Effect of geogrid-facing connection on MSE wall deformations induced by laterally loaded piles

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ABSTRACT: Piles have been increasingly installed in Mechanically Stabilized Earth (MSE) walls with geogrid reinforcement to support lateral loads from bridges or sound barrier walls. Laterally loaded piles can induce deformations of the MSE wall. The magnitude of the deformation depends on several factors, one of which is the geogrid-facing connection method. To investigate this effect, reduced-scale model tests with block units were conducted in the laboratory, in which mechanical and frictional connections were used. A rigid pile with a pinned connection at the bottom of the pile was adopted. Three pile offset distances to the wall facing were also considered in this study. After the construction of the wall, the pile was loaded laterally at the top of the pile by a loading system that included a pulley and weights. A digital scale was used to measure the lateral load. The wall facing deformations were measured by a photogrammetry method. The model tests clearly showed that the wall facing deformations increased with the increase of the load magnitude and decreased with the pile offset. The geogrid-facing connection affected the wall deformations at higher loads. The effect of the geogrid-facing connection became less significant when the pile offset distance became larger. The geogrid-facing connection also affected the deformation profile of the MSE wall induced by the laterally loaded pile. In general, the mechanical connection resulted in less wall deformation than the frictional connection, especially when the pile had a small offset distance.

Keywords: Connection; Deformation; Geogrid; MSE wall; Pile

1 INTRODUCTION

Mechanically Stabilized Earth (MSE) wall is one type of retaining walls that maintains its stability using layers of metallic or geosynthetic reinforcement. In general, the cost of MSE walls is lower than that of other types of retaining walls. Piles constructed within or behind an MSE wall have been increasingly used to support structures, such as sound barrier walls, traffic signs, and bridge footings (Han 2015; Han et al. 2017). The most important application of the piles within or behind the MSE wall is a mixed bridge abutment, in which the piles are used to support the bridge seat. Anderson and Brabant (2005) indicated that vertical and lateral loads are transmitted from the bridge seat to the piles. The reinforcement of the MSE wall usually resists the lateral load and minimizes part of the load from reaching the wall facing.

However, the use of mixed abutments for bridges has created challenges for design and there is no specified design procedure to follow. Several researchers have been motivated to conduct full-size tests to understand the behavior of piles within MSE walls under lateral loads. Berg et al. (2007) reported a case study to drive steel piles through the backfill and reinforcement of an MSE precast panel wall and identified its advantage over a regular approach. Pierson et al. (2009) studied the capacities and deflections of several laterally loaded piles in MSE walls at different pile offsets, which were constructed by the Kansas Department of Transportation. They concluded that an increase of the distance between the wall facing and the pile increased the lateral pile capacity and the width of the influence of the lateral load. Rollins et al. (2011) investigated the steel reinforcement and pile offset effects on the lateral resistance by conducting full-scale tests on two piles in an MSE wall. They found that if the reinforcement length was equal or greater than 1.6H (H is the wall height), the effect of pile offset from the wall could be neglected.

All the above studies were based on the MSE wall facing mechanically connected with reinforcement layers. In reality, reinforcement layers may be frictionally connected with MSE wall facing. The effect of reinforcement-facing connection on the performance of laterally loaded piles in an MSE wall has not been investigated in the past but will be discussed in this paper. The effect of reinforcement-facing connection also depends on the offset distance of piles to the wall facing. This paper will focus on the effect of geogrid-facing connection on MSE wall deformations induced by laterally loaded piles.

2 MODEL TESTS

Figure 1 shows the typical cross section of a model test with a laterally loaded pile in an MSE wall. Six model tests were conducted in this study, which include three tests with mechanical connection and three tests with frictional connections. For each connection type, piles were located at three offset distances from the piles to the wall facing. Test materials, test box, and instrumentation of these model tests are discussed below.

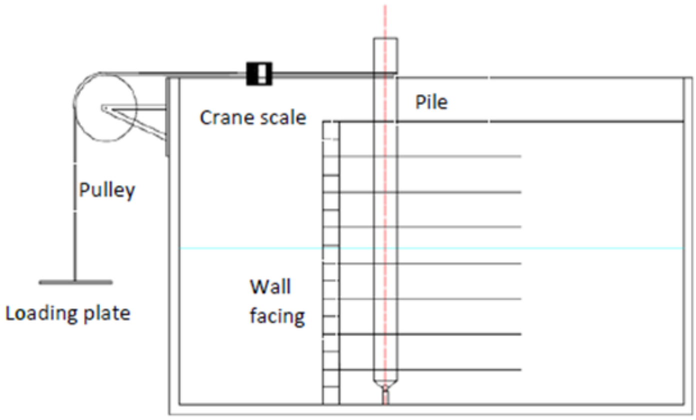


Figure 1. Typical cross section of a model test

2.1 *Test materials*

2.1.1 *Backfill soil*

Kansas River sand, poorly-graded sub-rounded sand, was used in this study and its mean grain size was 0.6 mm. The maximum dry unit weight of the sand was equal to 18.75 kN/m^3 while its minimum dry unit weight was equal to 16.29 kN/m^3. Triaxial tests were conducted to determine the peak friction angle of 40° at the relative density of 70% (Xiao et al. 2015).

2.1.2 *Facing blocks*

To model the facing of a model MSE wall, several concrete blocks were cut into small blocks with the height, length, and width of each block of 45, 50, and 50 mm, respectively, which are the same as those used by Xiao et al. (2015). Based on the height of these blocks, the vertical spacing between reinforcement layers of 90 mm (i.e., two block heights) was chosen for the tests of this study.

2.1.3 *Reinforcement*

In this study, the internal stability of the wall was maintained by using punched-down biaxial polypropylene geogrid with apertures. Per the manufacturer, the ultimate tensile strengths were equal to 12.4 kN/m in the machine direction (MD) and 19 kN/m in the cross-machine direction (XMD). Since the most common geogrid used as reinforcement in MSE walls in the practice is uniaxial geogrid, two ribs for every four ribs were cut in the MD to simulate the uniaxial geogrid. Xiao et al. (2015) found the removal of the ribs in the MD did not change the strength in the XMD.

2.1.4 *Geogrid-facing connection*

A special mechanical connector was used to provide an appropriate anchorage between the wall facing and the geogrid. This connector consisted of two metal parts. The first part was a piece of aluminum angle with two holes on the sides while the other part was an aluminum bolt that went through the angle holes and fixed the geogrid as shown in Figure 2(a). The mechanical connectors were used with each geogrid layer along the wall height. On the other hand, frictional connection was used in other tests as shown in Figure 2(b), which only depended on the friction between the wall blocks and the geogrid layers.

(a) Mechanical connection

(b) Frictional connection

Figure 2. Geogrid-facing connection

2.1.5 *Test pile*

To simulate a rigid pile seated on a hard layer, an aluminum pile of 915 mm long and 63.5 mm in outer diameter was used. This pile was connected at the base of the test box by a leveling mount as shown in Figure 1. The benefit of the leveling mount was to provide a pin connection between the model pile and the hard base of the test box. Figure 2 shows the pile, the leveling mount, and the pin connector. By considering this system, the pile can be freely rotated around the pin connection.

2.2 *Test box*

All the tests were done using a test box that had a rectangular shape as shown in Figure 1. The inside height, length, and width of this box were 830, 1400, and 400 mm, respectively. This box had a wooden base. In addition to three wooden sides, the front side was made of a 25-mm thick transparent plexiglass. Moreover, this box was divided into two halves for ease construction. The lower half was fixed to the base and the two wooden sides were fixed by long screws. An H-shape steel beam was attached above the lower part using a silicon glue. The steel beam was used as a base or frictional seat to the free upper part of the transparent plexiglass. The upper half was removable during the test and could be seated from the bottom on the H-beam and fixed from the side using clamps.

A special loading system was attached to the box to apply the lateral load on the pile as shown in Figure 1. This system consisted of pulleys, steel cables, loading weights, a crane scale, and a loading plate. The main purpose of the pulleys was to change the vertical load from the weights to a lateral load on the pile. The crane scale was used to record the load applied onto the pile after weights were added.

2.3 *Instrumentation*

A crane scale was used as a load cell in this study to measure the lateral load on the pile as shown in Figure 1. The ultimate capacity of this scale was 300 kg, and its accuracy was 0.01 g. During the test, the scale was connected to the steel cable using an S hook and fixed to the pile using a U steel connector and a bolt.

The deflections of the upper part of the pile were measured using two displacement transducers with a capacity equal to 100 mm and 50 mm. To measure the deflections of the wall facing, a special measuring system was used. This system included a measuring frame with scale papers, group of bolts with different lengths attached on wall blocks and a camera to capture the movement of the indicative bolts above the scale papers.

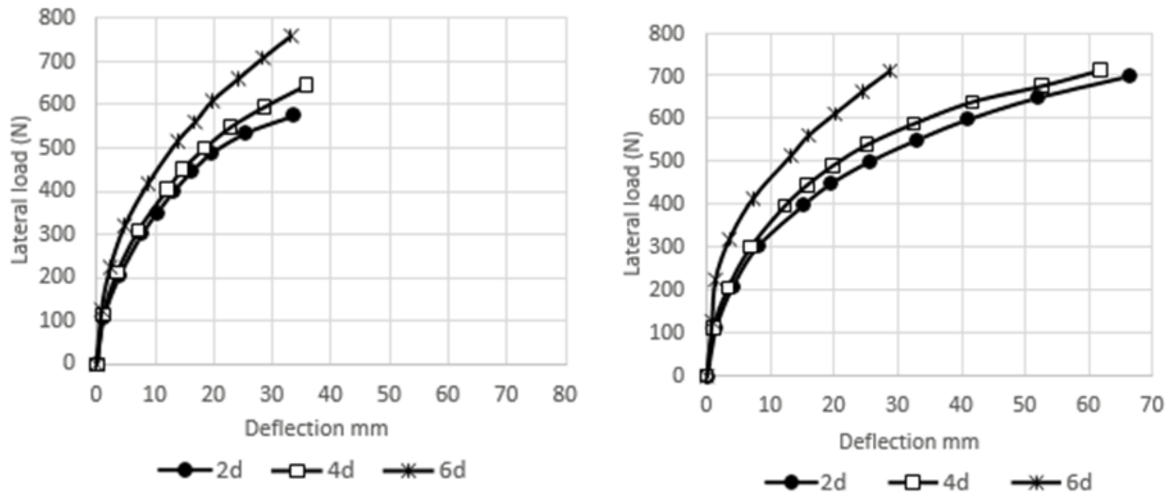
2.4 *Test Setup and loading*

All the walls tested in this study had a height of 720 mm and were constructed and compacted with eight 90-mm thick soil layers to a relative density of approximately 70%. The mass-volume control method was used to ensure this density. The pile was pre-set at a specific location. Three offset distances of piles were used in this study: 2d, 4d, and 6d (d is the pile diameter). The length of geogrid layers was 504 mm, which is 70% the wall height based on the design specifications by AASHTO (2014). All the geogrid layers were mechanically or frictionally connected to the wall facing. The area of the geogrid penetrated by the pile was removed before the placement of the geogrid. Two sets of weights were used to apply the lateral load as shown in Figure 1: (1) 10-kg-weights were applied to the pile for 10 minutes at earlier test stages and (2) 5-kg-weights were applied for 5 minutes at the later test stages to capture the failure.

3 TEST RESULTS AND DISCUSSION

3.1 *Lateral load-deflection curves of piles*

Figure 3 presents the lateral load-deflection curves of piles at different offset distances with mechanical and frictional connection between geogrid and wall facing at the elevation of 783 mm from the pin connection of the pile. It is clearly shown that an increase of the pile offset distance increased the lateral load capacity of the pile in the MSE wall at higher loads (e.g., higher than 600 N). The piles in the MSE wall with mechanical connection had higher load capacities and smaller deflections at the same higher load than those in the MSE wall with frictional connection. Broms (1964) recommended that the ultimate pile capacity should be estimated as that corresponding to 20% of the pile diameter. Table 1 lists the ultimate load capacities of all laterally loaded piles based on the criterion recommended by Broms (1964), showing that the pile offset distance had an obvious effect on the ultimate load capacity of the pile but the type of connection had little effect.



(a) Mechanical connection (b) Frictional connection

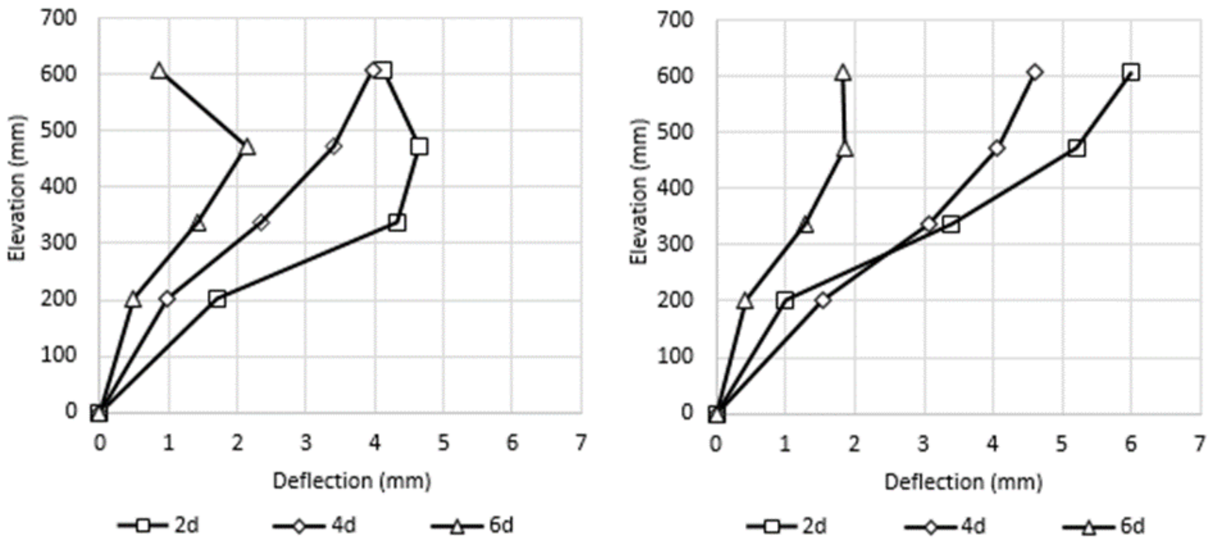
Figure 3. Lateral load-deflections of piles with different type of geogrid-facing connection

Table 1. Ultimate load capacities of laterally loaded piles in MSE walls

Connection type	Offset distance	Ultimate load capacity (N)
Mechanical	2d	368
Mechanical	4d	405
Mechanical	6d	504
Frictional	2d	391
Frictional	4d	416
Frictional	6d	494

3.2 *Deflection of wall facing*

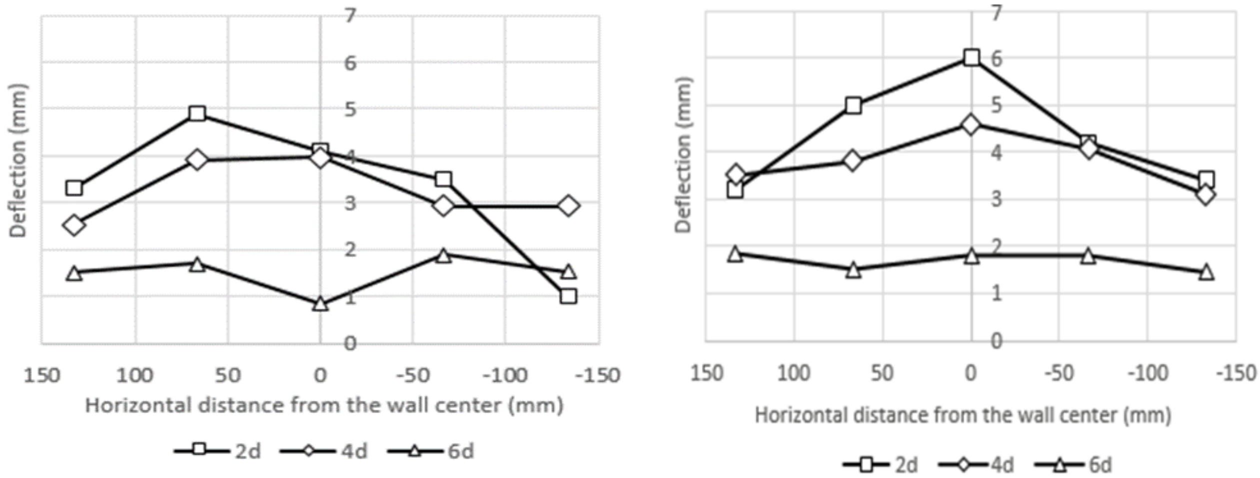
Figure 4 shows the lateral deflection profiles of wall facing along the centerline of the piles with the elevation for the walls with mechanical and frictional connection between geogrid and wall facing. This figure clearly shows that the pile at the larger offset distance had smaller wall facing deflections than that at the smaller offset distance. When the pile was located at the offset distance of 6d, the type of connection had little effect on the wall facing deflection. However, when the pile was at the smaller offset distance (especially 2d), the wall with the frictional connection had larger wall facing deflections.



(a) Mechanical connection (b) Frictional connection

Figure 4. Lateral deflection profiles of wall facing along the centerline of the piles with elevation (lateral load = 400 N)

Figure 5 shows the lateral deflection profiles of wall facing at the transverse distances from the centerline of the piles at the elevation of 0.84H (H is the wall height). It is clearly shown that the wall facing had smaller deflections when the piles had larger offset distances from the wall facing. The type of geogrid-facing connection had a more obvious effect on the lateral deflection of wall facing when the pile was located at the smaller offset distance from the wall facing (especially for 2d offset distance).



(a) Mechanical connection (b) Frictional connection

Figure 5. Lateral deflection profiles of wall facing at the transverse distances from the centerline of the piles at the same elevation (lateral load = 400 N and elevation = 0.84H)

4 CONCLUSIONS

This paper presents six laboratory model tests to investigate the effects of geogrid-facing connection on the deformations of MSE walls induced by laterally loaded piles at different offset distances from the wall facing. The following conclusions can be drawn from this study:

(1) An increase of the offset distance of the pile increased the lateral load capacity of the pile but reduced the lateral deflection of the wall facing.

(2) Mechanical connection between geogrid and facing increased the lateral load capacities of piles at large pile deflections. However, the type of geogrid-facing connection had little effect on the ultimate load capacity of the pile at the deflection corresponding to 20% pile diameter when the pile offset distance ranged from 2d to 6d (d is the diameter of the pile).

(3) The type of geogrid-facing connection had little effect on the lateral deflection of wall facing when the offset distance of the pile was equal or larger than 4d. Mechanical connection reduced the lateral deflection of wall facing as compared with frictional connection when the offset distance was equal to 2d.

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