Journal of Materials and Engineering Structures

Research Paper

Performance of a Modified Shear Box Apparatus for Full Scale Laboratory Study of Segmental Retaining Wall Units

Md Zahidul Islam Bhuiyan [a]****, Faisal Hj. Ali*** [b]***, Firas A. Salman*** [c]

[a] *Liang United Engineering Studio, 47301 Petaling Jaya, Selangor, Malaysia*

[b] *Department of Civil Engineering, National Defense University of Malaysia, 57000 Kuala Lumpur, Malaysia*

[c] *Eliot Sinclair & Partners, Christchurch, New Zealand*

A R T I C L E I N F O

Article history :

Received 16 November 2014

Revised 28 April 2015

Accepted 30 April 2015

Keywords:

Shear box apparatus

Segmental concrete blocks

Interface shear

Retaining wall

A B S T R A C T

The paper outlines the performance of a modified large scale shear box apparatus, which is mainly used to execute full scale laboratory study of segmental retaining walls. A typical apparatus has already been adopted by the current ASTM and NCMA test protocols and by literature studying of those test protocols, it is found that protocols recommend a fixed vertical actuator with roller or airbag configuration as a proposed vertical loading assembly. Previous research study demonstrated that vertical loading arrangement greatly influences the interface shear capacity of block systems and fixed vertical actuator with flexible airbag shows better loading arrangement for the blocks which have dilatant behavior. However, airbag arrangement is strenuous and time-consuming loading assembly compared to fixed vertical actuator which increases normal load with shear displacement due to bending of vertical actuator locked with the top block during shear loading. For the drawbacks of fixed vertical loading arrangement, the apparatus used in this study was fully redesigned and modified in terms of normal loading arrangement specially. A moveable vertical loading assembly is used in the modified apparatus which allows the piston movement with the top blocks during shear testing. The results outlined in this paper report that normal load remains constant over the period of shear testing for a wide range of surcharge loading. It could easily be concluded that the modified apparatus might be a better alternative to the existing apparatus used in the test protocols.

1 Introduction

A large-scale direct shear box apparatus is mainly designed to evaluate the performance parameters (shear and connection strength) of segmental block systems using a full scale laboratory study and these parameters have influence on facing stability as well as internal stability of SRW systems [1].

* *Corresponding author. Tel.: +6016 2881087.*
E-mail address: mdzibhuiyan@gmail.com

RESEARCH REVIEW of Sciences and Technologies

e-ISSN: 2170-127X, © Mouloud Mammeri University of Tizi-Ouzou, Algeria

A typical test apparatus for full scale laboratory study of segmental retaining wall (SRW) units was designed and developed by Bathurst and Simac [2] and later on adopted in ASTM and NCMA standard guidelines.

Nowadays, a variety of blocks is available and applied with different types of connection systems in segmental retaining wall constructions. To find out the performance parameters according to ASTM and NCMA protocols, it is necessary to design and develop a suitable test facility which is well-suited for all types of block systems, and effective enough to simulate actual field condition. While the apparatus is not a standard one, it could be modified and redesigned according to the user's block systems as well as available technologies [3-4]. However, the performance tests need to be done according to the standard guidelines' requirements [5-8]. Reviewing a comprehensive literature study of the existing test protocols [5-9], it was found that protocols recommend a fixed vertical actuator with roller or airbag arrangement (Fig. 1). Bathurst et al. [10] reported that normal loading arrangement greatly influences the performance parameters of different block systems. From the investigation, it was concluded that fixed vertical actuator with flexible airbag arrangement provides better loading arrangement that keeps the normal load constant over the period of shear testing although the use of flexible airbag is strenuous and time-consuming test arrangement.

In this investigation, a modified apparatus with a moveable vertical loading assembly was used for full scale laboratory study of interface shear tests of I-Block system (Fig. 2). A series of interface shear tests was executed to plot shear force-displacement relationships for comparing the performance of moveable vertical loading assembly under different surcharge levels against previously developed fixed vertical loading arrangement.

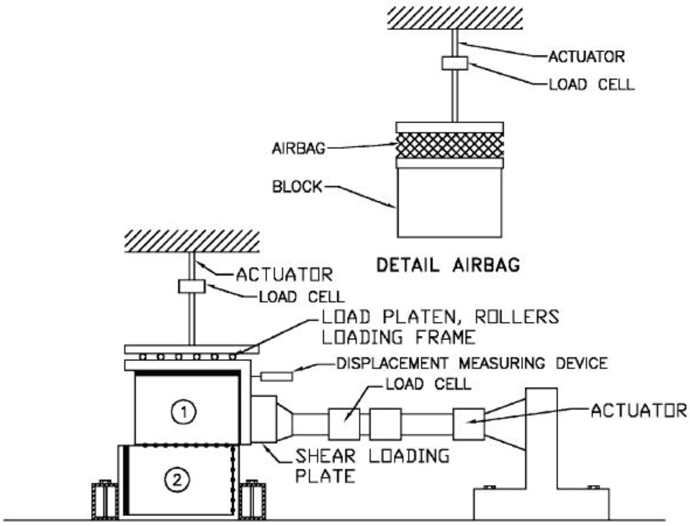


Fig. 1 – Interface shear test apparatus with fixed vertical actuator (not in scale) [5]

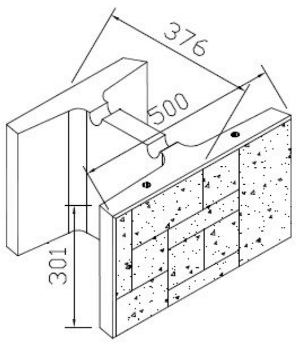


Fig. 2 – Schematic of the innovated I-Block (dimensions in mm)

2 Test methodology

2.1 Apparatus

The apparatus was designed and developed at University of Malaya to satisfy the ASTM and NCMA criteria for full-scale laboratory testing of segmental concrete units. It is a modified large-scale direct shear box apparatus with connection testing facility for modular block units [11]. It mainly consists of loading frame, hydraulic actuators, and a fabricated electric hydraulic pump (Fig. 3).

Loading frame is the skeleton (frame structure) of the apparatus that provides a platform for testing setup and support to other assemblies such as actuators, platens, clamping device and guide frame etc. The width of the platform is about 2000 mm that supports a long base course of segmental units for shear testing, and connection testing as well. The frame is capable to withstand high reaction forces developed by the vertical and horizontal actuators/pistons, and its capacity is approximately 600 kN for normal (surcharge) and horizontal loads (shear or pullout).

As the vertical and horizontal actuators, double-acting hydraulic cylinders are used. Hydraulic cylinder is mechanical actuator that converts fluid energy into directional force through linear movement of piston. Double-acting hydraulic cylinder provides both pull and push loads, and also better for fast retraction. The vertical and horizontal actuators are capable of applying surcharge load and push/pull out force respectively and simultaneously. The vertical actuator is mounted with the loading frame using steel rollers to allow movement of topmost block layer during shear testing as illustrated clearly in Fig. 3. The cylinder bore diameters for vertical and horizontal actuators are 150 and 180 mm respectively, which are capable of applying 129 and 295 mm stroke to expedite test setup.

The electric pump system was fabricated locally using available hydraulic accessories in Malaysia. Pumps are mechanical devices which move fluid by suction or pressure. Two gear pumps of 0.98 and 6.55 cm^3/rev displacement capacities are selected for vertical and horizontal hydraulic jacks respectively. Two pumps are combined with each other according to manufacturer's design and then connected with the shaft of an induction motor of 2.2 kW capacity. Pumps and motor are installed over the reservoir tank, which is filled up using high viscous hydraulic oil. High pressure (27 MPa) hoses made of synthetic nitrile rubber liner and reinforced by two braids of high tensile steel wire are chosen for hydraulic systems, which transport high viscous pressurized fluid in whole hydraulic circuit. Two main parts of the apparatus; actuators and pump system are linked each other by means of four hoses. The ends of the hoses are connected with the cylinders and pump system using couplers (male-female) and manifolds. The electric pump system can easily be dismantled from the cylinders by unplugging the male and female couplers and therefore the pump system can easily be set in any convenient place according to the apparatus installment (Fig. 3).

Two 4-way directional control valves with pressure adjustable knob are mounted in the pump system with a view to controlling the direction of hydraulic fluid easily in the double-acting system (cylinders). The directional valves for the vertical and horizontal actuators are operated manually using lever arm. To monitor the pressure reading of the hydraulic system two pressure gauges are also attached with the advance ports of manifold (Fig. 4). A flow regulator valve of controlling maximum regulated flow 1500 cm^3/min is attached to control recommended displacement 1 mm/min and 20 mm/min for shear and connection test, respectively. Another flow controlled valve (like as horizontal one) of regulated flow 6000 cm^3/min (max.) is used to control the plunger movement of the vertical actuator because of speedy movement of plunger of the vertical actuator. The vertical flow control valve installed to apply normal load on the blocks at a nominal speed as well as fast restoration of the cylinder. Details of hydraulic system of the electric pump are sketched in Fig. 4.

2.2 Interface shear test

A general test setup for interface shear tests with I-Block system is illustrated in Fig. 5. According to the test protocols [5, 7], two layers/courses of modular block units were used for conducting interface shear tests. The bottom course consisting of two I-Blocks was placed on platform to coincide running joint with the centerline of the horizontal actuator and braced laterally against restraining plate. The back of bottom course was fixed by using a back support beam, which was bolted with platform to prevent bending of bottom course during shear testing. A single I-Block was placed centrally over the running joint formed by the two underlying units to simulate the staggered construction procedure used in the field. A photograph of typical setup for interface shear testing is shown in Fig. 3.

Surcharge/Normal load was imposed by vertical actuator over the top block through two steps. Firstly, the piston of vertical actuator was moved down slowly to the top block and the downward displacement of the piston was physically controlled by a flow regulator valve mounted in the hydraulic pump system (Fig. 4). Secondly, whenever, the vertical loading platen came in contact with top block then pressure adjustable knob was used to control the surcharge load imposed for every interface shear test. This surcharge load imposed over the top block was maintained manually from zero to a desired level, which was simulated an equivalent height of stacked blocks.

Because of using stiff rubber-mat over the top block, it might be expected that almost 100% of applied normal load directly transferred through concrete block frame. The shear/horizontal load was applied against the top course and immediately above the shear interface to minimize moment loading at a constant rate of 1 mm/min of horizontal piston [9]. The constant rate of horizontal actuator was maintained by another flow regulator valve mounted in the hydraulic pump system for the horizontal actuator. A steel plate with a gummed stiff rubber-mat was attached to geosynthetic loading clamp (Fig. 5) to concentrate shearing load only over the centrally installed top block. A horizontal seating load of 0.22 kN was applied to the top block to ensure close fitting of the block systems and after that the load and displacement devices were set to zero [7].

For each normal load level, shear force-displacement relationship was plotted to compare the variation of the applied loads against shear displacement. Shear force (ultimate) was calculated using equation 1 as follows:

Ultimate shear force, $$V_p = F_p / L_i \qquad (1)$$

Where:

V_p = Ultimate (peak) shear force (kN/m)

F_p = Ultimate (Peak) shearing load (kN)

L_i = Total length of top segmental concrete unit over the interface surface

3 Instrumentation and precision

The rate of displacement (mm/min) of horizontal actuator was calibrated against flow control valve using linear variable displacement transducers (LVDTs). Two displacement transducers of 50 mm capacity with a high level of accuracy (0.001 mm) were used to monitor shear displacement during interface shear testing. To get precise pressure reading from the actuators, two pressure transducers of 25 MPa capacities were mounted with the actuators and the precision level were upto 0.01 MPa.

A high capacity tension and compression load cell was used to calibrate the cylinders against pressure transducers and the accuracy level of load cell was upto 0.1 kN. All measurements were recorded at 10 seconds time interval in a high resolution data logger during testing.

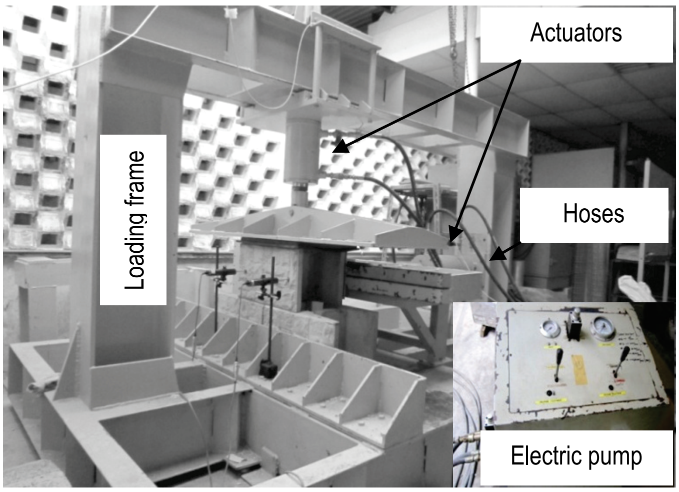


Fig. 3 – Photograph of test apparatus showing rubber mat, blocks and LVDTs

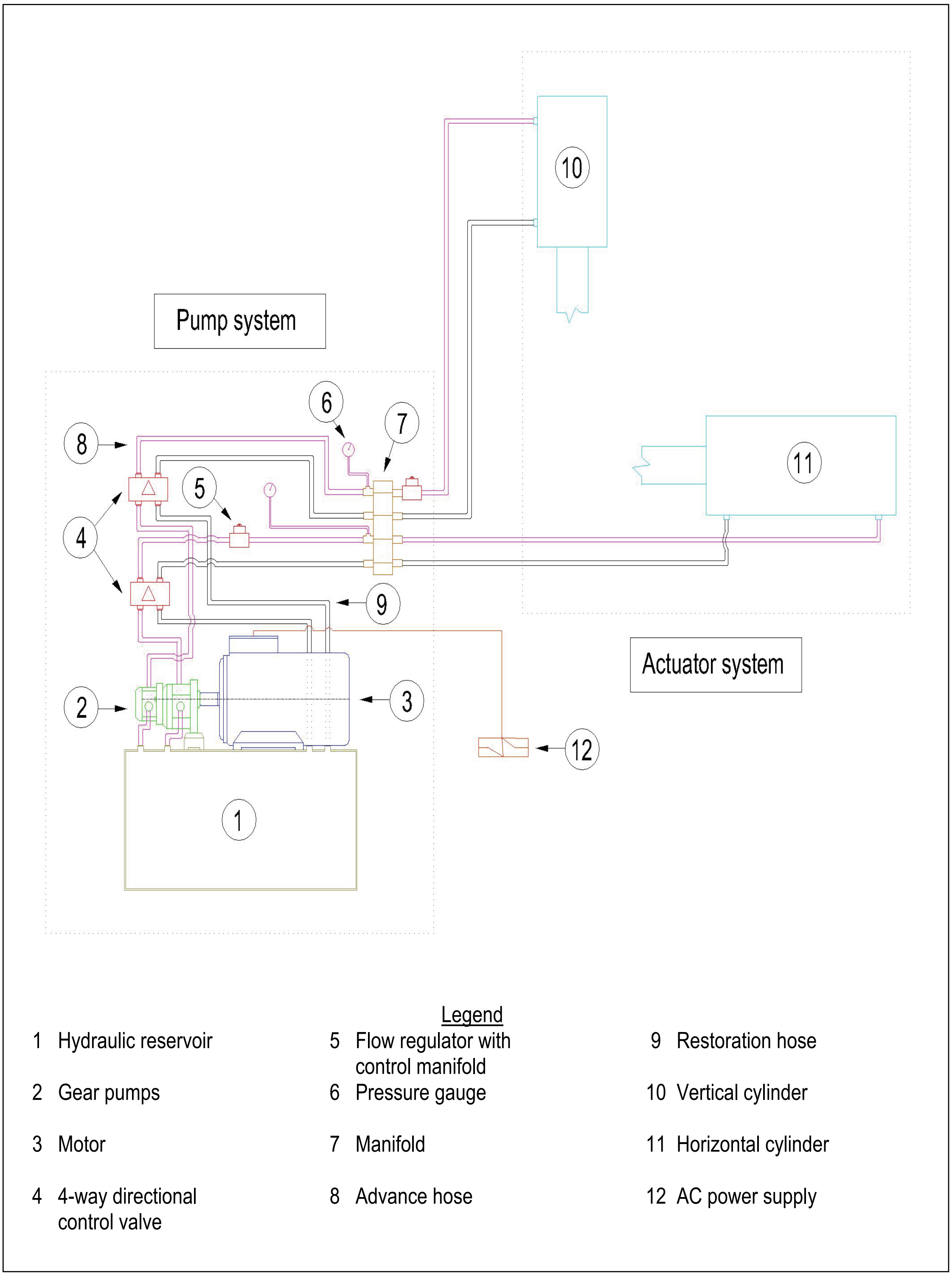


Fig. 4 – Hydraulic circuit of pump

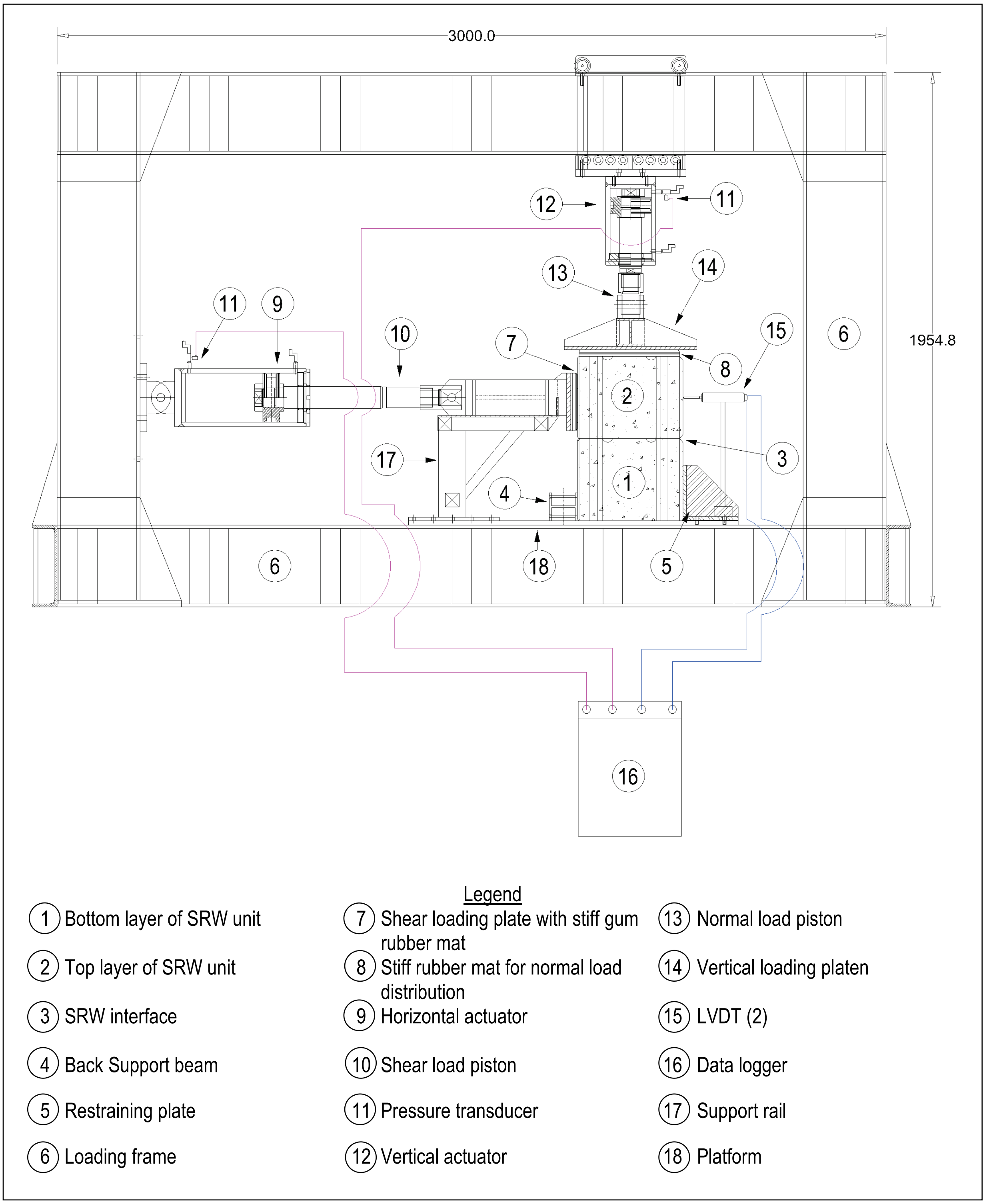


Fig. 5 – Generic interface shear testing arrangement (dimensions in mm)

4 Result and discussions

The results of interface shear tests were compared with fixed vertical piston as reported by Bathurst et al. [10]. Shear force-displacement graphs were plotted along with different normal forces to evaluate the fluctuation of surcharge loads against shear displacements and the frictional performance of the segmental concrete units under four normal loading conditions.

Bathurst et al. [10] found out that fixed vertical actuator/piston arrangement ameliorates normal load with shear displacement rather than becoming constant. This happens due to bending of vertical piston with the advancement of top block that causes locking of the piston with top block and hence increase normal load significantly (Fig. 6). From the Fig. 6, it is seen that the corresponding shear force also goes up gradually with the displacement rather than reaching steady state condition. As a result, the shear strength might be overestimated than actual/true values. However, in the modified test apparatus, a moveable vertical actuator was mounted with loading frame owing to the drawbacks of fixed vertical actuator.

Figs. 7-10 compare the frictional behavior of hollow modular blocks under different normal loads and more importantly also evaluate the normal load response of moveable vertical actuator against shear displacement for those surcharge loads. From the Figs. 7-10, it is clearly seen that normal load variation is almost constant over the period of shear testing although some very little and insignificant fluctuations can be seen in Fig. 10, which might easily be ignored compared to Fig. 6. This may results due to the presence of steel rollers in between the vertical piston and loading frame (Fig. 5), which allows the piston to move horizontally with the mobilization of top block without any bending against shear displacement. As a result, normal loads remain constant and steady throughout interface shear testing. Figs. 7 and 8 demonstrate that the shear forces rise up sharply at the beginning of shear mobilization and reach a peak value after a significant amount of advancement, and hence become plateau after fully mobilization of frictional resistance. Fig. 8 shows a sudden fall of shear resistance which happens due to spalling cracks at top block's interface (Fig.11 (a)), after that shear force increases again and reach its peak value. On the other hand, Fig. 10 illustrates the significant rises and falls in shear force throughout displacement, resulting in saw-teeth shear force curves than the plots against low surcharge loads (Figs. 7-9). This may be attributable to force concentration at the concrete-to-concrete interface which expedites propagation of shear cracks easily at the blocks' webs under high normal load (Fig. 11(b)) although the net compressive strength of I-Block is much higher [12].

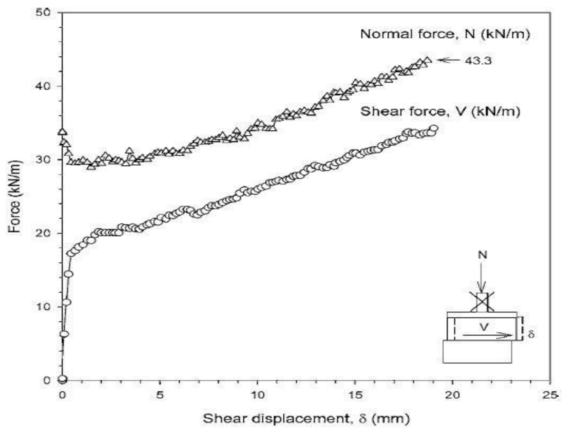


Fig. 6 – Normal load response against shear displacement for fixed vertical loading arrangement [11]

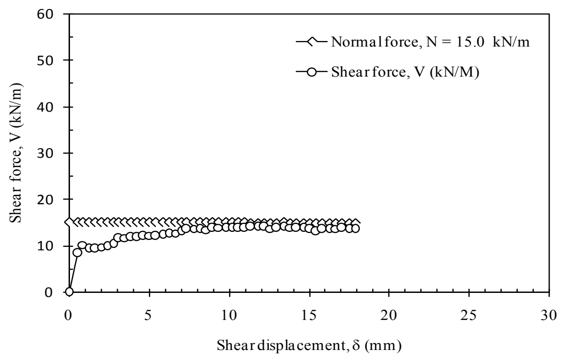


Fig. 7 – Shear force versus displacement

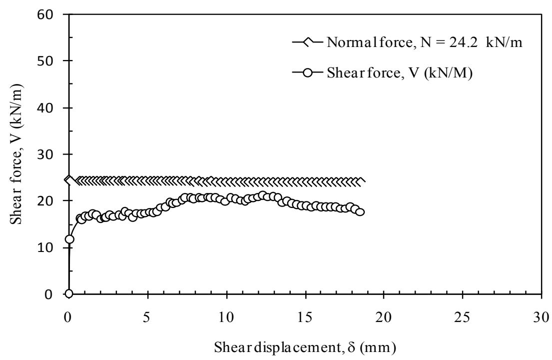


Fig. 8 – Shear force versus displacement

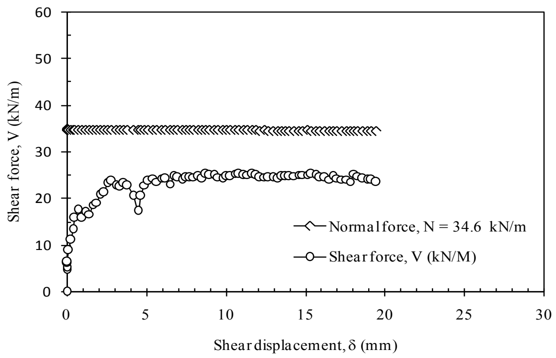


Fig. 9 – Shear force versus displacement

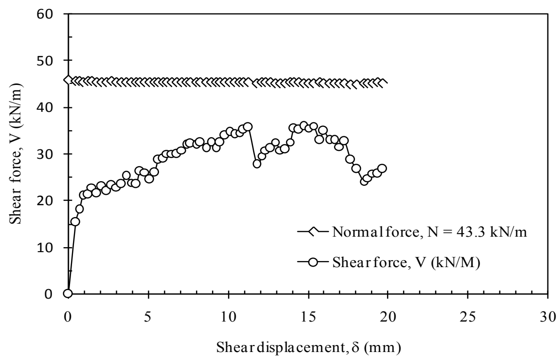
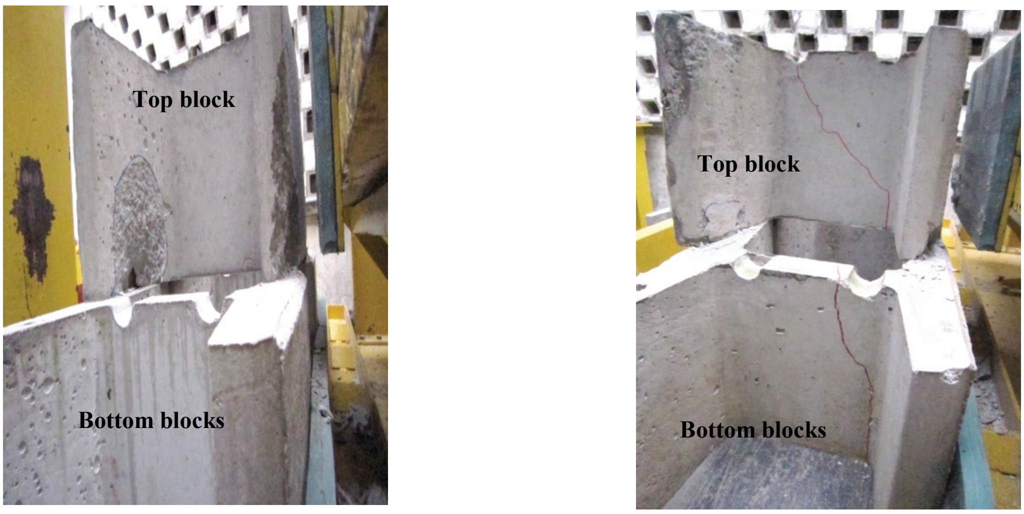


Fig. 10 – Shear force versus displacement



(a) (b)

Fig. 11 – Photographs of failure patterns in blocks: (a) Spalling and (b) Shear cracks in webs

5 Conclusion

Normal loading arrangement has a great influence on full-scale laboratory study of segmental retaining wall units. The current ASTM and NCMA test protocols recommend a fixed vertical actuator with roller or airbag configuration as a proposed vertical loading arrangement. In this study, the response of a newly developed moveable vertical piston was examined from low to high surcharge loading conditions and the performance was compared against previously developed fixed vertical loading assembly. The following major conclusions can be drawn from this comprehensive study:

- Moveable vertical loading assembly assures a constant normal load over the period of shear testing even at high surcharge loading condition and it also helps out to estimate the actual shear strength for the corresponding normal force rather than overestimating it.
- Moveable normal loading arrangement is user friendly and speedy test set up compared to fixed vertical piston because in this arrangement roller system was mounted in between the piston and loading frame, and therefore no need to use flexible airbag which is a complex system to control the applied normal force. This system could frequently be used for full-scale laboratory study of flat interface modular block systems which are unlikely to show any dilatant behavior.
- At high surcharge load, shear cracks easily propagate through the webs of the empty block systems due to force concentration at shear interface although it poses high net compressive strength and thus the cracks drop the capacity of mobilized shear resistance.

Acknowledgements

The financial support for this research was provided by a grant (Fundamental Research Grant Scheme - 2010) from the Ministry of Higher Education of Malaysia awarded to the second author. The authors are also grateful to Soil & Slope Sdn Bhd, a research collaborator company, which provided other technical and material supports.

REFERENCES

[1]- R.J. Bathurst, M.R. Simac, Design and performance of the facing column for geosynthetic reinforced segmental retaining walls. In: Proceedings of the International symposium on mechanically stabilized backfill, J. Wu (ed.) Denver, Colorado, Balkema, 1997, pp. 193-208.

[2]- R.J. Bathurst, M.R. Simac, Laboratory testing of modular concrete block - geogrid facing connections. STP 1190 Geosynthetic Soil Reinforcement Testing Procedures (S.C.J. Cheng editor). In: ASTM, 1993, pp. 32-48.

[3]- Geotech Interaction testing report TG #02546.2: 6 SF Units with Synteen Geogrids, Thiele Geotech, Inc. 2005.

[4]- E. Guler, B. Astarci, Friction between facing elements and geotextiles in geosynthetic reinforced soil retaining structures. In: Proceedings of Second International Conference on new development in Soil mechanics and Geotechnical Engineering, Near East University, Nicosia, North Cyprus, 2009, pp.138-145.

[5]- ASTM Standard D6916-06c. Standard test method for determining the shear strength between segmental concrete units. Annual book of ASTM standards, ASTM International, West Conshohocken, PA, 2006.

[6]- ASTM Standard D6638-01. Determining connection strength between geosynthetic reinforcement and segmental concrete units (Modular Concrete Blocks). Annual book of ASTM standards, ASTM International, 2001.

[7]- NCMA, SRWU-2. Determination of shear strength between segmental concrete units. National concrete masonry association (NCMA), Herndon, Virginia, USA, 1997.

[8]- NCMA, SRWU-1. Determination of connection strength between geosynthetics and segmental concrete units."National concrete masonry association (NCMA), Herndon, Virginia, USA, 1997.

[9]- ASTM Standard D6916-03. Standard Test Method for Determining the Shear Strength between Segmental Concrete Units. Annual book of ASTM standards, ASTM International, West Conshohocken, PA, 2003.

[10]- R.J. Bathurst, S. Althoff, P. Linnenbaum, Influence of Test Method on Direct Shear Behavior of Segmental Retaining Wall Units. Geotech. Test. J. 31(2) (2008) 1-9.

[11]- F. Ali, M.Z.I. Bhuiyan, Design and Fabrication of the Apparatus for Laboratory Study of Segmental Retaining Wall Units. Electron. J. Geotech. Eng. 19 (2014) 17245-17257.

[12]- M.Z.I. Bhuiyan, F.H. Ali, F.A. Salman, Effect of Flexibility of Geosynthetic Inclusion on the Interface Shear Capacity of Segmental Block System. Electron. J. Geotech. Eng. 19 (2014) 254-265.