Joint Transportation Research Program

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SPR-4329 2025

Monitoring of a Steel-Reinforced MSE Abutment Wall and Evaluation of its Bearing Capacity Based on the CPT and DCPT

Introduction

A two-span bridge, supported by steel H-piles and mechanically stabilized earth (MSE) bridge abutments, was constructed as part of a new interchange on I-65 in Whitestown, Indiana. The east and west MSE abutment walls consisted of precast concrete facing panels, ribbed steel strips, and coarse-grained backfill soil. A section near the middle of the east MSE abutment wall was selected for instrumentation and performance monitoring. The main goals of the project were (1) to investigate the performance of a steel strip-reinforced MSE abutment wall during construction and while in service, and (2) to verify, based on the dynamic cone penetration test (DCPT) blow count, the INDOT procedure for estimating the factored bearing resistance of MSE wall foundations in fine-grained soils. This report presents the site investigation results, the instrumentation layout, and the response of the MSE abutment wall to both dead and live loads for various stages during and after bridge construction.

Findings

- The ratio of the vertical stress measured at the base of the leveling pad to the vertical stress calculated based on the self-weight of the wall facing increased from 1.6 at stage 1 of wall construction to 2.4 at stage 5 (the end of wall construction). It subsequently increased to 3.2 after the bridge was constructed and opened to traffic (stage 11). The factor of safety for the leveling pad against bearing capacity failure was estimated to be 3.0 at the end of wall construction and 2.3 after the bridge was constructed and opened to traffic.
- The coherent gravity method, the simplified method and the simplified stiffness method are sensitive to the value of the backfill soil peak friction angle ϕ_p used to calculate T_{max} at the end of wall construction. For ϕ_p = 40°, the simplified stiffness method provided the best estimate of T_{max} for the four instrumented levels of steel strips considered in this study, whereas for ϕ_p = 34°, the methods generally overpredicted the maximum reinforcement tensile loads at the end of wall construction. For the Whitestown MSE abutment wall, the value of T_{max} increased by about 3%–5% during the time period between the end of bridge construction until up to 4 months after the bridge was opened to traffic. Because the contribution of dilatancy towards soil shear strength may progressively degrade during the service life of the MSE abutment wall due to traffic and other events (e.g., earthquakes and rainstorms), the critical-state friction angle ϕ_c of the backfill soil could be the most appropriate value of friction angle to use in MSE abutment wall design.
- The maximum lateral displacement of the wall facing [= 12.1 mm (0.48 in.) or 0.24% of the height H of the reinforced fill] at the end of bridge construction occurred at a depth of 2.8 m (9.2 ft or 0.56H) below the top of the reinforced fill; this is close to the depth where the maximum tensile load T_{max} [= 21.8 kN/m (1,494 lb/ft)] was measured in the instrumented steel strips. During the live load test, the lateral displacement of the wall facing increased by a maximum value of 0.8 mm (0.03 in.) compared to the measurement before the test; this occurred at a depth of 0.3 m (1 ft or 0.06H), which was near the elevation of the topmost reinforcement level, where the largest increment in tensile load [= 0.9 kN/m (62 lb/ft)] was measured during the test.
- The vertical displacement w of the MSE wall foundation (below the leveling pad) increased from 20 mm (0.8 in.) at the end of wall construction to 26 mm (1.02 in.) at the end of bridge construction; no significant change in pad settlement was observed during the live load test. The relative settlement w/B of the leveling pad was 6.5% at the end of wall construction and 8.5% at the end of bridge construction. The value of the secant modulus of subgrade reaction of the leveling pad decreased by 20%: from 11,450 kPa/m (73 ksf/ft) for a pad settlement of 12.7 mm (0.5 in.) to 9,150 kPa/m (58 ksf/ft) for a pad

settlement of 25.4 mm (1.0 in.).

- The results of the DCPTs performed in the foundation soil prior to wall construction showed that the factored bearing resistance [= 6,600 psf (316 kPa)] obtained using the chart in *INDOT Construction Memorandum 15–08* (Miller, 2015) was greater than the factored bearing pressure [= 5,100 psf (244 kPa)] at the base of the MSE wall foundation specified in the contractor's working drawing. In addition, the value of 6,600 psf (316 kPa) was close to the MSE wall factored bearing resistance of 7,000 psf (335 kPa) derived from the geotechnical report (based on the bearing capacity equation) and specified in the project contract documents.

Implementation

The following steps should be considered for the preparation and testing of the MSE wall foundation.

1. Perform SPT borings and CPT soundings as part of the initial site investigation to determine the site stratigraphy and foundation soil profile for the MSE wall project.
2. Excavate weak, fine-grained, surficial soil layers below the MSE wall foundation based on the geotechnical report for the specific MSE wall project under consideration.
3. After excavation, compact and proof-roll the surface of the fine-grained foundation soil in accordance with INDOT specifications.
4. Perform plate load tests in accordance with AASHTO (2020) and ASTM D1194 on the proof-rolled, fine-grained foundation soil (along the footprint of the MSE wall) to obtain an unfactored bearing resistance of at least 3 tsf for MSE walls shorter than 20 ft high.
    - A plate diameter of 12 in. (30 cm) may be used for MSE walls shorter than 20 ft (6 m) high, whereas a larger plate diameter of 30 in. (75 cm) is suggested for MSE walls taller than 20 ft (6 m). According to ASTM D1194, the plate load test should be performed until a peak load is reached or until the total settlement reaches at least 10% of the plate diameter. Scale effects, as mentioned in AASHTO (2020), should be considered when extrapolating the results of a plate load test (which reflects the soil response to loading only up to a depth of about two plate diameters) to a full-scale MSE wall foundation. In addition, it is recommended to ensure that, prior to performing the plate load tests, the undrained shear strength of the fine-grained foundation soil at the MSE wall project location increases with depth, down to a depth that corresponds to the width of the MSE wall foundation. The value of 3 tsf (300 kPa) for the unfactored bearing resistance was derived based on a typical backfill soil unit weight of 120 pcf (18.85 kN/m^3) and a factor of safety of 3 against bearing capacity failure. Further research is needed to determine the unfactored bearing resistances for Indiana soils from plate load test results.
5. Backfill the excavation with compacted B-borrow material and follow the quality control procedures provided in INDOT specifications.
6. Construct the MSE wall on top of the compacted B-borrow material.

Based on the results of the instrumentation of the Whitestown MSE abutment wall, the following points may be considered for implementation in MSE wall design.

1. Determine the critical-state friction angle ϕ_c of the backfill soil from direct shear or triaxial compression test results and perform MSE wall external and internal stability design checks using ϕ_c to account for potential degradation of the dilative component of soil shear strength during the service life of the MSE abutment wall.
2. For the reinforcement-panel connection limit state check, set the value of the reinforcement-panel connection load T_{con} equal to the value of the maximum tensile load T_{max} in the reinforcement.
3. Perform preliminary bearing capacity and factor of safety calculations for the leveling pad with the assumption that the unfactored bearing pressure (or unit load) at the base of the leveling pad is equal to two to three times the vertical stress due to the self-weight of the wall facing. Increase the width of the leveling pad and/or the concrete grade, as needed, to ensure the stability and serviceability of the wall.

Recommended Citation for Report

Sakleshpur, V. A., Prezzi, M., Salgado, R., Becker, P., & Zafari, Y. (2025). *Monitoring of a steel-reinforced MSE abutment wall and evaluation of its bearing capacity based on the CPT and DCPT* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2025/04). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284317845

View the full text of this technical report here: https://doi.org/10.5703/1288284317845

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