Mechanically Stabilized Earth Walls and Uneven Reinforcement Lengths (Trapezoidal Walls) – Design Development and Challenges

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Abstract. A composite trapezoidal MSE-embankment system was designed and constructed to support the embankment widening project at a Highway Bridge in New Zealand. The widening necessitated the construction of retaining walls on the existing abutment slopes and under the existing bridge. To suit the constructability and achieve a customized cost effective solution, the use of traditional rectangular MSE reinforcement lengths, which would require vertical excavation into the existing abutment slope, was replaced by the use of Trapezoidal-shaped reinforcement lengths. This paper assesses the consideration of a designed and constructed Trapezoidal Wall for a highway Bridge abutment, and variations on the conventional assessment of failure mechanisms to ensure the wall achieved the design intent. A few options are discussed and compared. Numerical analysis is carried out to establish the achievement of wall stability and serviceability requirements. The successful application of this wall is demonstrated by observed stability and the monitoring during and post-construction.

Keywords: MSE wall · Trapezoidal · Uneven reinforcement

1 Introduction

Coffey was engaged by New Zealand Transport Agency (NZTA) to prepare a MSE wall bridge abutment design, including both temporary construction and permanent wall design, for the widening of the highway overbridge abutments as part of overall highway improvements. The project proposes to widen the existing northbound and southbound carriageways from two lanes and a hard shoulder to three lanes plus a bus lane. A shared cycleway and pedestrian path will be provided adjacent to the northbound carriageway.

This paper presents the challenges faced in the design of the proposed widening, the design development and methodologies, assessment outcomes, and the construction performance of the final embankment widening solution, which comprises trapezoidal shaped reinforced soil walls.

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2 Retaining Wall – Challenges and Design Development

The embankment widening comprised cut heights up to 8 m above natural ground level. The MSE wall design underwent two stages of development, starting with a conventionally designed rectangular block by others, and concluding in a trapezoidal-shaped block (uneven reinforcement lengths) buttressing the existing embankment. A trapezoidal MSE wall was adopted in the final redesign. There were two options prepared for the construction phase, refer to Fig. 1. Option 1 – soil nail, and option 2 – inner soldier (pin) pile. Option 2 was selected for temporary construction support after cost comparison. This approach resolved the constructability issue in the previous design, where the whole abutment cut can be completed in one operation with the vertical rectangular cut requiring sheet piling and soil nail support being avoided. The discussion below is concentrated on the permanent trapezoidal wall.

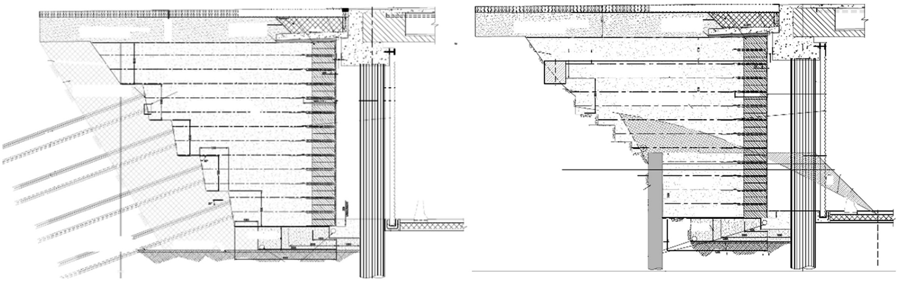

Fig. 1. Options for temporary construction phase Left: Option 1–soil nail; Right: option 2–inner pin pile

In the absence of design standards specifically for the proposed trapezoidal-MSE solution, the Federal Highways Administration (FHWA 2006) document on “Shored Mechanically Stabilised Earth (SMSE) Wall Systems Design Guidelines” was used as a guiding document. Design refinements were made based on FHWA’s (2006) recommendations, resulting in the final design solution, whereby the “base” of the RSW was shortened to 4 m. The design necessitated approximately a 1V:1H temporary excavation into the existing embankment to accommodate the widened base. Reference can be made to Fig. 1 (right) for an illustrative sketch summarising the relative dimensions and design features adopted during at the Final Design phase for the Road Abutments.

The updated final redesign challenged the original design mechanisms. The following sections provide some detailed discussion of the issues.

3 Design Analysis – Geotechnical Capacity and Discussion

The trapezoidal MSE walls have been analysed and designed for internal stability and global stability using appropriate computer software.

All design loads, geotechnical parameters and criteria are summarized in the Design Report (Coffey 2017). Global stability was assessed using the software SLIDE version 7.0. We have modelled the maximum above ground wall height of 8 m for the western abutment and 7 m for the eastern abutment, the trapezoidal MSE wall has been superimposed on to the existing slope surface which is approximately 35°.

The bearing capacity was checked through our spreadsheet-based program. On the basis of this work, a 1 m thick No Fines Concrete foundation is required to support the MSE wall due to surface traffic loads.

Static sliding and over turning analysis were ignored in the analyses based on the discussion presented in Sect. 3. However, the potential seismic sliding mechanism was analysed as discussed below (cases C1 and C2).

The following Global Stability Cases have been analysed for the longitudinal wall and outputs are presented in the Design Report (Coffey 2017).

- Case A (required FoS>1.5): Long-term static case, using drained parameters and anticipated long-term groundwater profiles;
- Case B (required FoS>1.2): Short Term Static Case – using the elevated groundwater profile which is approximately 2 m higher than the long-term groundwater profile;
- Case C1 (required FoS>1.2): Seismic Case – Ultimate Limit State (ULS) Peak Ground Acceleration (PGA) with total stress parameters; and
- Case C2 (required FoS>1.0 or displacement <50 mm): Maximum Credible Earthquake (MCE) Seismic Case – MCE Peak Ground Acceleration (PGA) with total stress parameters. An MCE event has been considered as 1.5 times the ULS PGA. Where a factor of safety is below 1.0 under the MCE Seismic Case a displacement analysis has been calculated in accordance with Jibson, 2007

Deformation analysis was undertaken for the proposed MSE wall using finite element software Plaxis 2D under the long-term groundwater case. The forecasted lateral movement under SLS conditions is less than 18 mm, and the majority of this was expected to happen during the construction phase.

4 Construction Performance

The monitoring plan was prepared, and the observation prisms were installed during and post construction to confirm the performance of the trapezoidal MSE wall as per the design predictions.

The corresponding trigger levels were derived from the design analysis and referred to bridge structural acceptance or capacity from the structural team. The trigger levels that were used are: Alert Level of 5 mm, alarm level of 10 mm and action level of greater than 15 mm. The relevant contingency plan was summarized in the IFC drawings and The Design Report (Coffey 2017).

5 Conclusions

A composite trapezoidal MSE-embankment system was adopted to support an embankment widening project for a highway overbridge abutment. The concept behind this system exploits the self-supporting characteristics of the existing embankment and consequent elimination of lateral earth pressures imposed on the buttressing MSE wall. The mechanics behind this system deviates from conventional MSEW design theory, such as those followed by typical design standards, AS4678 and R57 (2012). Adoption of design guidelines provided in FHWA (2006) “SMSE Wall Systems Design Guidelines” was utilised in the development of the Final Design, which rendered a trapezoidal-MSE wall with narrow a 4 m base width for an 8 m high wall sitting on a stepped 1V:1H interface with the underlying embankment. Finite element analyses were undertaken to assess stability and formulate deformation predictions. Instrumentation points on the existing bridge and MSE wall registered deformations within the expected magnitudes at the time of writing, thereby confirming the observed stability and successful performance both during and post-construction.

Based on the detailed comparison with the conventional design and construction, it is demonstrated that the Coffey trapezoidal MSE wall design and construction was a most cost-effective and constructible solution for this project.

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