ABSTRACT

The Central Corridor Grade Separation project involves elevating high-use at-grade railroad tracks to enhance traffic flow through the active downtown corridor of Wichita, Kansas. Retaining walls ranging in height up to 25 feet above grade are required to meet existing railroad right-of-way restrictions. The Central Corridor site is underlain by sand and clay fill overlying variable thicknesses of compressible silt and clay. Without soil reinforcement, the construction of the walls over the fill and compressible soils would result in excessive settlements and the high bearing stresses imposed by the walls and rail loads exceeded the soil bearing capacity.

Several options were evaluated to support the heavy wall loads and reduce the serviceability risks by limiting settlements. Considerations for potential solutions required that all construction remain within the existing confined railroad right-of-way, and that the construction impact on adjacent structures was minimal. After careful consideration by the design team, the design-build Geopier® Rammed Aggregate Pier™ (RAP) system was selected to support the retaining wall.

This paper describes the design and construction of the selected alternative. This paper is of particular significance because it represents the first published case history that presents field performance results for a large heavy Railway facility utilizing this technology.
BACKGROUND
The construction of heavy Railway facilities including embankments, walls, and high-tonnage track on weak and compressible soils can result in significant settlement and instability. Settlements may take months or years before the majority of settlement is completed, depending on the soil compressibility and the thickness of the compressible layer. Additionally, high shear stresses induced by the new construction and heavy loads can lead to slope instability in weak soils or bearing capacity failure beneath retaining walls. Excessive post-construction settlement magnitudes and track and embankment instability can cause long-term maintenance problems, serviceability risks, and safety hazards for these facilities. Controlling settlement and stability is critical to maintain serviceability and safety for heavy railroad infrastructure.

Although used since the late 1980’s for building foundation support, the Geopier® Rammed Aggregate Pier™ (RAP) soil reinforcement system is a relatively recent innovation in railroad construction that provides effective solutions to reinforce weak soil and provide embankment/wall stability, bearing capacity improvements, settlement control, and track support.

Figures 1 through 3 illustrate RAP elements used to reinforce and stabilize weak or compressible soils beneath retaining walls, embankments, and track, respectively.

CENTRAL CORRIDOR RAILROAD GRADE SEPARATION PROJECT
The Central Corridor Grade Separation project involves elevating high-use at-grade railroad tracks to enhance traffic flow through the active downtown corridor of Wichita, Kansas.

The merger of the Union Pacific and Southern Pacific Railroads in 1996 added to the potential for significant rail traffic increase along the Central Corridor route through the city. A feasibility study was conducted to evaluate options for constructing a rail bypass to serve the railroads and help alleviate disruption of public traffic flow. The study recommended making improvements along the existing train routes by elevating the tracks and passing over cross streets with grade separation structures. The primary Central Corridor project extends for three miles through industrial and residential areas with tight
right-of-way limits, thereby requiring the use of retaining walls to support the elevated tracks. Three existing bridges were modified or replaced, three new bridges were added, and five street closures were included in the design. A total project budget of $98 Million was established for the project.

Elevating the tracks while maintaining existing rail traffic required several phases of construction. Depictions of construction phasing are shown in Figures 4 through 7. The first phase consisted of constructing a single temporary track near the edge of the right-of-way. Once rail traffic was moved from the main lines to the temporary line, Phase 2 started with placement of embankment fill confined by a permanent precast concrete retaining wall on one side and temporary Mechanically Stabilized Earth (MSE) wall on the other side. Following completion of the Phase 2 fill, walls, ballast and rails, traffic is elevated to the first permanent track in Phase 3. Phase 4 includes the removal of the temporary track, widening of the fill to encapsulate the temporary MSE wall, completion of the second side of permanent precast concrete retaining wall, and addition of the second elevated main track. The finished fill allows for an access road and possible third future track.

Construction involves over 19,000 lineal feet of precast concrete (T-Wall®) retaining wall along the alignment ranging in height up to 25 feet above grade. Additionally, phased wall construction requires approximately 9,000 feet of temporary MSE wall also ranging in height up to 25 feet. Design bearing pressures on the foundation soils beneath the retaining walls are as high as 6,000 psf.

The Central Corridor site is underlain by highly variable sand and clay fill overlying irregular thicknesses of compressible silt and clay soils, up to approximately 27 feet thick. These unsuitable bearing soils are underlain by medium to dense sands underlain by shale bedrock. The groundwater level is approximately 13 feet below grade.

Engineering calculations indicated that the construction of the grade separation retaining walls over the uncontrolled fill and compressible silt and clay soils would result in excessive total settlements of up to 6.5 inches. As a result of the variability in the soil profile, excessive differential settlements were expected.
The high bearing stresses imposed from the retaining walls and rail loads were in excess of the unreinforced soil bearing capacity. Furthermore, a slow rate of consolidation was anticipated within these compressible materials which could cause long-term maintenance issues for the Railway.

A number of potential alternatives were evaluated to support the heavy loads and reduce the serviceability risks by limiting total settlements to 2-inches, and to significantly reduce the potential for differential settlements. Construction activities were required to remain within the existing confined railroad right-of-way, with minimal impact on nearby adjacent structures.

Three primary alternatives were evaluated to support the heavy loads over the unsuitable bearing materials. These alternatives included: 1) massive over-excavation and replacement of the unsuitable soils with granular fill up to 27 feet deep, 2) deep foundation (pile) support of the structure which would require a Load Transfer Platform (LTP), and 3) Rammed Aggregate Pier soil reinforcement. While all three alternatives were deemed to provide acceptable performance for the project, cost, schedule, and constructability were of concern.

The deep foundation and LTP solution could be designed to provide the strictest level of settlement control for the project, however, it was determined that this solution would result in the greatest cost. The over-excavation and replacement alternative involved significant logistical difficulties due to confined site access, shallow groundwater conditions, and required massive quantities of imported and exported materials. This alternative would also require significant temporary shoring to protect adjacent structures and contain construction within right-of-way. These difficulties combined with a highly variable undercut thickness to reach the underlying sands resulted in a costly solution.

After evaluation of the RAP design and construction approach, project team members collectively approved the RAP System as a Ground Improvement solution for the project. Figure 8 depicts a typical cross section of the railroad grade separation retaining wall showing the RAP elements extending through the uncontrolled fill and compressible silt and clay layers.
DESIGN AND CONSTRUCTION

RAP soil reinforcing elements are installed prior to construction of retaining walls, embankment fills, and other heavy Railway structures to reinforce and stiffen compressible foundation soils, reduce the magnitude and duration of settlement, improve bearing capacity and improve the composite shearing strength and stability.

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 reinforced soil (lower zone) as described in published literature (Lawton and Fox 1994, Lawton et al. 1994, Wissman et al. 2000). Upper zone calculation procedures are computed using a weighted modulus method that accounts for the stiffness of the RAP elements, the stiffness of the matrix soil, and the area coverage of RAP elements below supported facilities. Settlements within the lower zone are computed using conventional geotechnical approaches.

The procedure used to install the Rammed Aggregate Piers is shown in Figure 9. The process first involves drilling a cavity. For the Central Corridor project a drill diameter of 30 inches was used. Drill depths at the Central Corridor site ranged from about 6 to 30 feet, as needed to penetrate the uncontrolled fill and compressible silt and clay layers. Pre-drilling at the Central Corridor site allowed Quality Control personnel to visually inspect the soil, ensuring that the reinforced zone extended to the appropriate depths.

Layers of aggregate were placed into the cavity in thin lifts of about one-foot compacted thickness. A specially designed high-energy beveled tamper was then used to ram each layer of aggregate using vertical impact ramming energy, resulting in high levels of strength and stiffness. The beveled tamper densifies aggregate vertically and forces aggregate laterally into cavity sidewalls. This tamping action increases stiffness of the surrounding soil and increases lateral stress within the matrix soil surrounding the densified aggregate pier. This results in excellent coupling with surrounding soils. Following
installation, retaining wall, embankment, and rail loads are concentrated on the stiff aggregate piers, resulting in engineered settlement control.

GROUND IMPROVEMENT SOLUTION

The RAP Ground Improvement design consisted of soil reinforcing elements spaced at 7.5 feet and 8 feet on-center along the lengths of the alignments directly beneath the precast concrete T-Wall and temporary MSE walls, respectively. The RAP elements were extended through the unsuitable bearing soils to reach the underlying competent sands. Slightly wider spaced elements were incorporated in limited areas where the underlying native sands were found to be shallow and/or shorter wall heights were planned. The design solution was incorporated to meet and exceed bearing capacity, global stability, and settlement control requirements set forth in the project specifications.

The RAP solution resulted in lower cost compared to conventional deep foundations or over-excavation and replacement alternatives, provided a faster construction schedule, eliminated the need for extensive temporary shoring, and reduced groundwater impacts. A total of 7,700 RAP elements were installed for support of the extensive retaining walls and heavy rail loading. The RAP system was installed in multiple phases to facilitate phased wall and track construction. A photograph of RAP installations on site is provided in Figure 10.

PERFORMANCE VERIFICATION AND RESULTS

The success of the innovative RAP soil reinforcement system was verified in several ways. A verification program was implemented to provide full time Quality Control during RAP installations as well as monitor performance of the ground improvement system during and following wall construction. Vibration monitoring adjacent to RAP installations proved that the impact on neighboring structures was low and well within the project requirements.
As part of the verification program full scale modulus load testing was completed on three non-production RAP elements to verify design stiffness assumptions. The results of the modulus tests revealed that actual RAP stiffness modulus values were two to three times greater than the design stiffness value.

During wall construction settlements were continually monitored throughout the project alignment at minimum spacing intervals of 150 feet to verify that design and performance criteria were met. Measured settlements along the face of the precast concrete T-Wall following completion of the west wall and embankment fill revealed total settlement magnitudes generally ranging from 0.75 to 1.5-inch – less than the project settlement criterion of 2 inches. A graph containing survey results of several settlement monitoring points along the west wall is provided in Figure 11. Photographs of precast concrete T-Wall and MSE wall during construction are provided in Figures 12 and 13, respectively. The RAP soil reinforcement solution performed as intended and met or exceeded the project performance requirements.

CONCLUSIONS

As demonstrated at the Central Corridor Railroad site in Wichita, Kansas, the Rammed Aggregate Pier (RAP) soil reinforcement system is an established innovation in railroad construction that can provide cost-effective solutions to reinforce weak and compressible soil to support settlement sensitive railroad structures.

Use of the RAP system in railroad construction is growing and provides embankment/wall stability, bearing capacity improvements, settlement control, and track support. To date, over 1,500 major structures are supported by the RAP system throughout the United States, including railroad embankments, retaining walls, and sections of railroad track.
ACKNOWLEDGEMENTS
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REFERENCES


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