Experience from design & construction of a stable feature MSE wall in Dubai

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Abstract. There has been continued development of various methods for mechanically stabilized earth (MSE) wall construction, often by specialized system providers, to solve problems when the available width of reinforced fill is highly restricted. The design manual FHWA-NHI-10-024 permits to reduce the length of soil reinforcements up to 30% of wall height in shored or stable featured walls. There are many instances where the available width is much less than the limits by design standards, necessitating innovative approaches. The current project involves constructing a link road as a diversion at the middle of an existing 6m high ramp made of concrete wall. The new ramp will be retained by MSE wall that will be joined to the old concrete wall within tight space limitations. To accomplish this 'stable feature MSE wall' within narrow space, it was imperative to adopt a novel method of actively connecting geogrid reinforcements and modular block fascia to existing concrete wall. This paper presents the challenges in designing a stable feature MSE wall in extremely narrow space. The presented approach of connecting the soil reinforcement to the concrete anchors was a determining factor in the project and could therefore be adopted for future projects under similar conditions.

1 Introduction

For the design of simple MSE walls, AASHTO (2012) and FHWA-NHI-10–024 (Berg et al. 2009) requires the minimum length of the soil reinforcement to be not less than 70% of the wall height ($L_{min} = 0.7H$). External and internal stability calculations are performed based on this preliminary reinforcement length. Generally, reinforcement length should remain consistent throughout the wall height. However, in steep terrains along stable consolidated soil or rocky slopes, considering the above-mentioned minimum soil reinforcement length criteria, the excavation or blasting works required for construction of a MSE wall becomes impractical, particularly if traffic must be maintained during construction of the MSE wall. For such situations, it is possible to consider complex type MSE walls with further reduced length of soil reinforcements and with some special detailing (Berg et al. 2009) under the broad category of Shored MSE Walls (SMSE walls) or Stable Feature MSE Walls (SFMSE

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Walls) with retained portion being a shored wall (Fig. 1a) or self-stable rock stratum (Fig. 1b).

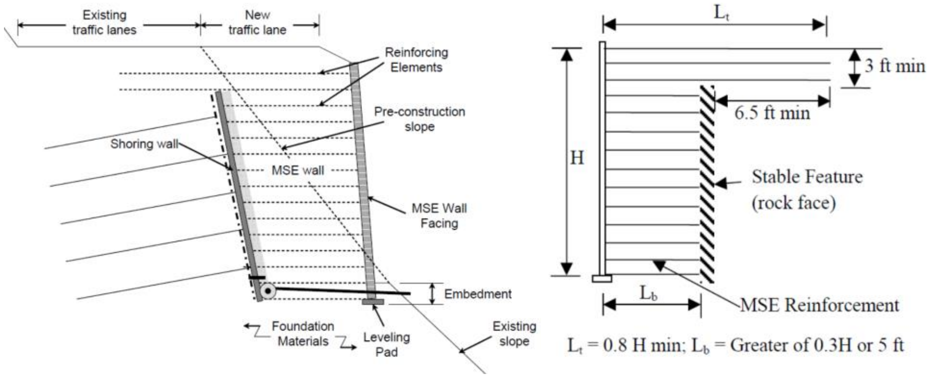

Fig. 1. (a) Cross section of a shored MSE (SMSE) wall system (Morrison et al., 2006). (b) Cross section of a stable feature MSE (SFMSE) wall system (Berg et al. 2009).

The design manual FHWA-NHI-10–024 (Berg et al. 2009) permits to reduce the length of soil reinforcements by up to 30% of wall height in SMSE or SFMSE walls. Nevertheless, it is common to find situations where the available width is much less than the design standard limits. Consequently, many studies have been conducted on this subject in the past (Leshchinsky et al. 2004, Lawson and Yee. 2005, Morrison et al. 2007, Fan and Fang. 2010, Yang et al. 2011 & Kakrasul et al. 2020). As well, specialized system providers tend to develop methods for design and construction of MSE walls, to resolve the challenges when reinforced fill widths are severely restricted in real projects, as in the case of the project referenced in the present paper. It is the purpose of this paper to share the challenges encountered while designing and building a SFMSE wall that is narrowly wider than the limits set by FHWA-NHI-10–024 (Berg et al. 2009).

2 Literature review

A review of recent studies on MSE walls with narrow fill widths is presented in this section. Centrifuge model studies by Frydman and Keissar (1987) examined how granular fill confined between a rigid retaining wall and an adjacent rock face transferred earth pressure to the wall. A comparison was made between the centrifuge model testing results and the Janssen's equation, developed originally for estimating corn pressures within silos. Frydman and Keissar (1987) found good match between their centrifuge test results and Janssen's equation. According to them, Janssen's equation could be used to estimate lateral earth pressures on retaining walls in at-rest condition. One of their major conclusions is that in the top portion of the wall, the theoretical at-rest value of the lateral earth pressure coefficient decreased with depth due to soil arching effect. In confined spaces with stable rock strata behind, MSE walls are expected to behave differently than traditional retaining walls, as are their magnitude and position of earth pressure and critical failure plane positions.

Due to the potential for soil reinforcements to have maximum tensile strength depending on their anchorage at the rear, Leshchinsky et al. (2004) and Lawson and Yee (2005) provided some practical suggestions for determining the tensile strength of soil reinforcements for limited fill spaces. They recommended anchoring the reinforcement to anchors or nails fixed across a rigid zone beyond the reinforcement and wrapping reinforcement around the back of the reinforced fill. According to Morrison et al. (2007), soil arching occurred near the shored interface of MSE walls with limited fill spaces. The results indicate that ignoring the arching effect in design calculations could lead to overestimation of pull-out resistance for narrowed MSE walls.

Fan and Fang (2010) investigated the distribution of active earth pressures on rigid retaining walls near rock faces through numerical modelling. Their study considered rock faces behind the fill space with varying slopes and distances from the wall. They found that the coefficients ($K_{a(c)}$) of active earth pressures on rigid walls near rock faces were considerably less than those of the Coulomb solution when the stiff boundary was within Rankine's active wedge width. Rock faces located within active wedges resulted in higher location of resultant of active earth pressures, i.e., $h/H > 0.33$. With increase of inclination of the rock face and with decrease in the width of the fill, it was observed that the h/H value increases. MSE Walls in confined space have a critical failure plane which is not linear like the Rankine failure plane, according to Yang et al. (2011). Moreover, they found that for short reinforcements, the critical failure plane would be bilinear based on their analytical studies. It partially passed through the reinforced fill and partially along the interface between the reinforced fill and the stable retained medium. Furthermore, they noted that the Rankine’s theory overestimates the inclination of the critical failure plane. The limited fill space may also result in inadequate anchorage length for soil reinforcement.

Based on the experimental studies on load-deformation behavior of MSE walls with limited fill space under static footing loading, Kakrasul et al. (2020) reported that connection of the reinforcement layers to the stable retained medium resulted in a significant reduction in the lateral deformation of the wall facing. They recommended either rear end connection or upwards bending of soil reinforcement in case of MSE walls constructed in limited fill width.

3 MSE wall in Business Bay Access project, Dubai, UAE.

The project involves constructing a new link road as a diversion at the middle of an existing 6m high ramp made of concrete walls (Fig. 2). The new link road's goal is to improve traffic connection within Dubai's Business Bay neighbourhood. The new ramp is built with modular block MSE wall system, as Sections A, B, C & D.

3.1 MSE wall section types A, B, C & D

For most of the stretch, it was feasible to consider simple MSE wall (Section A) with geogrid length ≥ 4.2m (70% of the wall height) (Fig. 3a). Sections B, C & D represented the cases where available width was less than 70% of wall height, due to the proximity to the existing concrete wall. The widths available for geogrid in Section B ranged from 2.5m to 4.2m. If the design length of geogrid exceeded the available width, it was wrapped inwards (Fig. 3b) to dissipate residual stresses within the reinforced fill. For the remaining stretches where available width was further reduced due to the location of concrete wall, it was required to actively connect the narrow MSE wall to the existing concrete wall through concrete anchors, as the cases in Sections C (Fig. 4) & D (Fig. 5). In Section B, the available widths for geogrid ranged from 1m to 2.5m. In this case, the geogrid was connected to the concrete wall through anchors and steel cables at all levels. Section D case was adopted where the width available was ≤ 1m. This was accomplished by actively connecting the modular block face to concrete anchors using steel stirrups and rebars.

The presence of the existing concrete wall in this project for Sections B & C is analogous to the category of stable feature MSE wall (SFMSE wall) as per FHWA-NHI-10–024 (Berg et al. 2009). Taking into account the recommendations from Lawson and Yee (2005) and

 https://doi.org/10.1051/e3sconf/202336802020

Kakrasul et al. (2020), the geogrid layers were either wrapped-up or connected to the concrete wall. As a result, residual stresses within the geogrid resulting from a limited width of reinforced fill are either dissipated within the fill or transferred to the concrete anchors.

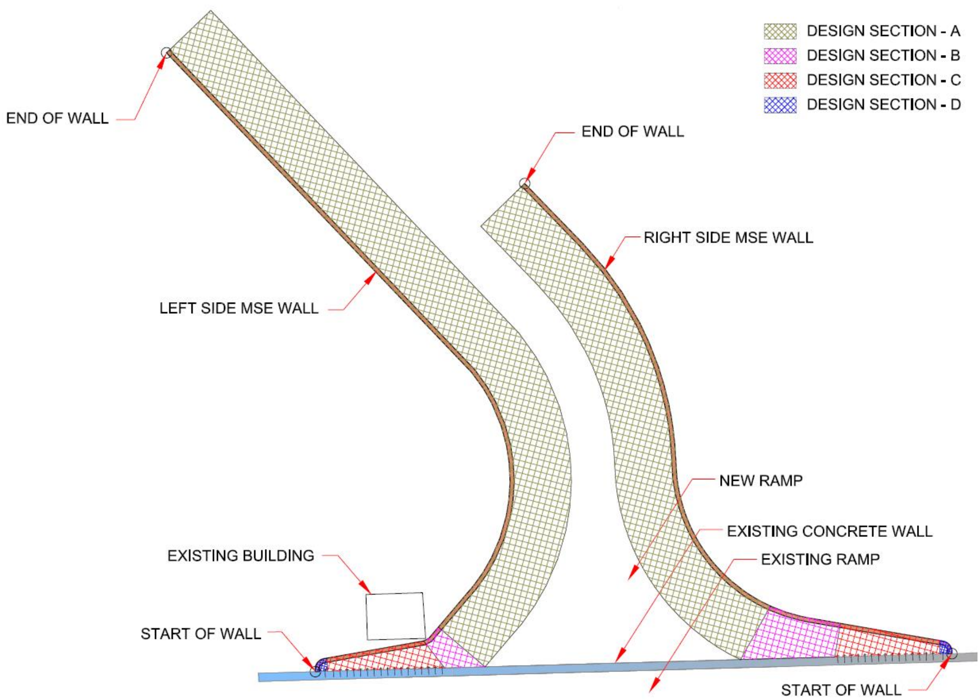

Fig. 2. Plan view of the project showing locations of Sections A, B C & D

3.1.1 Backfill types

With reasonable width available for compaction machineries, AASHTO A1a type backfill was used for section types A & B. To achieve the required compaction within the restricted width in Section type C, road sub-base material was used as the reinforced fill. The extremely narrow space between the modular block and concrete wall in Section type D was filled with cement stabilized aggerate fill. Cement stabilized aggregate fill consists of concrete mix which includes angular drainage stones without fines. Since cement stabilized aggregate fill is porous, drainage is built right into it, eliminating the need for a separate drainage layer. By adhering the aggregate fill to the wall block, a greater wall mass is created, thus eliminating the need for geogrids**.** Summary of the backfill types used in the project is presented in table. 1.

3.1.2 Soil reinforcement geogrid

Paragrid geogrid was used in the project. It comprises an open array of geocomposite straps, pressure and heat bonded together at specified centres to give the required performance characteristics. The geocomposite strap core are made from tendons of high tenacity polyester yarn protected by a polyethylene cover. The geogrid grades used in the project were 50 KN/m and 100 KN/m.

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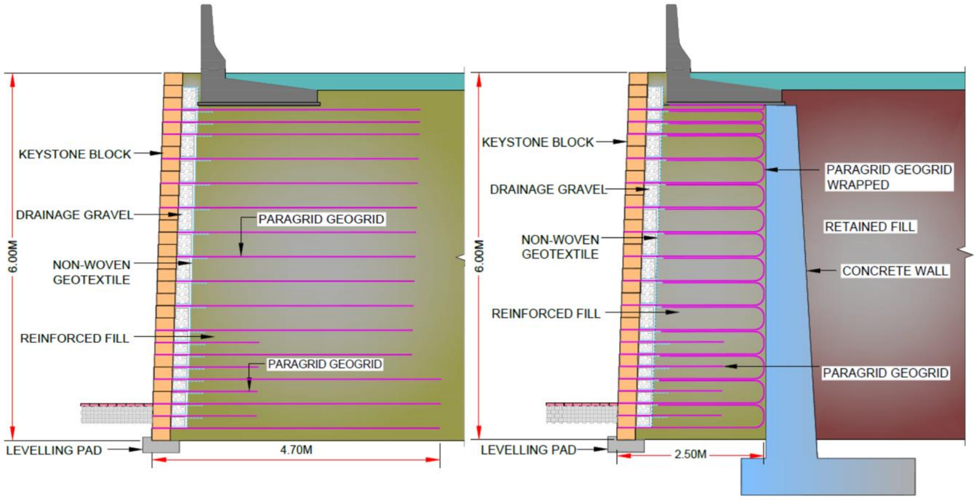

Fig. 3. (a) Details of Section A (available width ≥ 70% of wall height). (b) Geogrid wrapround arrangement in Section B (available width < 70% of wall height).

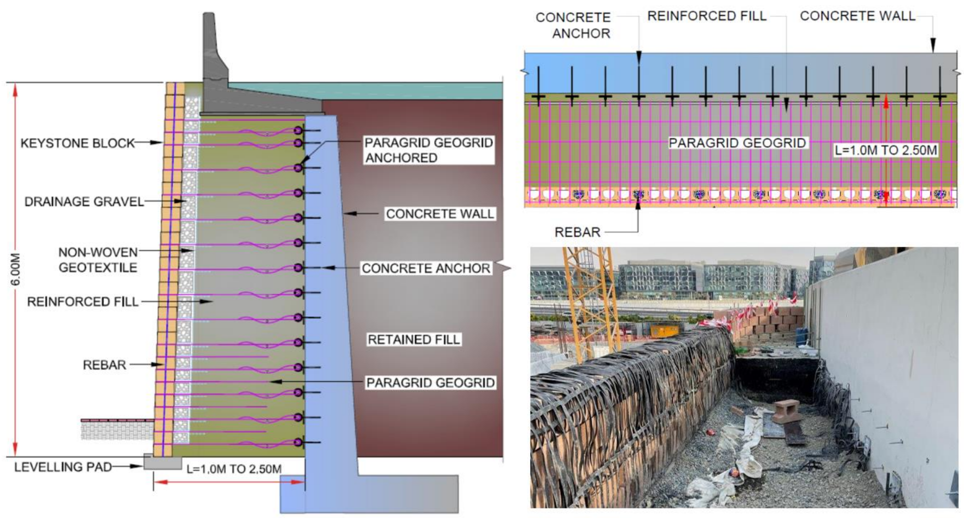

Fig. 4. Details of geogrid connection to concrete anchors in Section C.

Table 1. Backfill material types used in the project

Section type	Backfill type
A	AASHTO A1a soil
B	AASHTO A1a soil
C	Road sub-base material
D	Cement stabilized aggregate fill

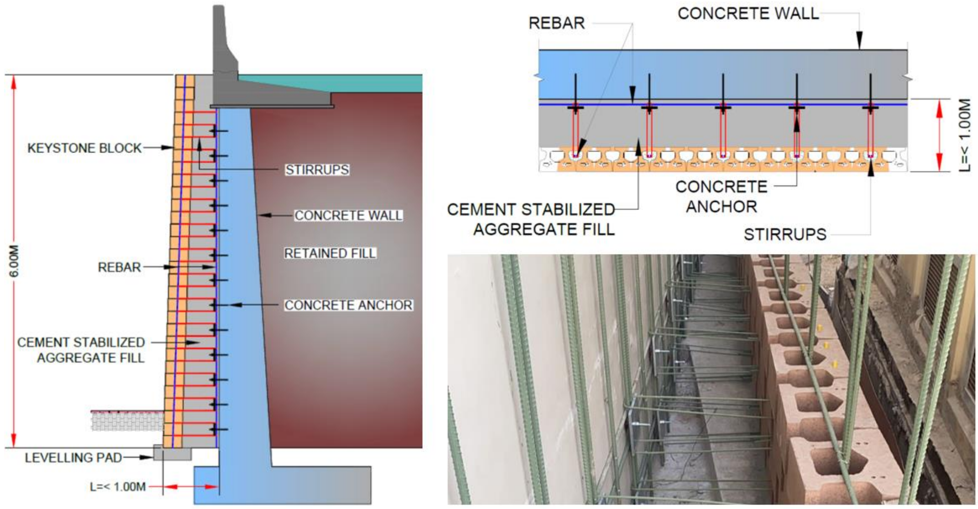

Fig. 5. Details of modular block connection to concrete anchors with steel stirrups and cement stabilized aggregate fill in Section D.

3.1.3 Design

Rankine's method and limit equilibrium method were used to analyse Section types A, B, and C. Since Section type D consisted of an anchored solid mass made by actively combining modular block facia, steel stirrups, rebars, concrete anchors and cement stabilized aggregate fill without any geogrids, conventional stability analysis were not performed.

Zinc coated concrete anchors made of carbon steel were used in the project (Fig. 6). Anchors were designed conservatively for the pull-out strength equivalent to the long-term design strength (LTDS) of the geogrid in each layer. In the actual field condition, the anchor load would be less than the LTDS of geogrid in many layers, taking into account the typical stress distribution within the soil reinforcement layers. Chemical adhesive was used to grout the anchor within the drilled hole in concrete wall. The stabilizing effect of anchors in terms of achieved factor of safety is demonstrated in figure. 7. A view of the competed SFMSE wall is shown in figure. 8.

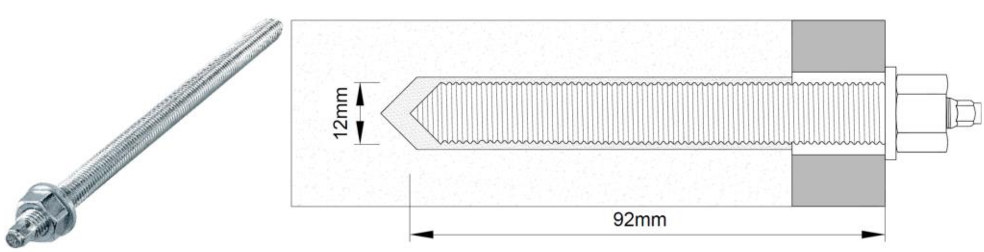

Fig. 6. Details of concrete anchor used in the project.

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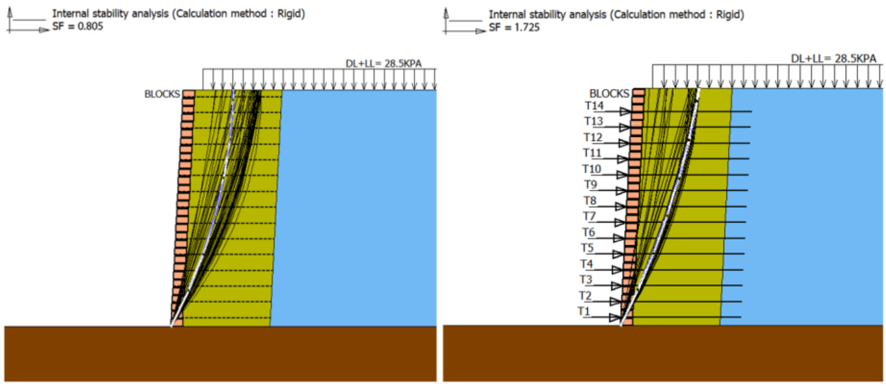

Fig. 7. Design software output showing factor of safety less than unity without concrete anchors and exceeding 1.5 with concrete anchors for Section C.

Fig. 8. Completed modular block wall in Business Bay, Dubai, U.A.E.

4 Scope for future research works

The present guidelines on SMSE or SFMSE walls from FHWA-NHI-10–024 (Berg et al. 2009) assumes an independent stable shored wall or rock face on rear side and the scope considers only the design of the narrow MSE wall portion in the front side. For the narrow MSE wall to be stable and independent from the stable shored wall or rock face, minimum length of the soil reinforcement should not be less than thirty percent of the wall height (L_{min} = 0.3H). Nevertheless, there can be instances where the available width in projects is further less than such minimum requirements. To meet such stringent site requirements, innovative approaches could be evaluated wherein the MSE wall with shorter soil reinforcements is realized by anchoring to the shored wall or stable rock face for the full height. This would involve soil nails or rock anchors at every level of the soil reinforcement to enable anchoring of soil reinforcements which in turn helps in transferring the residual tensile stresses that are not dissipated into the soil on account of shorter length of soil reinforcements. Principally, this scheme considers designing a composite wall by combining the effects and contributions of both soil nailed shoring wall or anchored rock face and the connected narrow MSE walls, such that the compound stability can be evaluated in terms of a combined system. Since such hybrid wall system in combination with soil nails or rock anchors are quite complex and not common in the industry, only limited information is available in the literature. To fully comprehend the behaviour of the composite MSE wall system under discussion, further study is required through advanced and detailed full-scale field, laboratory, analytical, and numerical works.

5 Conclusions

Through the case reference of a successfully completed project in Business Bay, Dubai, this paper attempts to present the specific design and construction details to be considered for stable feature MSE walls within extremely tight space limits. Some of the recommendations from previous research works mentioned in the literature review section were found extremely useful and adopted in the project under discussion. It is likely that future projects under similar conditions will benefit from the presented method of connecting soil MSE wall block into the stable feature behind.

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