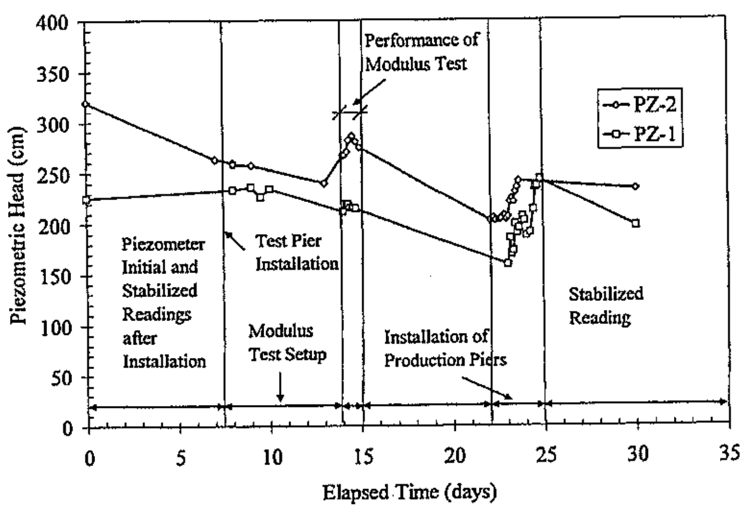


Figure 6. Piezometer Readings

Summary and Conclusions

Organic soils are difficult to stabilize and traditionally have required the installation of deep foundations, extending to hard bearing layers, to minimize the potential for settlement. At the FRIP project site, costly deep foundations were eliminated and replaced with Rammed Aggregate Piers designed to stabilize the organic soils and allow for slab-on-grade construction.

The design required that the piers posses sufficient strength to preclude excessive settlement and the development of bulging deformations during axial loading. Results from the modulus test and inclinometer measurements clearly demonstrate that the piers were sufficiently strong to withstand the applied loads without bulging and adequately stiff to achieve the required pier modulus value for settlement control. The piezometer readings indicated that excess pore pressure build-up within the organic layer during pier installation quickly dissipates. The test program that was performed on an isolated pier showed excellent results. Actual post construction settlements and pier bulging would be expected to be less than observed for the test pier due to the group consolidation effect from the installation of closely-spaced production piers.

The testing results demonstrate that Rammed Aggregate Piers are a cost-effective system for stabilizing organic soils to allow the use of shallow foundations and limit post-construction settlements. To date, over 50 projects have been constructed using Rammed Aggregate Piers to stabilize organic soils.

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