high-energy beveled tamper foot using vertical ramming energy, resulting in high levels of strength and stiffness (see Figure 2). The ramming process increases the stiffness of the surrounding soil and the lateral stress within the matrix soil surrounding the stiffer RAP elements.

The RAP elements were concentrated at a higher area replacement ratio (tighter spacing) beneath the wall face and within the reinforced backfill zones for total and differential settlement control, bearing capacity, and global stability. Behind the main reinforced backfill, a lower area replacement ratio (wider spacing) was used to satisfy the settlement control criteria set forth in the project specifications.

The RAP soil reinforcement system design was verified through quality control, vibration monitoring, field modulus tests, and settlement monitoring. 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. Early during construction, vibration monitoring adjacent to RAP installations proved that the peak particle velocities measured at the ground surface were well within the project requirements and would have no negative effects on neighboring structures.

Full-scale modulus load testing was completed on three, non-production RAP elements to verify design stiffness assumptions. Modulus test results revealed that RAP stiffness modulus values were two to three times greater than the stiffness modulus value assumed for design. Vertical wall settlements were continually monitored during construction 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 inch to 1.5 inches — less than the project settlement criterion of 2 inches.

Peterson Contractors, Inc (PCI), licensed installer, completed RAP installation in two phases: Phase I was completed in less than four months and phase II was completed in three months. Two crews performed the installations in 133 working days, averaging 60 elements per day. Installation of RAP elements near the tracks did not interrupt the operations.

Table 1: Summary of recommended alternatives for wall support

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Advantages/Disadvantages</th>
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| Piles and load-transfer platform | • slow construction  
• requires partial over-excavation and replacement  
• requires shoring and dewatering when over-excavating in confined areas  
• better settlement performance  
• high vibration levels to adjacent structures |
| Over-excavation and replacement in the upper 27 feet of the profile | • slow construction  
• requires dewatering  
• requires temporary shoring  
• performance risk with adjacent structures  
• confined site access |
| Rammed Aggregate Pier | • quick installations  
• requires multiple mobilizations  
• no need for shoring or dewatering |

Figure 2: Three-step installation procedure of RAP elements.