International Conference on Science &
Technology: Applications in Industry
& Education (2008)(ISBN: 978-983-42204-1-9)

DEVELOPMENT OF A LABORATORY MODEL RETAINING WALL TEST FACILITY

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Abstract. *In an attempt to investigate the effectiveness of cement bound waste material geocomposite stabilised retaining wall, a laboratory model wall test facility has been developed. Detailed design of a steel rectangular model wall tank with dimension of 700 mm length x 450 mm width x 750 mm height is discussed. Scopes of works included structural stability analysis on the tank, development of instrumentation scheme and backfill preparation procedure. Upon completion of tank fabrication, repeatability testing using sand as backfill was conducted. Acceptable consistency of less than 15% difference was observed in the repeated testing.*

1. Introduction

Due to rapid development of the country, hillside developments and difficult sites involving the use of soil retaining wall has escalated. Alternative economic and safe wall design is desirable to reduce cost. One possible solution is the use of waste material (alone, in mixture with soil or bound with binder) as compressible layer or backfill behind soil retaining structure. Reported studies reveal that up to 50% reduction in lateral earth pressure can be achieved by using waste material (notably waste tire) as backfill material/backfill behind retaining structures (Humphrey et al., 1998, Tweedie et al., 1998, A Naser Abdul Ghani, 2003).

This study intends to investigate the effectiveness of cement bound waste material geocomposite as compressible layer behind retaining wall using laboratory modelling. A scale down model retaining wall was to be tested with and without the proposed geocomposite. Lateral earth pressures acting behind wall were to be measured to study the effectiveness of the geocomposite. As no model wall test facility is available in the research institution, a model test facility was developed. The model tank design, structural stability analysis of the tank, instrumentation scheme, backfill preparation procedure are discussed in this paper.

2. Literature Review

Review is conducted on past model wall studies on waste material as backfill or compressible layer. The model wall setup of these studies including instrumentation were reviewed thoroughly. McGown et al. (1987) constructed a 1 m high and 0.45 m wide wall composed of 20 facing units fixed to spring loaded shaft. The wall was placed in a rigid glass tank (1.92 m long x 0.45 m wide x 1.17 m high) and backfilled with Leighton Buzzard sand. Springs of different stiffness were used and the sand was reinforced by different number of geogrid. Load cell and displacement transducers were employed to monitor the load and wall movement. Higher lateral earth pressure and lower wall movement was observed for wall with higher spring stiffness. McGown et al. (1987) therefore suggested the use of compressible layer between the structural facing of retaining wall and the backfill to reduce lateral earth pressure acting behind wall.

Lareal et al. (1992) investigated the effectiveness of “pneusol” (a combination of old tires and soils) using a model wall tank of 1.2 m long, 0.8 m wide and 0.8 m high. Model tires were made of polyurethane foam cut into ring of 12 mm thick with internal and external diameter of 30 and 60 mm. The model tires were placed between layers of crushed sand with varying layer spacing and number of tires per layers. Two comparators were used to measure wall displacement. Active earth pressure was found to be reduced as a result of the “tire layers’’. Higher wall stability was observed with increasing number of tire per layer and decreasing sand thickness between layers.

Tweedie et al. (1998a, b) conducted laboratory model wall test using tire shred as backfill. A 4.47 m long, 4.457 m wide and 4.88 m high model wall was built with two concrete side walls and foundation. The backwall was constructed of removable timber lagging to facilitate easy backfill removal. Hinged instrumented front wall was used to facilitate rotation enabling testing at at-rest and active condition. Concrete block was used as surcharge. The effectiveness of using different sources of tire shreds as backfill was investigated. Load cell, pressure cell and inclinometer were used to measure the force, pressure and movement of the backfill respectively. It is observed that the active lateral earth pressure for the tire shred backfilled wall was 35% lower than wall with granular backfill. On the other hand, at-rest lateral earth pressure for tire shred backfilled wall was 45% lower than wall with granular backfill. Higher surcharge was also found to increase at rest-lateral earth pressure. However, reloading the tire shred has negligible effect on the at-rest lateral earth pressure.

Hazarika et al. (2002) investigated the use of ECS (highly compressible sponge) as compressible layer in a laboratory model wall of 1 m long, 0.295 m wide and 0.7 m high. The front wall and base of wall was instrumented with six and four earth pressure cells respectively. Dead weight surcharge was applied. ECS with varying thickness (1, 5, 10 and 15cm) and height (full height, partial height and wedge shape) were adopted. Pressure was reduced with the highest reduction of 35% using ECS. Thickness of ECS was found to affect reduction of pressure in which the reduction effect was loss when ECS is thicker than 10 cm.

A Naser Abdul Ghani (2003) constructed a glass model wall of 0.75 m long, 0.25 m wide and 0.6 m high. Two types of compressible layers were used, namely spongy compressible layer and cement bound shredded tire geocomposite of three different thicknesses (20, 40 and 60 mm). The front wall panel was instrumented with five earth pressure cells to measure the lateral earth pressure acting on wall. Compressible material behind the wall was found to reduce the lateral earth pressure significantly up to about 85%. Thicker geocomposite resulted in higher load reduction but the effect was loss when exceeding 60 mm. A lower geocomposite stiffness also resulted in higher load reduction.

In general, not many model wall studies have been conducted to investigate effectiveness of cement bound waste material geocomposite as compressible layer behind wall. It is observed that rectangular tank is usually used. The front panel of the tank normally acts as the model wall. Reported model tank/wall was found to vary in size and material. There seems to be no standard rule of thumb on the required size. Most model wall studies also found to monitor lateral earth pressure and wall movement.

3. Model Wall Tank Design

Figure 1 shows the details of the steel model tank. The model wall test was conducted in a steel rectangular tank with internal dimension of 732 mm high, 700 mm long, and 450 mm width. The model tank was made of 18 mm thick of steel and it is a water tight tank coated with antirust paint. The model wall was modelled in form of rigid front wall of the tank, indicating at-rest condition. The completed retaining wall model tank is as shown in Figure 2.

The front wall panel contains a total of six pressure transducers with three soil pressure transducers and three pore pressure transducers. These pressure transducers are placed paired at three different locations which located at elevations of 50 mm, 300 mm, and 550 mm. A circular opening was provided near bottom of back wall panel to enable easy sand removal upon completion of model test (Figure 2b). One of the longitudinal side walls was used to provide water draining and water level monitoring purpose as shown in Figure 2c. A valve was provided near the base of the side wall to let water in and out. A water level observation transparent pipe was also provided near the rear end of tank to facilitate water level monitoring.

Figure 3 shows a typical model test configuration. Typical model test configuration includes the front panel as the instrumented fixed wall, followed by the cement bound waste material geocomposite as compressible layer and the sand as conventional backfill behind the geocomposite. The whole tank was placed on the testing platform of a loading frame (Figure 2a). Surcharge was applied using a steel loading plate with the dimension of 440 (B) x 620 (L) x 18 (H) mm (Figure 4) attached to the loading actuator of the loading frame.

The model tank design process involved the following considerations:

- A suitable model tank dimension
- A suitable model tank material
- A satisfactory model tank structural stability

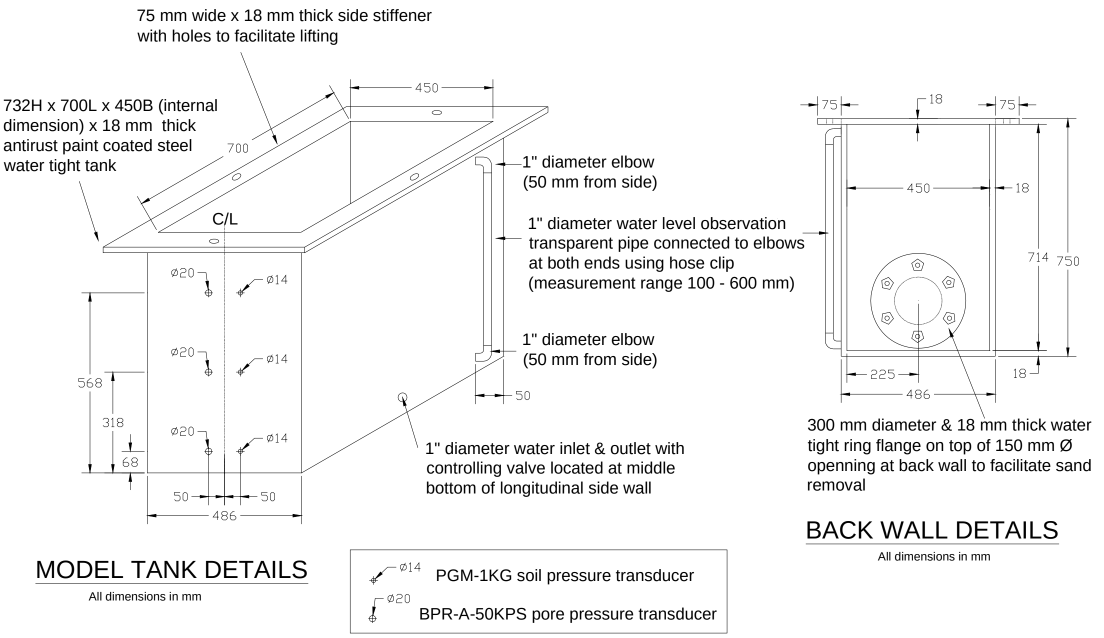

Figure 1. Model tank details

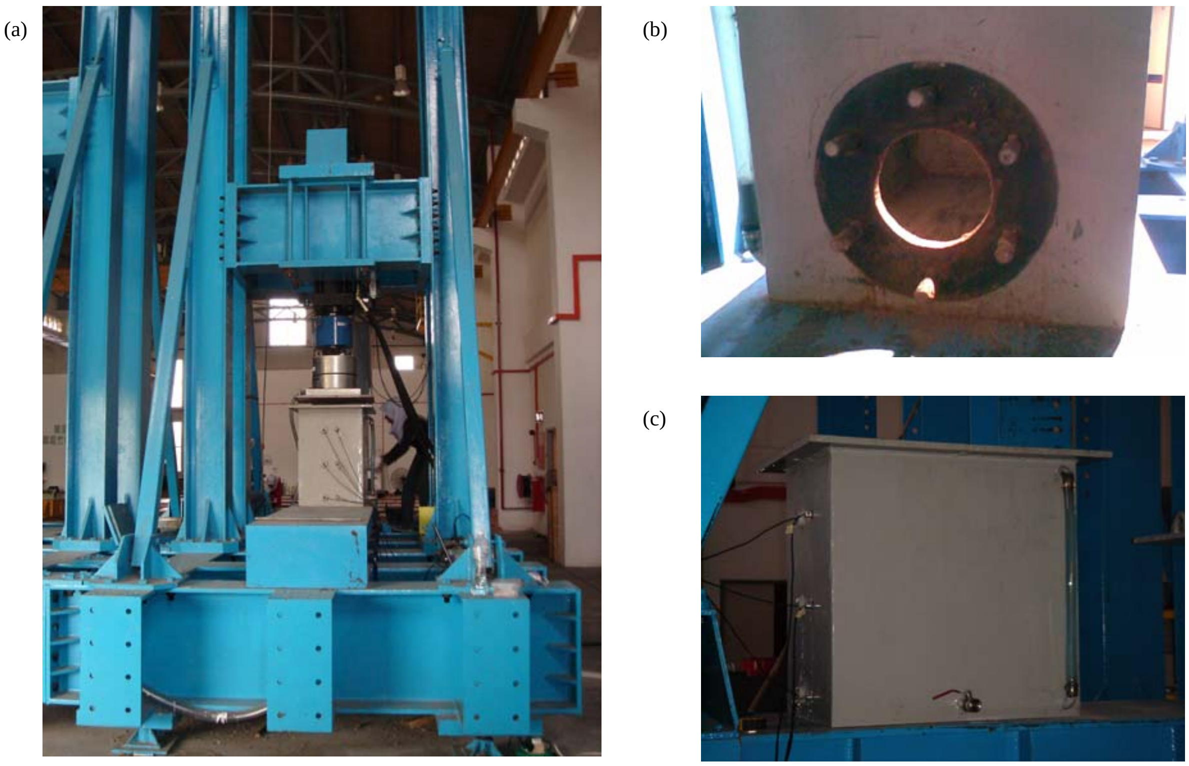

Figure 2. (a) Model tank on the load frame platform (b) circular opening to facilitate sand removal (c) water draining and monitoring details

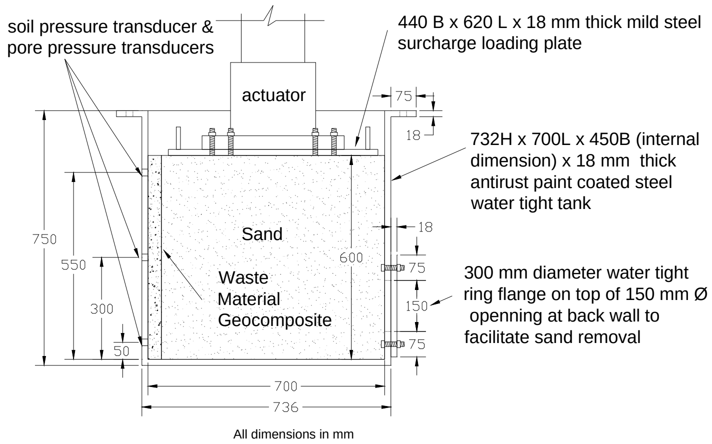

Figure 3. Typical cross section of model tank

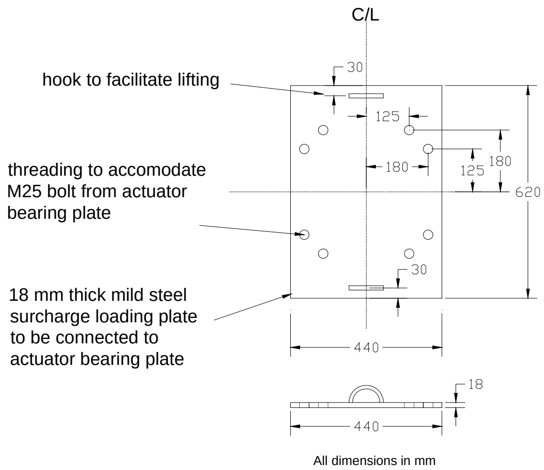

Figure 4. Surcharge plate details

3.1. Dimension of Model Wall Tank

Table 1 shows a summary of review conducted on dimensions of model tanks in reported model wall studies. The maximum, minimum and average values were computed on the height, width, length and three ratios (width/height, length/height and width/length) of the reported tanks. Based on the review, it was decided that a rectangular tank was to be fabricated and the dimension to be within the range of the reported studies. Model tank internal dimension of 732 mm height x 450 mm width x 700 mm length was selected after careful consideration. Another factor that influenced the selection of tank dimension is the availability of working space as the tank was to be placed on the loading frame platform with limited working space.

Table 1. Dimension of reported laboratory model wall tanks

References	**Height H (m)**	**Width W (m)**	**Length L (m)**	**W/H**	**L/H**	**W/L**
McGown et al. (1987)	1.10	0.46	2.00	0.42	1.82	0.23
Ahmad (1989)	1.10	0.46	2.00	0.42	1.82	0.23
Lareal et al. (1992)	0.80	0.80	1.20	1.00	1.50	0.67
Georgiadis & Anagnostopoulus (1998)	0.50	0.30	1.20	0.60	2.40	0.25
Tweedie et al. (1998a&b)	4.88	4.57	4.47	0.94	0.92	1.02
Hazarika (2002)	0.60	0.30	1.00	0.49	1.67	0.30
A Naser Abdul Ghani (2003)	0.60	0.25	0.75	0.42	1.25	0.33
Minimum	0.50	0.25	0.75	0.42	0.92	0.23
Maximum	4.88	4.57	4.47	1.00	2.40	1.02
Mean	1.37	1.02	1.80	0.61	1.62	0.43
Proposed Dimension	**0.732**	**0.45**	**0.70**	**0.61**	**0.96**	**0.64**

3.2. Material of Model Wall Tank

Steel was selected as the model tank material as it is more durable and higher in bending resistance. Initially perspex tank was preferred to enable observation of water level and also failure pattern. However, perspex tank is more susceptible to wall buckling due to high lateral earth pressure caused by a fully submerged sand and application of surcharge. In addition, perspex tank also required more care in lifting and handling as the testing platform is above floor level.

3.3. Structural Stability of Model Wall Tank

The structural stability of the model tank was analysed using structural engineering software STAAD Pro. 3D finite element model of tank was generated using plate elements and analysis of plate stresses was conducted for the determination of suitable tank and weld thickness. The loading acting on the top and bottom of the four inner wall of the tank was first computed using Rankine's theory of lateral earth pressure. The following worst loading condition was considered:

- Full sand height of 600 mm (friction angle of 34.5 degree obtained from direct shear test and sand average density of 1.576 kN/m^3)
- Full surcharge of 20 kPa
- Full water height of 600 mm

Based on the above assumption, top loading of approximately 8.67 kPa and bottom loading of 17.65 kPa was obtained. Subsequently, finite element mesh was generated on a tank with dimension of 600 mm height x 450 mm width x 700 mm length as shown in Figure 6. Maximum sand height of 600 mm instead of full wall height of 732 mm was considered in the analysis to avoid over-design and unnecessary wastage/cost. The main structural consideration is on the bending of plate and the critical stresses at joint area for effective weld design. With the graphical output on bending moments in x, y and xy direction as shown in Figure 6, it is observed that the maximum bending moment of 0.291 kNm/m was registered in y-direction near the middle top edge of the longitudinal plate section. Based on this maximum bending moment of 0.291 kNm/m, 18 mm plate thickness and weld thickness of 12 mm was recommended. To further reinforced the model tank, side flanges were provided on all four top edges of wall.

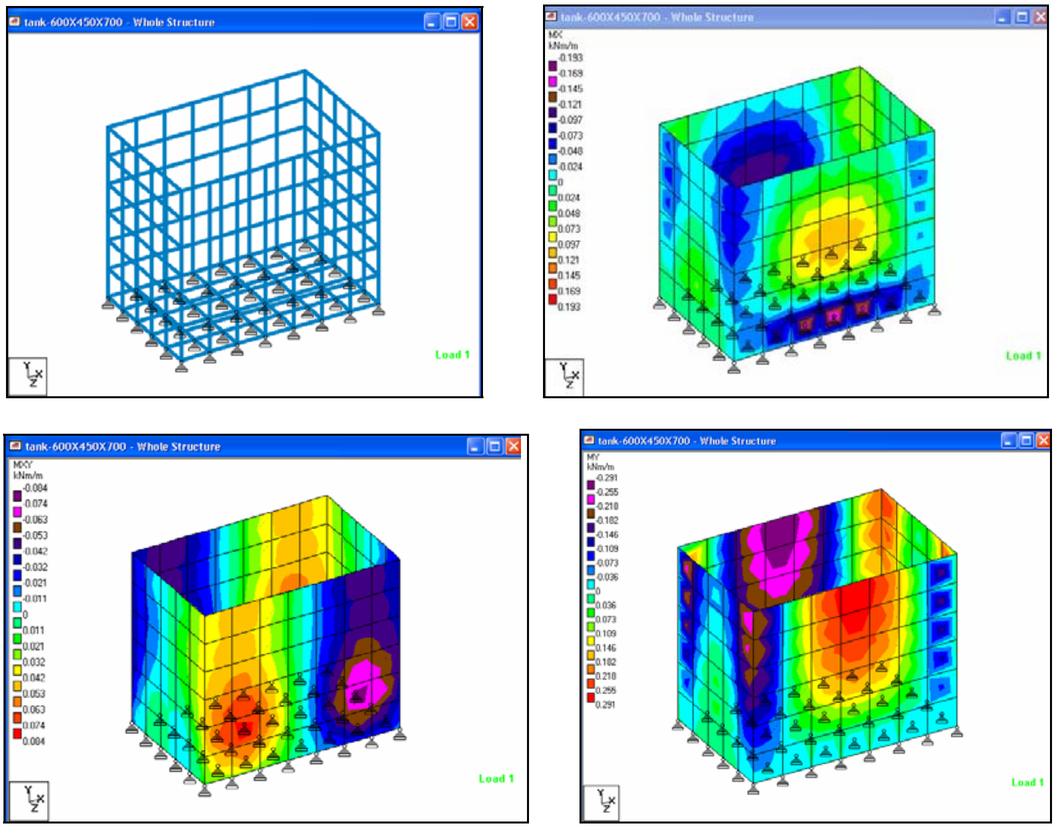

Figure 6. Finite element modeling of the model tank using STAAD Pro (meshing and bending moments on wall)

4. Instrumentation Scheme

As this study intends to measure effectiveness of compressible layer by means of lateral earth pressure reduction, three soil pressure transducers and pore pressure transducers were placed in pair to measure the lateral earth pressure and hydrostatic pressure acting on top, middle and bottom of the model wall. These pressure transducers are located at elevations of 50 mm, 300 mm, and 550 mm of the front model wall panel. The soil pressure transducers used in this study were Kyowa PGM-1KG with rated capacity of 100 kPa. On the other hand, the pore pressure transducers used in this study were Kyowa BPR-A-50KPS with rated capacity of 50 kPa. Both pressure transducers were calibrated simultaneously using the model tank that was progressively filled with water. Two data logging devices were employed; namely Kyowa UCAM-70A and IPC Global HJS-1000. Kyowa UCAM-70A was a portable data logger that was used to measure the data generated by the soil pressure and pore pressure transducers. IPC Global HJS-1000 was the control unit that was attached to the load frame. It was used to control the load frame in form of application, monitoring and logging of surcharge.

5. Backfill Preparation Procedure

A standard backfill preparation procedure was devised in order to ensure consistency in test result. A steel sand rainer was design and fabricated as shown in Figure 7a. The steel rainer was used to rain the sand into the model tank at uniform density. A transparent hose of 25 mm diameter and 2 m length was connected to the opening of the rainer to rain the sand into the tank as shown in Figure 7b. The sand rainer was raised 1.9 m above the platform level at a fixed location and progressively raised at every 100 mm interval to ensure a consistent sand density. Two density pots were placed at two constant positions at the three transducer levels (depth of 0.05, 0.30 and 0.55 m from base) for consistency checking in density as shown in Figure 7c. An overall average sand density of 1.576 g/cm^3 was achieved with less than 5% difference for all model tests conducted.

(a)

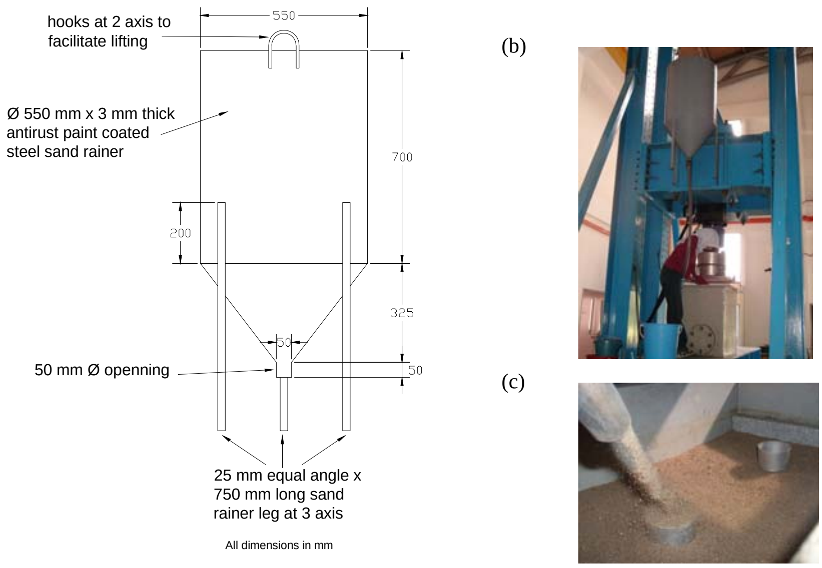

Figure 7. (a) Sand rainer details (b) Sand raining in process (c) checking of sand density using two density pots

6. Repeatability of Model Wall Test

Upon completion of the model wall tank, model wall test using sand as backfill was conducted to provide control data. To investigate the repeatability and consistency of test result, two identical tests were conducted. Figure 8 shows the lateral earth pressure distribution for model wall backfilled with 600 mm high sand that was fully submerged under water. Theoretical lateral earth pressure value of ($K_o\gamma H + \gamma_w H$) was also computed using Rankine's lateral earth pressure theory. Coefficient of lateral earth pressure at rest, K_o was determined using Jaky's equation ($K_o = 1 - \sin \phi$) and friction angle of sand (34.50°) was obtained from direct shear test. Average sand unit weight, γ of 15.46 kN/m^3 was adopted based on density measured during sand raining. It is observed that the measured values were within the range of the theoretical value. To examine the repeatability of the model test results, the difference between the identical test pair was computed. Acceptable repeatability was observed with the highest computed difference of 14.16%.

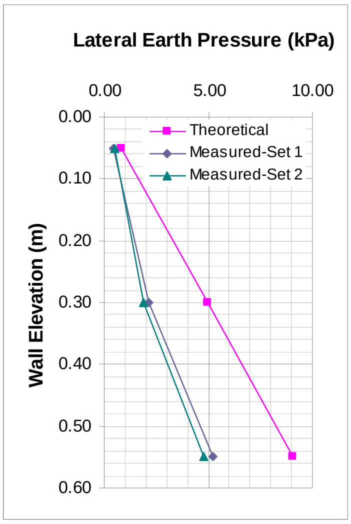

Figure 8. Lateral earth pressure distributions behind the sand backfilled model wall

7. Conclusion

A model tank has been designed and fabricated to investigate the effectiveness of cement bound waste material geocomposite as compressible layer behind retaining wall. The rectangular tank was built in steel with internal dimension of 732 mm height x 450 mm width x 700 mm. Finite element analyses using STAAD Pro was conducted to examine structural stability of tank and wall thickness of 18 mm was proposed to prevent wall bending. Calibrated soil pressure transducers and pore pressure transducers were installed in pair at top, middle and bottom of wall to measure the lateral earth pressure and hydrostatic pressure behind wall at these locations. A backfill (sand) preparation procedure was developed to ensure consistent sand density. A sand rainer was designed and fabricated to rain the sand from a fixed height into the tank to achieve a uniform sand density. Upon completion of model wall tank fabrication, repeated testing using sand as backfill was conducted. The measured lateral earth pressures were within the range of theoretical values and acceptable repeatability was observed with the highest computed difference of 14.16% between the two data sets.

Acknowledgements

The authors thank the Ministry of Higher Education, Malaysia (Fundamental Research Grant Scheme) for providing funding for this study.

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