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# Numerical analysis of a mechanically stabilized earth wall reinforced with steel strips

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## Abstract

A mechanically stabilized earth wall with steel strip soil reinforcement was built and instrumented by the Public Works Research Institute of Japan. Measured reinforcement loads and vertical toe loads are compared to values predicted using the finite difference program FLAC. Backfill and foundation soil properties were not reported in the original case study. A novel relative error technique was used to select the best estimates of the single-value elastic modulus for both soils. The relative errors were computed from the calculated and measured values of the tensile load in the steel strips and the vertical toe load at the end of the wall construction. Minimum relative errors were visually detectable in the contour plots of the weighted relative errors, and these minima were used to select the elastic moduli of the baseline backfill soil and the foundation soil. The baseline values were shown to yield predicted tensile and vertical toe loads that are judged to be in good agreement with the measured data. Parametric analyses were carried out to examine the quantitative influence on the computed reinforcement loads and the vertical toe load of the various soil modulus, interface shear stiffness and interface friction angles around the baseline values.

*Keywords:* Numerical analysis; MSE walls; Steel strips; Concrete panel facing; FLAC

## 1. Introduction

Mechanically stabilized earth (MSE) walls, constructed with steel strip reinforcing elements and incremental concrete facing panels, are now an accepted technology in Japan and worldwide. The first wall of this type in Japan was constructed in 1972 (Hirai et al., 2003). There are now estimated to be more than 30,000 of these structures in Japan (Ochiai, 2007). A useful history of the development of this technology and relevant codes of practice in Japan can be found in the paper by Miyata and Bathurst (2012a). The first instrumented steel strip wall in Japan was constructed in 1978 and was 6 m in height (Chida and Nakagaki, 1979).

The behavior of MSE walls is complicated, and performing an accurate simulation of these walls using numerical modeling techniques (e.g., finite element and finite difference methods) is a challenge. This challenge is due to the complex interactions between the soil and the reinforcing elements, the soil and the facing panels and the incremental construction technique. A recent case study was reported by Damians et al. (2015) who used the finite element method to simulate the performance of a well-instrumented 17-m-high steel strip wall constructed in the USA (Runser et al., 2001). The numerical

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results were judged to be in reasonable agreement with a range of measured response features. In contrast, there are many examples in the literature of numerical simulations of instrumented MSE walls constructed with extensible polymeric reinforcement materials using the finite element method (Karpurapu and Bathurst, 1995; Rowe and Skinner, 2001; amongst others) and the finite difference method (Hatami and Bathurst, 2005, 2006; Huang et al., 2009, 2010; Abdelouhab et al., 2011; amongst others).

The value of the numerical models that have been validated against well-instrumented MSE wall structures is that the numerical models can then be used to carry out parametric analyses of similar structures with other component material properties and geometry. These parametric analyses can be used to gain further qualitative and quantitative insight into the behavior of the structures and to improve the accuracy of simplified design and analysis methods found in design guidance documents such as PWRC (2003) in Japan, BS8006 (2010) in the UK and AASHTO (2012) in the USA. A validated numerical model is also useful for the design of unusual structures that fall outside the range of properties and geometry that are typically assumed using conventional limit equilibrium-based design methods.

There are some examples of the finite element modelling of field-instrumented steel strip reinforced soil walls in Japanese conference papers for which the concrete facing and the steel strips were modelled using elastic beams and truss elements, respectively. Yorita et al. (1995) modelled the performance of a single 7.5-m-high wall that was one tier of a five-tier 40.5-m-high reinforced embankment using an elastic-perfectly plastic soil model. They reported that a good agreement was obtained between the measured and the calculated horizontal pressure readings, but that the calculated reinforcement loads did not agree well with the measured values. Kawai et al. (1999) modelled a 13.5-m-high wall and investigated the influence of concrete panel stiffness on reinforcement loads using an elastic soil model. Summaries of the two walls reported by Yorita et al. (1995) and Kawai et al. (1999) can be found in the paper by Miyata and Bathurst (2012b). Mori et al. (2001) used both elastic and elastic–plastic soil models and discussed the advantages of using elastic–plastic models to predict the measured reinforcement loads in an 8.75-m-high wall. Arai et al. (2007) reported the predicted and measured reinforcement loads for a 4.0-m-high wall that was subjected to surcharge loads using concrete blocks. They used both elastic and elastic–plastic soil models. All of these studies have demonstrated the challenge involved in achieving a reasonable agreement between measured and predicted reinforcement loads. Nevertheless, these field-instrumented wall cases are not attractive for numerical modelling for one or more of the following reasons: (1) project details and instrumentation are limited, (2) many numerical modelling details are absent and the numerical and predicted results are limited (e.g., the conference papers are only two pages in length) and (3) project structures are complicated and project details, including soil–structure interactions, are not modelled. In none of these case studies were measured steel strip interaction parameters available.

This paper provides details on a 6-m-high steel strip MSE wall, reported by Chida and Nakagaki (1979), that was instrumented with strain gauges bonded to selected steel strips and vertical load cells at the base of the facing panels. In situ pullout tests were also carried out on steel strips embedded in the soil backfill at panel locations adjacent to the instrumented wall section. The wall was judged to have performed well. The data collected from this wall made it a valuable case study to test and validate advanced numerical models used to simulate the performance of these types of structures under operational (end of construction) conditions.

The current study is focused on the development and validation of a numerical model to reproduce the measured responses of this wall at the end of construction. The paper describes the methodology used to select the optimum material properties, to maximize the accuracy of the numerical predictions, and demonstrates the sensitivity of the numerical outcomes to a range of input parameter values. The numerical finite difference method program, FLAC (Itasca, 2011), was used to perform the numerical simulations.

## 2. Problem definition and model parameters

### 2.1. Test wall

A 6-m-high test wall (Fig. 1) was built by the Public Works Research Institute of Japan in 1978 (Chida and Nakagaki, 1979). The facing of the wall was constructed using 1.5-m-high cruciform-shaped concrete panels with a thickness of 180 mm. Silty sand was used as the backfill material. A 2-m-thick sloped layer of loam was used to surcharge the wall. In the current study, however, comparisons between the predicted and the measured wall performance are restricted to the end of construction prior to surcharging. The test wall was reinforced by smooth steel strips that were 100 mm wide and 2.3 mm thick. The length of the steel strips varied with the elevation. The first two layers of steel strips, just above the facing toe, were 4.0 m long. The third and fourth layers were 4.5 m long, and the rest of the steel strips were 5.0 m long. The measured tensile loads were deduced from the strain gauges bonded directly to five of the eight steel strips at seven different locations along each strip.

### 2.2. Model parameters

The FLAC numerical grid used to model the problem is shown in Fig. 2. Compressible bearing pads at the horizontal

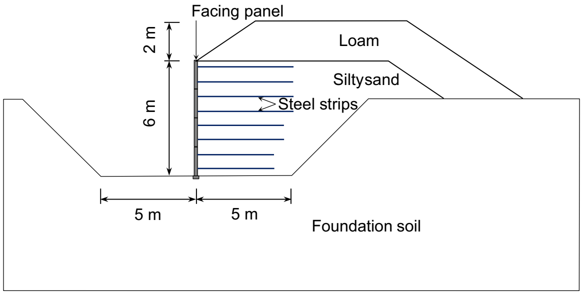

Fig. 1. Schematic showing test wall reinforced with steel strips (adapted from Chida and Nakagaki, 1979). Note: The loam surcharge condition, following the end of construction, was not simulated in the current investigation.