Laboratory evaluation of deformations of geosynthetic-reinforced retaining walls subjected to footing loading

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ABSTRACT: Geosynthetic-reinforced retaining (GRR) walls have been increasingly used to support footings worldwide. Lateral displacements of wall facing and settlement of a footing on the wall under loading are key parameters to evaluate the performance of the GRR wall. This study evaluates the lateral displacements of the wall facing and the settlement of a loading plate on reduced-scale GRR wall models in the laboratory. The models were constructed in a test box under a plane strain condition in the geotechnical testing laboratory at the University of Kansas. The wall models were constructed with modular concrete block and wrapped-around facing. The dimension of each model test wall was 1.2 m long, 0.45 m wide, and 1.0 m high. Geogrid layers used as reinforcement in the models had a length of 0.7 m and vertical spacing of 0.2 m. A 0.2 m wide strip footing was placed on the top surface of each model wall with an offset distance of 0.2 m from the facing. A laser tape having an accuracy of 0.1 mm was used to measure the settlement of the loading plate and the lateral displacements of the wall facing. Two cameras were used for photogrammetry on different sides of the model to capture the wall distortion. Tape readings and photos were taken during the loading stage. Test results showed that the photogrammetry and laser tape methods measured similar wall facing deformations and footing settlements for both walls. The maximum lateral displacements measured by the laser tape and photogrammetry methods were at the depths of 0.38H (H is the wall height) and (0.25 to 0.30)H from the top of the walls with modular block and wrapped-around facing, respectively. The comparison also shows that the wall with wrapped-around facing had larger settlement and lateral wall facing displacements than the wall with modular block facing.

Keywords: Footing; Geosynthetic; Laser tape; Wall facing; Photogrammetry; Retaining Wall.

1 INTRODUCTION

A geosynthetic-reinforced soil (GRS) system is a composite fill that includes geosynthetics as horizontal reinforcement layers in the fill (Wu et al. 2006, Yasrobi et al. 2009a, Han 2015, Han et al. 2017). The GRS technology has been used in the construction of slopes, embankments, retaining walls, and shallow foundations (Wayne et al. 1998, Yasrobi et al. 2009b, Rahmaninezhad 2009, Han 2015, Jiang et al. 2016). Geosynthetic-reinforced retaining (GRR) walls are widely used for roadways and residential areas with large elevation changes throughout the world. Recently, GRR walls have been increasingly used as abutments to support shallow foundations of bridges instead of traditional deep foundations, such as piles (Lee and Wu 2004, Skinner and Rowe 2005, Kakrasul et al. 2016, Han et al. 2017, Rahmaninezhad et al. 2017). In this technology, GRR abutment walls directly support bridge beams on spread footings and approaching roadway embankments. The key parameters to evaluate the performance of GRR walls are lateral displacements of wall facing and settlement of footings on the wall under loading.

Kakrasul et al. (2016) used the photogrammetry and a laser tape to measure the movement of the facing of the limited space GRR wall and the settlement of a footing on the reduced-scale GRR wall models under loading. Xiao et al. (2016) used the photogrammetry and dial gauges to measure the settlement of a footing on the reduced-scale GRR model with modular blocks under loading and to capture the wall distortion and movement as well. Ruiken et al. (2012) and Jacobs et al. (2012) also used the photogrammetry to monitor the performance of geogrid-reinforced soil models in the laboratory. Survey method (i.e. total station) has been used to monitor the lateral displacements of the wall facing of geosynthetic reinforced retaining walls (Abu-Hejleh et al. 2001, Yoo and Jung 2004, Zornberg 2007, Stuedlein et al. 2010). Inclinometers have also been employed to monitor the lateral movement of the fill material behind the facing of geosynthetic-reinforced retaining walls (Abu-Hejleh et al. 2001, Yoo and Jung 2004, Stuedlein et al. 2010, Jiang et al. 2016). Sabermahani et al (2009) and Ehrilich et al. (2012) used displacement transducers (LVDT sensors) to measure the facing displacements and the settlement on the geosynthetic reinforced retaining structures.

The objective of this study was to evaluate the deformations of GRR walls with different types of facing subjected to footing loading in the laboratory. The settlement of the footing, the vertical deformations of the backfill, and the lateral displacements of the facing of GRR wall models subjected to footing loading were evaluated using two measurement methods: photogrammetry and laser tape techniques.

2 EXPERIMENTAL WORK

2.1 *Wall models*

Two laboratory wall models, designated as Wall 1 and Wall 2, were constructed at the geotechnical laboratory of the University of Kansas. The models were constructed inside a box with a dimension of 2.4 m long, 1.1 m high, and 0.45 m wide. Two sides of the box were transparent, which allowed for visual observation and picture-taking of wall deformations, footing settlement during the test. Two different types of facing: modular block and wrapped-around, were designed and constructed. Wall 1 had modular block facing (Figure 1) while Wall 2 had wrapped-around facing (Figure 2). The height and the length of the models were 1.0 m and 1.25 m, respectively.

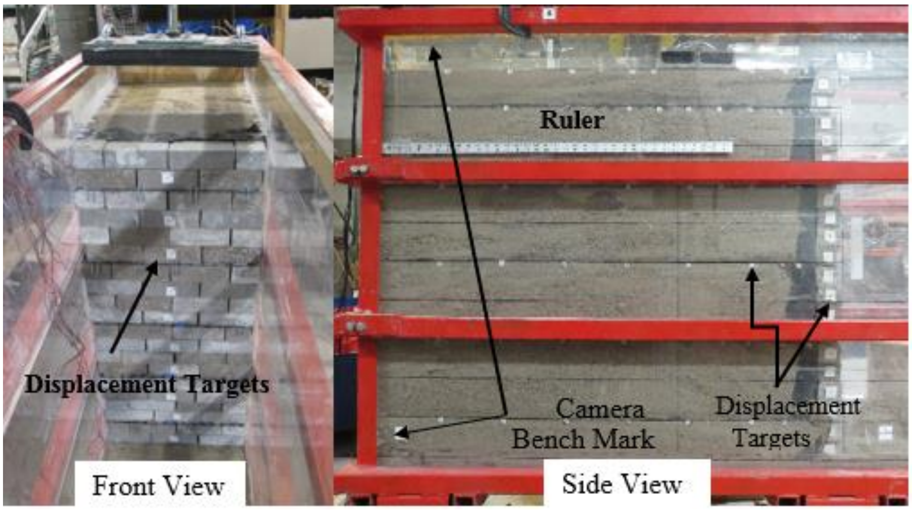

Figure 1. Wall 1

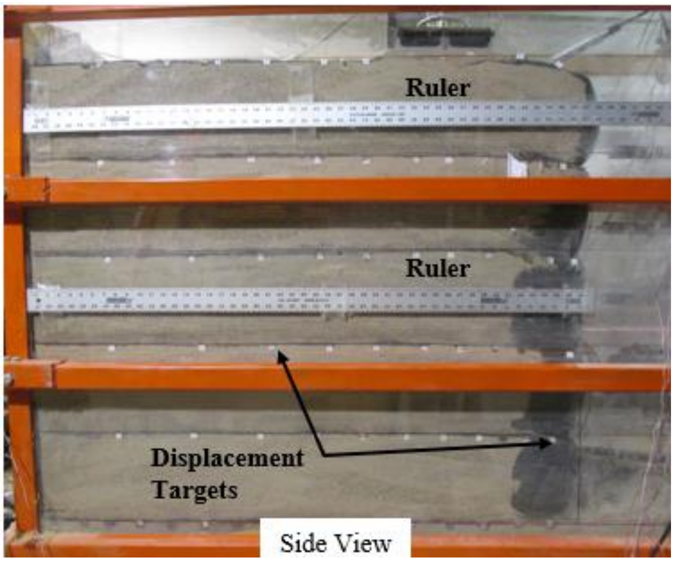

Figure 2. Wall 2

For each wall model, reflection targets and fixed benchmarks were attached on the wall and the loading plate at a number of pre-selected locations. These targets were attached along the height of the wall at the center of the wall facing (see the front view in Figure 1) and on either side of the wall facing (see the front views in Figures 1 and 2). Reflection targets were also placed on the top of each soil layer along the length of the wall (i.e. X-direction) at either side of the wall models (Figures 1 and 2). Fixed benchmarks were placed on two wall sides of the model wall and on the ground at each side of the model.

2.2 *Methods of measurements*

2.2.1 *Laser tape method*

A laser tape having an accuracy of 0.1 mm was used in this study to measure the settlement of the loading plate and the lateral displacements of the wall facing of the GRR wall models. As illustrated in Figure 3, a fixed benchmark as a place for the laser tape and a reflected mark on a target object (i.e. a model wall) are required to attain the desired measurement (i.e. the distance between the laser tape and the reflected mark). In addition to the benchmarks attached on the wall facing, a number of fixed benchmarks were attached at the end of the box along the model height and perpendicular to the benchmarks attached on the wall facing. The measurements provided by the laser tape were recorded manually because the laser tape used in this study could only store up to four successive measurements. Tape readings were taken at each loading stage during the test.

2.2.2 *Photogrammetry method*

In this study, two digital cameras were used on either side of the model to capture wall movement, lateral wall displacements, and footing settlement during the test. Photos of the wall model were taken at each loading stage and then analyzed using different software. Figure 3 shows the locations of the camera and calibration benchmarks.

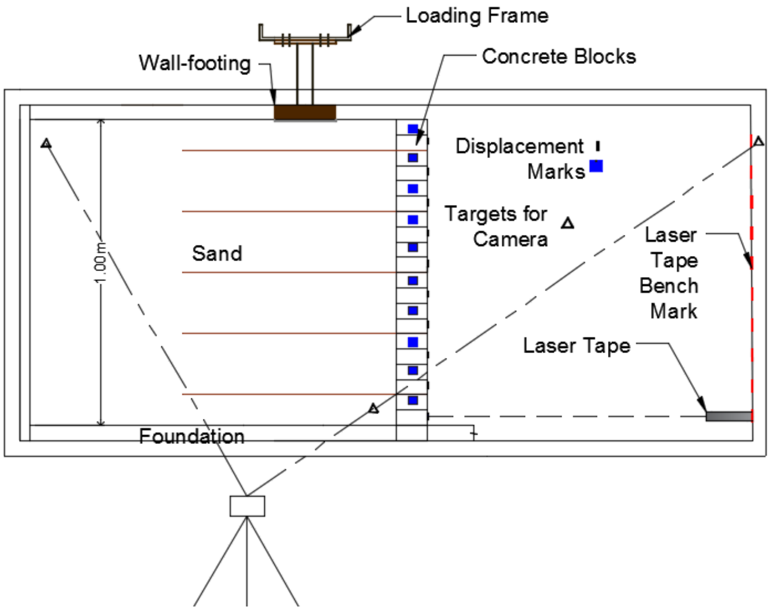

Figure 3. Camera and Laser Tape Setup

3 TEST RESULTS

3.1 *Wall 1*

Figure 4 shows the measured lateral displacements under footing loads for the Wall 1 model test. Figures 4(a) and 4(b) show the results of laser tape and photogrammetry measurements, respectively. These two measurement methods resulted in similar shapes and magnitudes of displacements of wall facing at the same load.

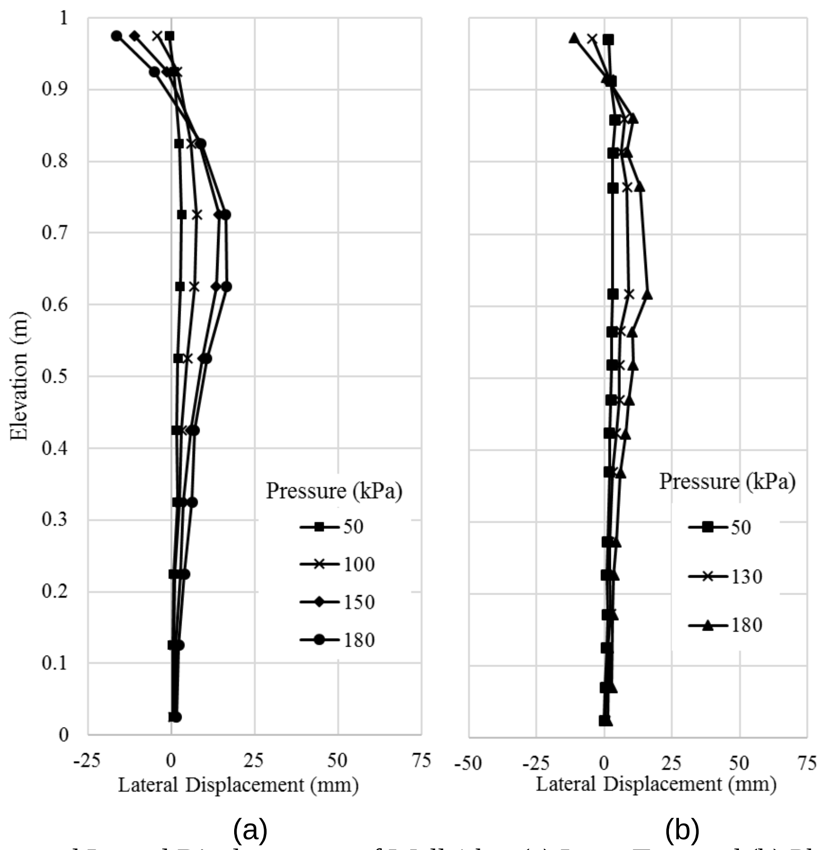

Figure 4. Measured Lateral Displacements of Wall 1 by: (a) Laser Tape and (b) Photogrammetry

Figure 4 also shows that the maximum lateral facing deformations measured by both methods occurred at the depth of approximately 0.38H (H is the wall height) from the top of the wall during loading.

Figure 5 shows the settlement profile under loading obtained from the photogrammetry technique for the Wall 1 model test. The laser tape method was not used to determine the settlement profile of the wall because it could interface with other instruments and required longer time during the test. However, the settlement of the footing plate under loading was measured through the reflected targets attached on either side of the footing, using the laser tape.

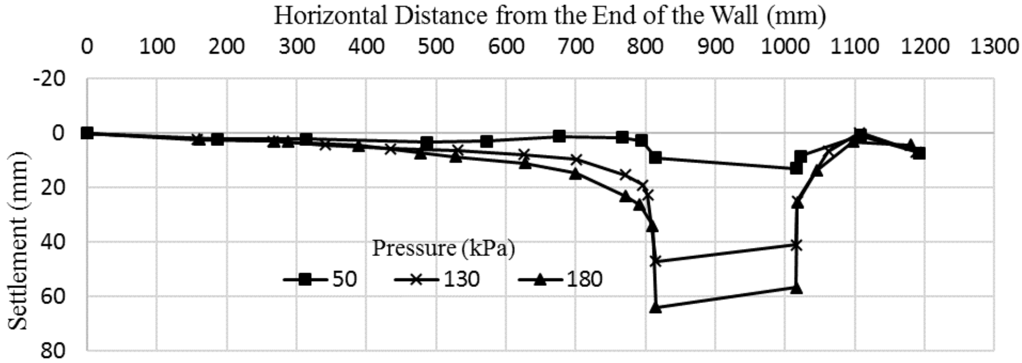

Figure 5. Settlement profiles under footing loads for Wall 1

Figure 6 presents the measured footing settlement by the laser tape and photogrammetry. This figure shows a reasonable agreement between the results of laser tape and photogrammetry measurements. However, the photogrammetry technique measured relatively larger footing settlement than the laser tape before the applied pressure was lower than 150 kPa.

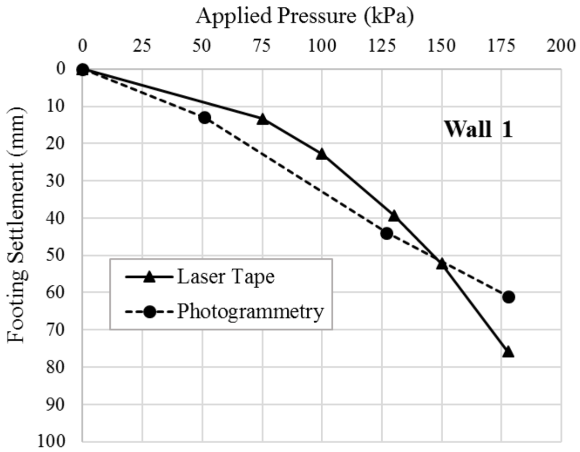

Figure 6. Pressure-Settlement Curve for Wall 1

3.2 *Wall 2*

Figure 7 shows the measured lateral displacements under footing loads for the Wall 2 model test. Figure 7(a) shows the results of the laser tape method while Figure 7(b) shows the measurements of the photogrammetry technique. The measured values of these two methods were similar. For example at the wall height of 0.7 m the laser tape measured lateral facing displacement under 180 kPa as 36 mm (Figure 7(a)) while the measured lateral facing displacement from the photogrammetry measurements (Figure 7(b)) was 34 mm. The two methods of measurement showed slightly different locations of the maximum lateral displacement. Figure 7(a) shows that the location of the maximum lateral facing displacement occurred at the depth of approximately 0.3H from the top of the wall while Figure 7 (b) shows the maximum lateral facing displacement occurred at the depth of approximately 0.25H.

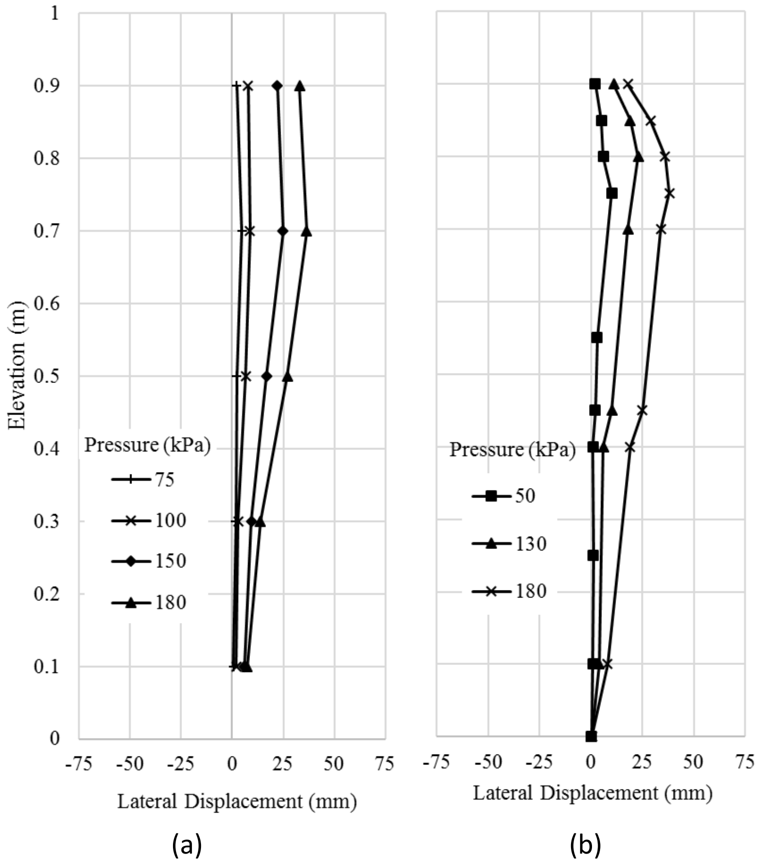

Figure 7. Measured Lateral Displacement of Wall 2 by: (a) Laser Tape and (b) Photogrammetry

The Wall 2 model had wrapped-around facing, which was relatively flexible and deformed vertically under footing loading. In contrast, the Wall 1 model had modular block facing, which was relatively rigid and hence the modular block facing did not deform vertically under footing loading. Since the wrapped-around facing deformed vertically, the laser tape method was not able to measure the lateral deformations of the wall facing of Wall 2 at the same height.

Figure 8 shows that large compression occurred in the backfill under footing based on the photogrammetry measurements. Since the wrapped-around facing of the Wall 2 was flexible, the facing deformed vertically. However, no compression was observed in the wall facing of the Wall 1 model test because the facing of the model was relatively rigid.

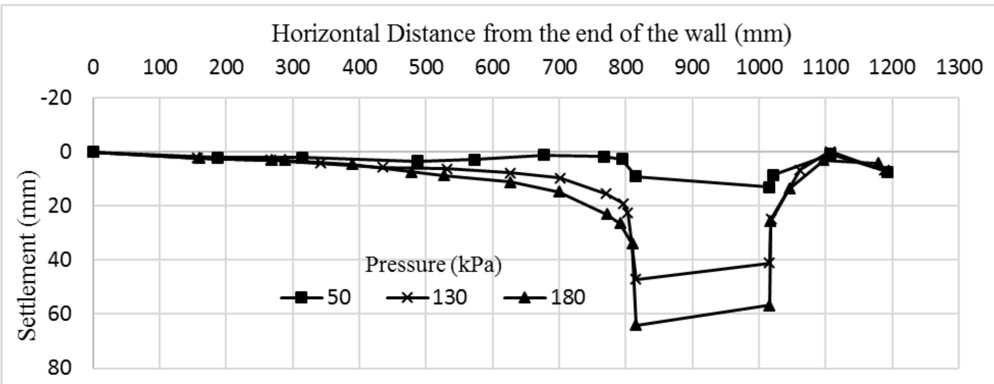

Figure 8. Settlement profiles under footing loads for Wall 2

Figure 9 shows the measured settlement of the footing under loading for the Wall 2 model using the laser tape and the photogrammetry technique. This figure shows that the photogrammetry method measured smaller footing settlement than the laser tape.

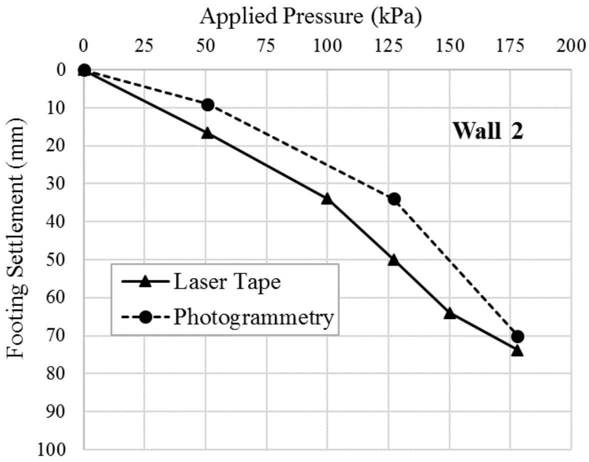

Figure 9. Pressure-Settlement Curve of Wall 2

3.3 *Comparison of lateral wall displacements and settlement profiles*

Figure 10 shows the measured lateral wall facing displacements of Wall 1 and Wall 2 under loading using the laser tape technique. This figure shows that the lateral displacements of the both walls are almost the same under the applied pressure of 100 kPa. However, the wall with wrapped-around facing (Wall 2) had much larger lateral displacements under the higher applied pressure (i.e. 180 kPa) than the wall with modular blocks. This comparison indicates that the flexible wrapped-around facing wall had larger lateral displacements than the rigid modular block facing wall under footing loading.

Figure 11 shows the settlement profiles of these two walls under the applied pressure of 180 kPa. The modular block facing (Wall 1) behaved relatively rigid so that the footing settlement was reduced as compared with the wrapped-around facing (Wall 2). For the wall with wrapped-around facing under footing loading, the settlement began from the back of the footing and became the maximum value under the footing and developed into the facing. For the walls with modular block facing, the settlement was nearly symmetric to the centerline of the footing and localized under the footing.

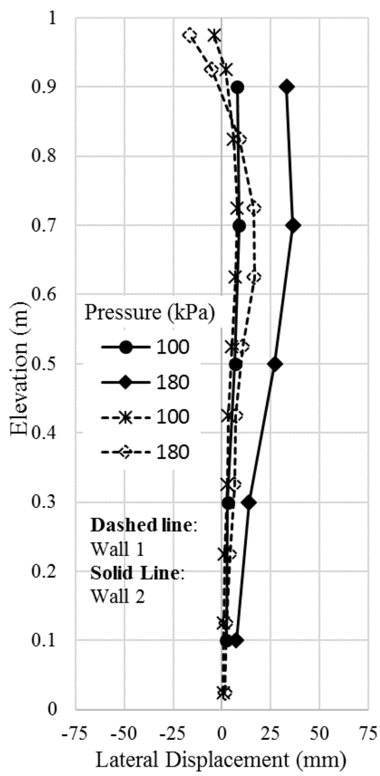

Figure 10. Comparison of Measured Lateral Displacements of Wall 1 and Wall 2

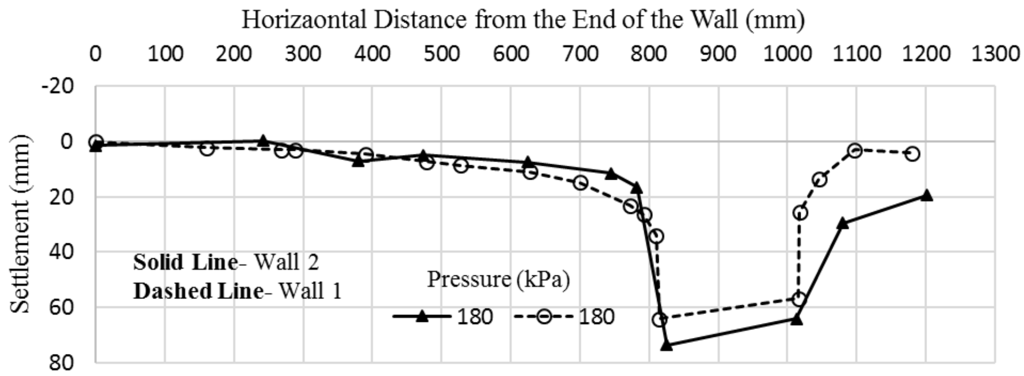

Figure 11. Comparison of Settlement profiles under Footing Loads for Wall 1 and Wall 2

4 CONCLUSIONS

In this study, photogrammetry and laser tape methods were used to measure the lateral displacements of the wall facing and the settlement of the loading plate on the geosynthetic-reinforced retaining (GRR) walls with modular block and wrapped-around facing in the laboratory.

Test results exhibited that the photogrammetry and laser tape methods measured similar wall facing displacements and footing settlements for both walls with modular block facing and wrapped-around facing.

The test results showed that both model walls behaved similarly under a low applied pressure. However, under a high applied pressure, the wall model with wrapped-around facing had larger settlement and wall facing displacement than that with modular block facing. In addition, the model with wrapped-around facing had large compression and lateral displacement occurring in the backfill under the footing and between the centerline of the footing and the wall facing. The maximum lateral displacement occurred at the depths of approximately 0.38H (H is the wall height) and (0.25 to 0.30)H from the top of the wall for the walls with modular block and wrapped-around facing, respectively.

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