Case History: Value Engineering of Driven H-Piles for Slope Stability on the Missouri River

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ABSTRACT: In order to increase rail traffic capacity, a rail line owner added an additional track adjacent to an existing main line along the Missouri River near Gasconade, MO. The new track was placed on the existing railroad embankment between the existing track and the Missouri River, requiring measures to improve the stability of existing embankment slopes. The initial design included permanent soldier pile retaining walls along portions of the project alignment and jet-grout "shear pins" in other locations to provide the required slope stability. Due to site access issues, the contractor proposed using driven HP 310x79 (HP12x53) piles as an "equal or better" alternate to the jet-grouted columns. This alternate was accepted and constructed with substantial cost and schedule benefits to the overall project.

INTRODUCTION

The subject of this paper is a case history in which driven steel H-piles were utilized as part of a value-engineering effort to replace jet-grout columns for stabilization of an embankment slope. The change from jet-grout columns to driven piles provided substantial benefits to the cost and schedule for the project. The overall project involved adding an additional track adjacent to an existing main line railroad along the Missouri River near Gasconade, MO. The location for the new track is on the existing embankment between the existing track and the river, requiring either the construction of retaining walls or stabilization of the existing embankment slopes.

Initial analysis and design was performed for the owner by others prior to the authors' involvement in the project. Details of the analyses were not made available to the authors. Restrictions on site grading resulted in proposed embankment slopes of 2:1 (H:V) in areas where retaining walls would not be used. The initial analyses performed by others established that these proposed embankment slopes would have factors of safety in the range of 1.2 to 1.5 when accounting for the proposed grading and loading from the new tracks. A row of jet-grouted columns was therefore designed to act as shear pins to improve the stability of the embankment slopes. The proposed 0.9 m (3 ft) diameter jet-grout columns were to be spaced 1.5 m (5 ft) center-to-center along the crest of the slope, extending from a distance of 1.2 m (4 ft) below grade down to bedrock. The jet-grout shear pins were planned along eight sections of the project alignment, which varied in length from 15 to 305 m (50 to 1000 ft). The height of the slope in these sections varied from 7.6 to 11.3 m (25 to 37 ft). A typical cross-section of the project alignment is shown in Figure 1. A detail of the designed jet-grout column shear pins is shown in Figure 2.

After the project was awarded, it was determined that the available space between the river and the existing rail line was often less than needed to safely operate jet grouting equipment while keeping the rail line open to traffic. Temporary work areas would need to be constructed for staging of the jet grout equipment and providing adequate, safe work space. The specialty contractor determined that driven piles could be safely installed without the need to build temporary work areas, resulting in the proposal of an "equal or better" alternate to the jet-grouted columns. The proposal consisted of driven HP 310x79 (HP12x53) A572 Grade 50 steel pile sections spaced 0.9 m (3 ft) center to center along the crest of the slope, extending from the ground surface down to bedrock. This paper describes the general site conditions and constraints that induced consideration of value-engineered alternatives, evaluations performed to demonstrate equivalency of the driven steel H-piles and jet-grouted columns, and the economic advantages of the value-engineered system.

SUBSURFACE CONDITIONS

Eleven soil borings were drilled along the project alignment for the pre-design site investigation. Standard Penetration Tests (SPT) and field vane shear tests were performed in four of the soil borings. In general, the subsurface conditions observed consisted of fill material overlying alluvial and residual soils overlying bedrock. The fill consisted of various materials, including clay, cinders, sand, gravel, rock fragments, cobbles and boulders. The alluvial soils were typically sandy silts and silty sands. Some deposits of residual clay were encountered immediately above the dolomite/limestone bedrock. The depth to rock was generally 7.6 to 10.7 m (25 to 35 ft). The depth of fill ranged from 1.5 to 9.1 m (5 to 30 ft).

Fourteen additional borings were drilled along the project alignment during development of the "equal or better" proposal to provide additional data as to the depth to rock and to attempt to obtain samples of the soil materials for laboratory shear strength testing. These borings generally confirmed that the depth to rock was relatively consistent at the site. Occasional boulders were encountered at shallower elevations, but the depth to bedrock was on the order of 6.1 to 10.7 m (20 to 35 ft) below existing ground surface. Attempts to obtain quality Shelby tube samples for undrained shear strength testing were generally unsuccessful with only a single suitable sample acquired out of many sampling attempts due to gravel and cobbles within the embankment soils. The measured undrained shear strength of this lone sample from an unconsolidated-undrained type triaxial compression test was approximately 48 kPa (1000 psf).

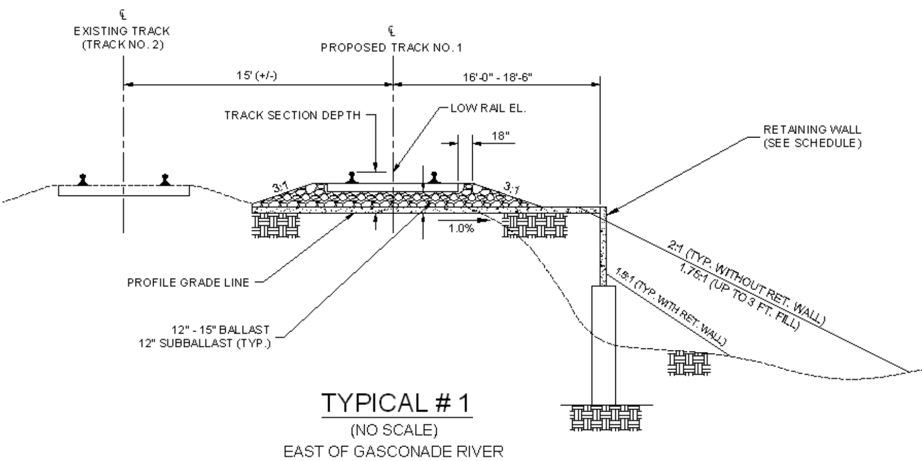

FIG. 1. Typical Cross-Section of Project Alignment (Retaining Wall Shown) (1 ft = 0.305 m)

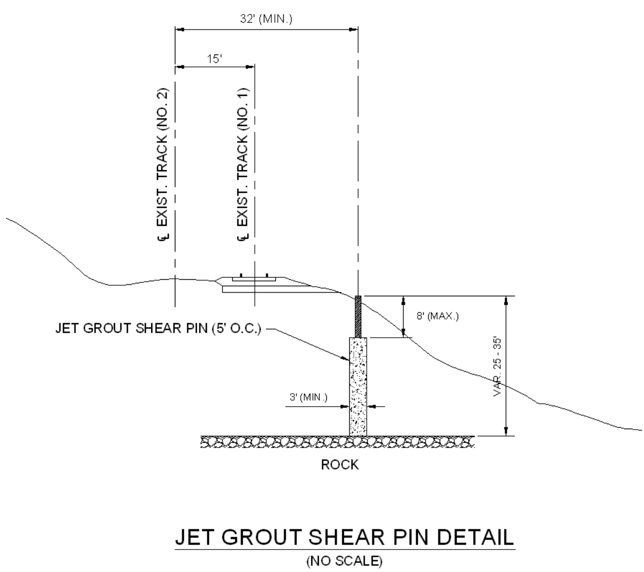

FIG. 2. Proposed Jet-Grout Shear Pin Detail (1 ft = 0.305 m)

ANALYSES

Because the primary objective for the value-engineered design was to demonstrate equivalence with the jet-grout columns, analyses focused on direct comparison of using H-piles for stabilization in lieu of jet-grout columns. Either stabilization technique had to be designed to resist the combination of earth pressure forces and live loads from the railroad lines. Resisting forces to be provided by the piles were predicted using soil-structure interaction analyses with loading induced by moving soil. The predicted resistance forces were then input into limit equilibrium stability analyses for comparison with results of analyses for the jet-grout columns. Analyses were also focused on evaluating stability for potential sliding surfaces that intersected the proposed locations of the new and existing tracks as the owner assumed risk and responsibility for any surficial slides that might occur beyond the rail tracks and timely maintenance of such slides should they occur.

In the original design, the embankment soils were modeled using drained, effective stress shear strength parameters with effective stress cohesion intercepts (c') ranging from 1.2 to 2.4 kPa (25 to 50 psf) and effective stress friction angles (φ') of 32 to 35 degrees. The stability analysis models represented the embankment soils above bedrock in multiple layers using this range of shear strength parameters. These analyses focused on achieving a factor of safety of 1.5 for the embankments.

The slope stability models used for the "equal or better" proposal modeled the soil above bedrock as a single material with the lower bound drained shear strength parameters from the earlier investigations [c'=1.2 kPa (25 psf), φ'=32 deg.]. In addition to comparing the H-piles to the jet-grout columns, these analyses were also focused on evaluating the embankment stability for potential sliding surfaces that intersected the proposed locations of the new and existing tracks.

Four cross-sections representative of the eight sections of the alignment requiring stabilization were selected for analysis. One cross-section, Station 4598+00, was deemed to be representative of most of the project alignment and was the focus of the initial analyses. This cross-section was used to define the slope model and perform sensitivity analyses to evaluate for the effect of variations in soil parameters. Once the model and soil parameters were finalized and the analyses completed for this cross-section, the same parameters were used to evaluate the other representative cross-sections.

In order to evaluate the equivalence of the H-piles as compared to the jet-grouted shear pins, a multi-step approach was used that included the following general steps:

(1) Stability analyses of the existing and proposed conditions for the embankments were performed to replicate results from the original design to ensure consistency among the stability models used for the value engineering evaluations and those used for the initial design. Results of these evaluations demonstrated that the stability models produced similar factors of safety for both the existing and proposed conditions.

(2) Back analyses of the existing embankment were performed to estimate minimum undrained shear strength values for the embankment soils that would result in a factor of safety of 1. Since the embankment is known to

have been stable for many years, thus having a factor of safety greater than 1.0, these analyses produced lower bound estimates of the average undrained shear strength for the embankment soils. These estimates were then used along with results of a limited number of field and laboratory strength tests to estimate undrained shear strengths for use in lateral pile-soil response analyses.

(3) Lateral pile-soil response analyses were performed to predict the shear resistance developed in the piles as the soil moves relative to the piles. Analyses were performed for potential sliding surfaces at various depths in the embankment to develop a shear resistance vs. sliding depth profile for the piles.

(4) Embankment stability analyses were performed to evaluate the embankment stability with the effect of the piles included. The piles were modeled using the computed shear resistance vs. sliding depth profiles from the lateral pile-soil interaction analyses.

(5) Finally, stability analyses were performed for the embankment with the proposed jet-grouted column shear pins for direct comparison with results of analyses performed for the H-piles.

The resisting forces provided by the H-piles were predicted using soil-structure interaction analyses with loading induced by moving soil. Calculations were performed for a soil movement of 127 mm (5 in) at 1.5-meter (5-foot) depth increments to simulate sliding surfaces that would intersect the pile in the slope. The mobilized shear force at the sliding depth (i.e. the predicted resistance force of the pile) was then input into the stability analyses as a user-defined reinforcement element. Figure 3 shows a plot of the predicted shear resistance as a function of sliding depth for one of the slide sections.

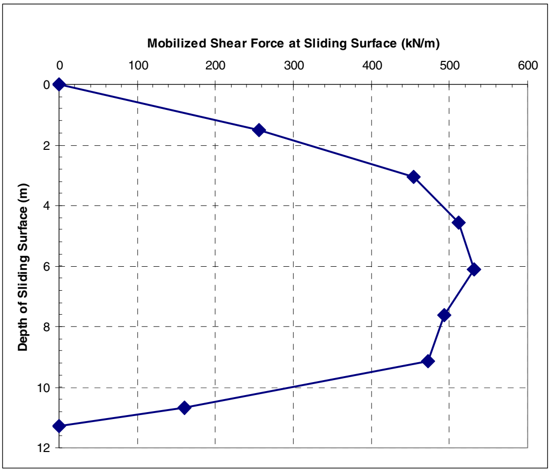

FIG. 3. Predicted Shear Resistance at Sliding Surface for H-Piles subjected to Soil Movement of 127 mm (5 inches)

The jet-grout columns were modeled as a user-defined reinforcement element with constant shear strength. Utilizing a value of f'_c = 3450 kPa (500 psi), a shear capacity of a single 0.9-meter (3-foot) diameter jet-grout column was calculated to be 85.9 kN (19.3 kips). At 1.5-meter (5-foot) center-to-center spacing, the jet-grout columns were modeled with a shear resistance of 56.3 kN/m (3.86 kips/ft).

Drained, effective stress shear strength parameters were used for all slope stability analyses since a drained analysis is appropriate for an existing embankment that has been in place for many years. Analyses of the lateral pile-soil response were generally performed using undrained shear strengths because of the empirical basis for these analyses and because of the potential for the pile-soil loading to be undrained. For the pile-soil response analyses, an undrained shear strength value of 36 kPa (750 psf) was used as a lower bound and 48 kPa (1000 psf) as an upper bound based on results of back-analyses for the existing condition and based on the limited field and laboratory strength tests available. A limited series of analyses considering the lateral pile-soil response to be drained were also performed. Results of these analyses indicated that the undrained lateral response is the critical loading condition with respect to pile-soil response. Thus, lateral pile resistance forces determined from the undrained analyses were used for the slope stability analyses.

SUMMARY OF STABILITY ANALYSIS RESULTS

Table 1 summarizes the results of the stability analyses, listing computed factors of safety for the originally designed stabilization using jet-grout columns and the proposed alternate stabilization using steel H-piles at the representative cross-sections. Figures 4 and 5 show typical results from analyses of the H-pile and jet-grout column stabilization options, respectively. For each stabilization option, computed factors of safety are shown for potential sliding surfaces that encompass both sets of tracks (referred to here as “double track”) and for potential sliding surfaces that encompass only the new set of tracks closest to the river (referred to here as “single track”).

Table 1. Summary of Calculated Factors of Safety

Cross-Section Station	*Jet Grout Column*		*HP12x53 H-Pile*	
	Double Track[1]	*Single Track*[2]	*Double Track*[1]	*Single Track*[2]
4546+00	1.5	1.4	1.5	1.4
4598+00	1.4	1.3	1.5	1.4
4606+00	1.5	1.4	1.5	1.4
4619+00	1.5	1.3	1.5	1.3

[1]Double track – potential sliding surfaces encompassing both sets of tracks
[2]Single track –potential sliding surfaces encompassing only the new set of tracks (closest to river)

Comparison of computed factors of safety for the two stabilization options reveals that factors of safety for stabilization with steel H-piles are equal to or greater than those computed for stabilization using jet grout columns for all cases evaluated. This demonstrates that the proposed steel H-piles would provide stabilization that was "equal or better" than that of the as-bid jet-grouted columns.

The factors of safety shown in Table 1 are based on evaluation of potential sliding surfaces that included the locations of the existing and proposed rail tracks alone and do not reflect the potential for sliding to occur to the river side of the H-piles or jet-grout columns. Computed factors of safety for potential sliding surfaces passing riverward of the jet-grout columns or H-piles were substantially lower than those shown in Table 1 (as low as 1.15), indicating a substantially greater risk of surficial sliding on the embankment slope than for sliding that would impact the rail tracks. The project owner was willing to accept this risk of surficial sliding and accept the responsibility for immediately and appropriately repairing any such slides that do occur to prevent the slides from enlarging and potentially compromising the jet grout columns or H-piles as neither were intended to act as free-standing supports.

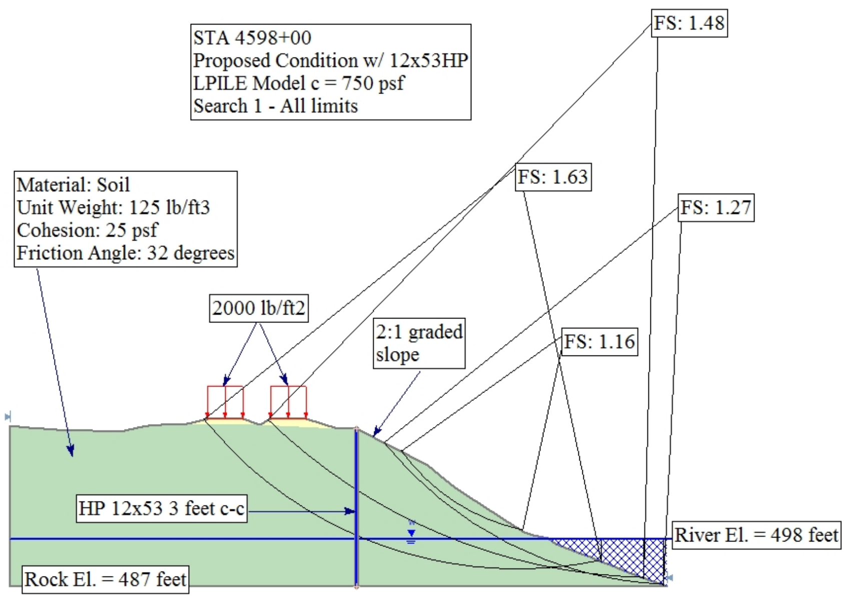

FIG. 4. Typical Result from Analysis of Embankment Stabilized Using H-Piles

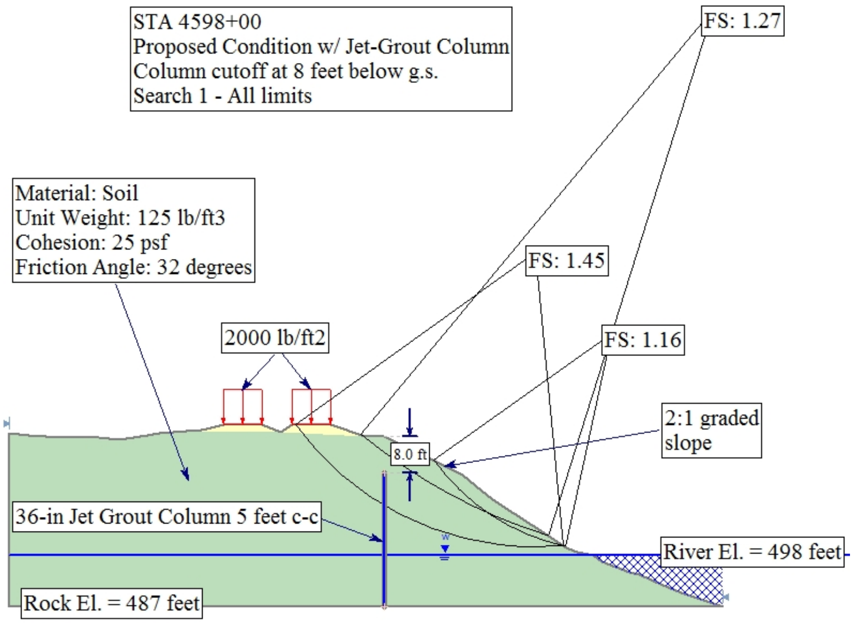

FIG. 5. Typical Result from Analysis of Embankment Stabilized Using Jet-Grout Columns

CONCLUSION AND PROJECT OUTCOME

The analyses performed to compare the proposed use of driven H-piles for slope stabilization in lieu of the as-designed jet-grout columns were described in this paper. The results of the analyses indicated that use of HP 310x79 (HP12x53) A572 Grade 50 steel H-piles placed on 0.9-meter (3-foot) centers near the crest of the embankment and driven to bedrock would provide stabilization similar or superior to use of jet-grouted columns recommended in the original design. The owner elected to accept the driven pile "equal or better" proposal as a substitute for the jet-grout columns. Pile installation began in September 2007 and was completed in late October 2007. Approximately 10,400 m (34,000 ft) of pile was installed at a cost savings of over $275,000 versus the jet-grout shear pin option. The driven piles were installed in approximately half the estimated duration for installation of the jet grout shear pins. Additional cost and schedule savings were provided to the owner by eliminating construction of temporary work areas that would be required for staging of the jet grout equipment.