Challenge Journal of Structural Mechanics

Seismic analysis of interlocking mortarless hollow block

Farzad Hejazi *, Jamalodin Noorzaei, Abang Abdullah Abang Ali, Mohd Saleh Jaafar

Department of Civil Engineering, University Putra Malaysia, 43300 Serdang, Malaysia

ABSTRACT

Various types of interlocking mortarless (dry-stacked) block masonry systems have been developed worldwide. However, the characteristics of dry joints under compressive load, and their effect on the overall behavior of the interlocking mortarless system, are still not well understood. This paper presents an investigation into the dry-joint contact behavior of masonry and the behavior of interlocking mortarless hollow blocks wall construction subjected to seismic excitation. In the system developed, the blocks are stacked on one another and three-dimensional interlocking protrusions are provided in the blocks to integrate the blocks into walls. The response of the mortarless hollow block wall with respect to acceleration displacement and stress have been discussed.

ARTICLE INFO

Article history:
Received 6 January 2015
Accepted 16 March 2015

Keywords:
Masonry systems
Seismic analysis
Mortarless block
Interlocking block
Finite element method

1. Introduction

Interlocking mortarless load bearing hollow block system is different from conventional mortared masonry systems in which the mortar layers are eliminated and instead the block units are interconnected through interlocking protrusions and grooves. Numerous analytical models have been developed to simulate the behavior of different types of structural masonry systems using Finite element method. Two main approaches have been employed in the masonry modeling depending on the type of the problem and the level of accuracy. The macro-modelling approach intentionally makes no distinction between units and joints but smears the effect of joints presence through the formulation of a fictitious homogeneous and continuous material equivalent to the actual one which is discrete and composite (Lotfi and Shing, 1991; Cerioni and Doinda, 1994; Zhuge et al., 1998). The alternative micro-modelling approach analyzes the masonry material as a discontinuous assembly of blocks, connected to each other by joints at their actual position, the latter being simulated by appropriate constitutive models of interface (Suwalski and Drysdale, 1986; Ali and Page, 1988; Riddington and Noam, 1994). An extensive critical review for the analytical models of different masonry systems can be found in the performed study done by Alwathaf et al. (2003).

The complex interaction between block units, dry joint and grouting material has to be well understood under different stages of loading; i.e. elastic, inelastic and failure. For interlocking mortarless masonry systems, very limited FE analyses have been reported in the literature (e.g., Oh, 1994; Alpa et al., 1998).

The existing FE analyses are simplified and hence show inaccurate prediction for the structural response of the masonry systems compared to actual behavior of the systems found experimentally. Furthermore, the existing models ignore the interaction between masonry block units, mortarless joint and grout as well as are incapable of simulating the failure mechanism of the masonry system.

In this study, a finite element model is proposed and a program code is developed to predict the behavior of the system under compression load. The developed contact relations for dry joint within specified bounds can be used for any mortarless masonry system efficiently with less computational effort. The bond between block and grout is considered to simulate the deboning and slipping of the block–grout interface. Furthermore, the stress–strain behavior of masonry blocks and grout materials under compression for uniaxial and biaxial stress state was modelled.

* *Corresponding author*. E-mail address: farzad@fhejazi.com (F. Hejazi)

2. Modelling of Mortarless Joint

In present study, the hollow prisms modelled using eight-noded isoparametric elements to simulate the masonry constituents, are shown in Fig. 1(a). Six-noded isoparametric interface element of zero thickness located between material elements to model the interface characteristics of the dry joint and bond between blocks are represented in Figs. 1(b-c), respectively. Fig. 2 shows the finite element geometric model of considered wall that was constructed by hollow blocks. Dimension of this model are 3 m width and 3 m height assumed. Therefore by considering the dimensions of each prism (30 cm with and 20 cm height), there are 10 prisms in horizontal and 15 prisms of hollow block in vertical direction.

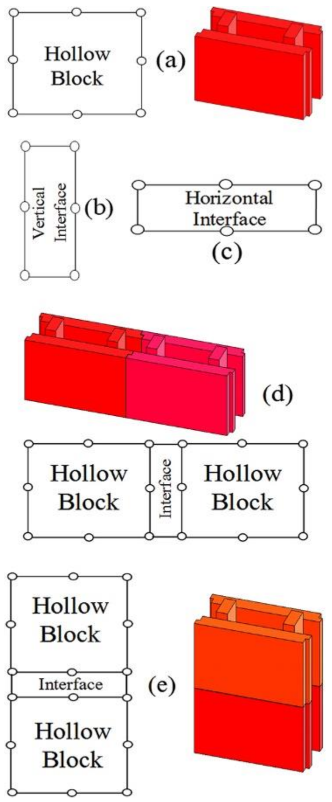

Fig. 1. (a) 8 node elements that was used for modeling of hollow block prism. (b) 6 node elements that was used for modeling of zero thickness vertical interface. (c) 6 node elements that was used for modeling of zero thickness horizontal interface. (d) Connection of two horizontal hollow block elements with vertical interface. (e) Connection of two vertical hollow block elements with horizontal interface.

In this finite element mesh as shown in Fig. 1(d) vertical dry joint between 2 horizontal block has been modelled by 6 node zero thickness vertical interface element and horizontal dry joint between 2 vertical block has been modelled by 6 node zero thickness horizontal interface element (Fig. 1(e)).

The considered wall is assembled by 150 blocks elements and 140 interface elements and model prepared by 865 elements and 2400 nodes. Therefore the final finite element mesh of wall is shown in Fig. 3.

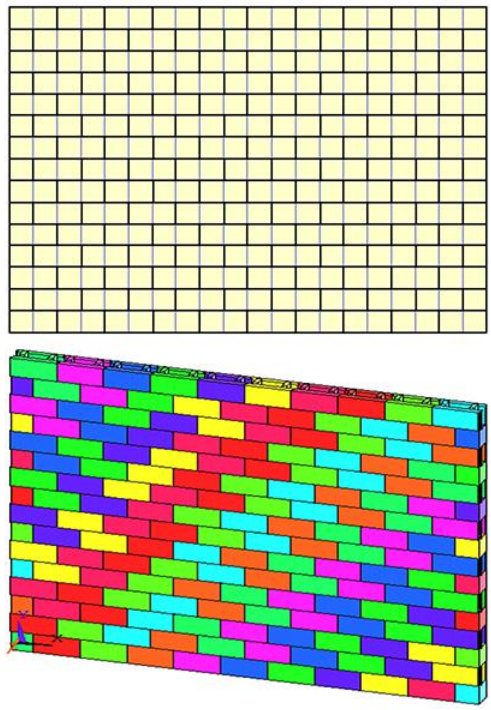

Fig. 2. Geometry of considered wall with 3 m width and 3 m height.

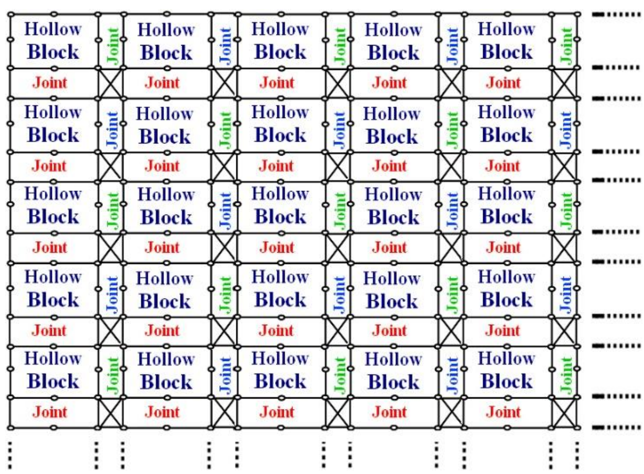

Fig. 3. Finite element model of hollow block wall.

3. Finite Element Analyses

A finite element program code has been developed to implement the proposed mortarless masonry model under seismic loading. Time history dynamic analysis of wall by imposing of suitable earthquake record for Malaysia and Indonesia are performed and shown in Fig. 4.

The time step of Malaysia earthquake record is 0.02 sec and duration of that is 20 sec and time step and duration of Indonesia record is 0.01 sec and 10 sec, respectively. Deformation of wall in imposing Malaysia and Indonesia earthquake excitation is shown in Fig. 5.

As seen in Fig. 5, top nodes of wall have high displacement in comparison with bottom nodes of wall and maximum displacement of wall occurs in the last top row of wall.

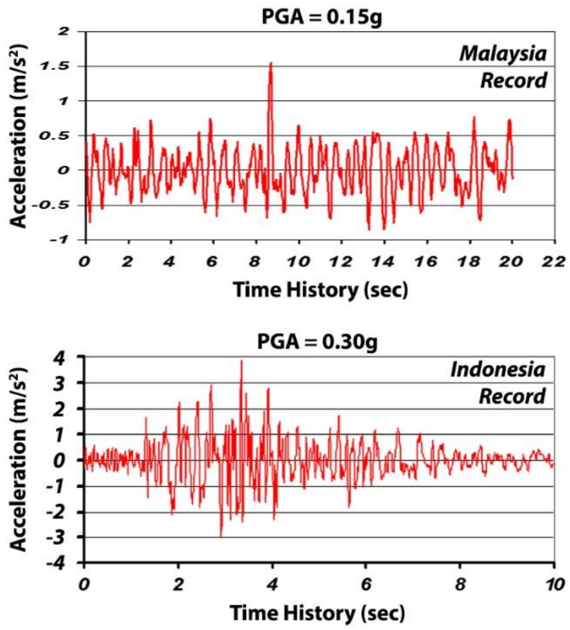

Fig. 4. Earthquake acceleration record for Malaysia and Indonesia.

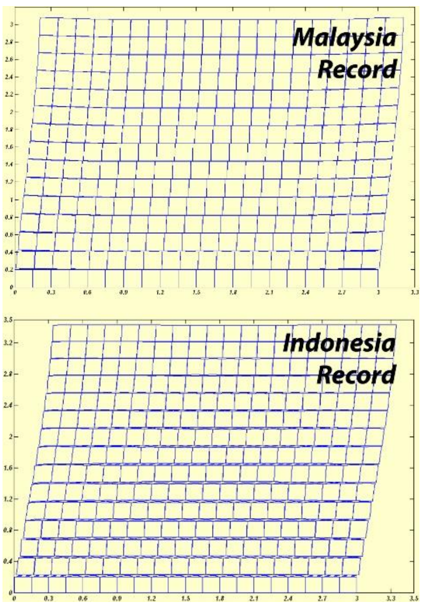

Fig. 5. Deformation of hollow block wall in Malaysia and Indonesia earthquake excitation (10 times exaggeration in *x* and *y* directions).

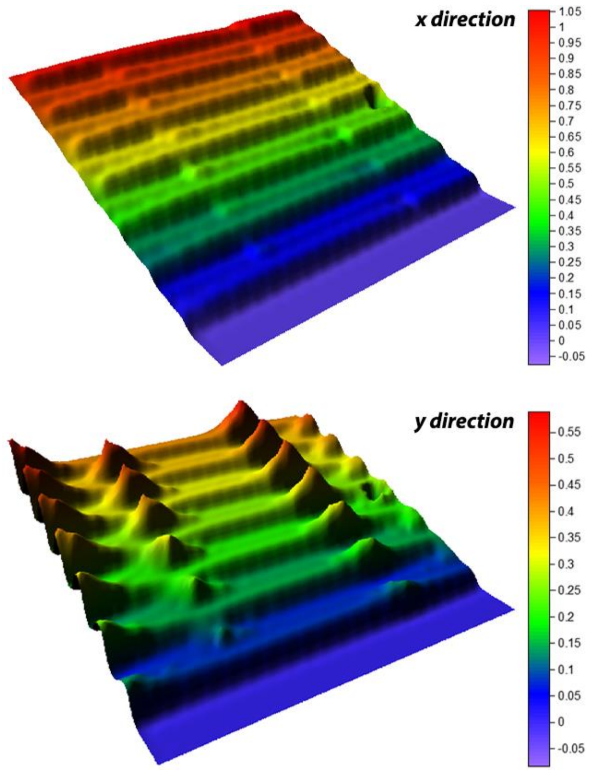

Fig. 6. Malaysia peak displacements in *x* and *y* directions (cm).

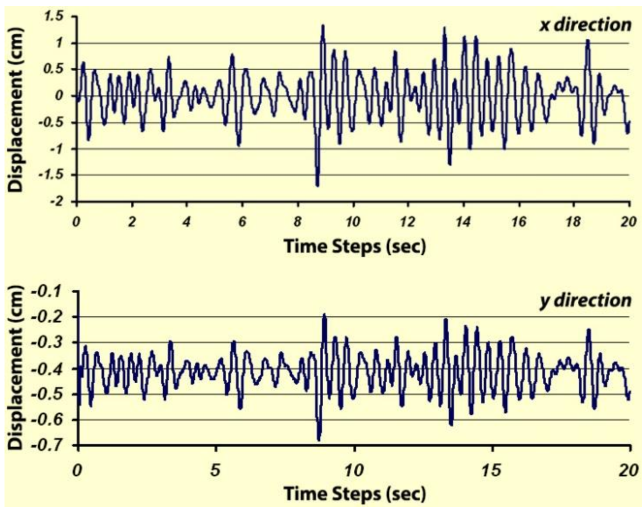

Fig. 7. Time-displacement history of top node of wall in *x* and *y* directions (cm).

4. Results and Discussion

4.1. Malaysia record excitation

Peak value of nodes' displacement in *x* and *y* directions during the earthquake excitation is determined by dynamic analyzes and values of that are plotted in Fig. 6.

The maximum displacement in *x* direction is 1.73 cm and in *y* direction is 0.71 cm. These values were less than allowable displacement for a masonry wall which were acceptable. The time history response and movement of wall during Malaysia earthquake load excitation, at top node of wall in *x* and *y* directions are shown in Fig. 7.

Peak value of each element stress *x* and *y* directions during the time steps of earthquake excitation are shown in Fig. 8. The maximum principle stress in *x* and *y* directions at bottom of wall is equal to 0.05222 and 0.1701 MPa.

Stress at bottom of wall is shown in Fig. 9. The stress values are very small because just single story building with very lightweight roof has been considered. Also just horizontal component of earthquake load imposed to wall and vertical component is neglected. So, maximum stresses in wall members are very smaller than the strength of blocks. Therefore the hollow block can be resist Malaysia earthquake excitation with allowable deformation and stress.

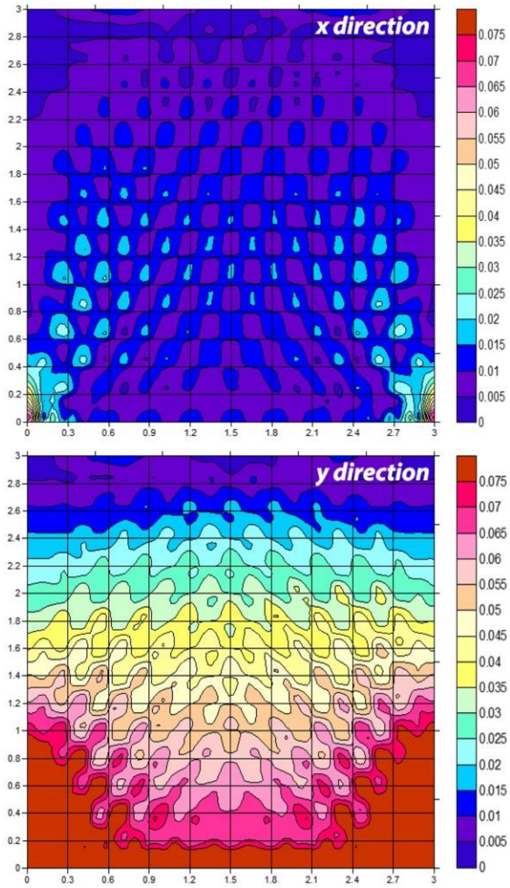

Fig. 8. Peak stresses in *x* and *y* directions (MPa).

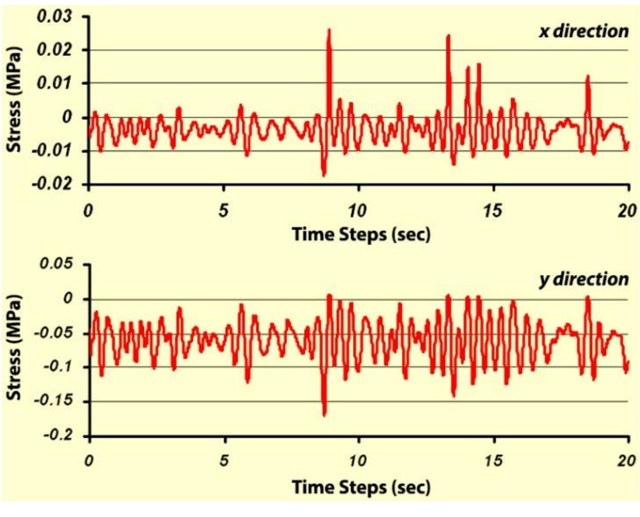

Fig. 9. Time-stress history of corner element in bottom of wall (MPa).

4.2. Indonesia record excitation

Peak value of nodes' displacement in *x* and *y* directions during the earthquake excitation is determined by dynamic analyzes and values of that are plotted in Fig. 10.

The maximum displacement in *x* direction is 2.13 cm and in *y* direction is 0.831 cm. The time history response and movement of wall during Indonesia earthquake load excitation, at top node of wall in *x* and *y* directions is shown in Fig. 11.

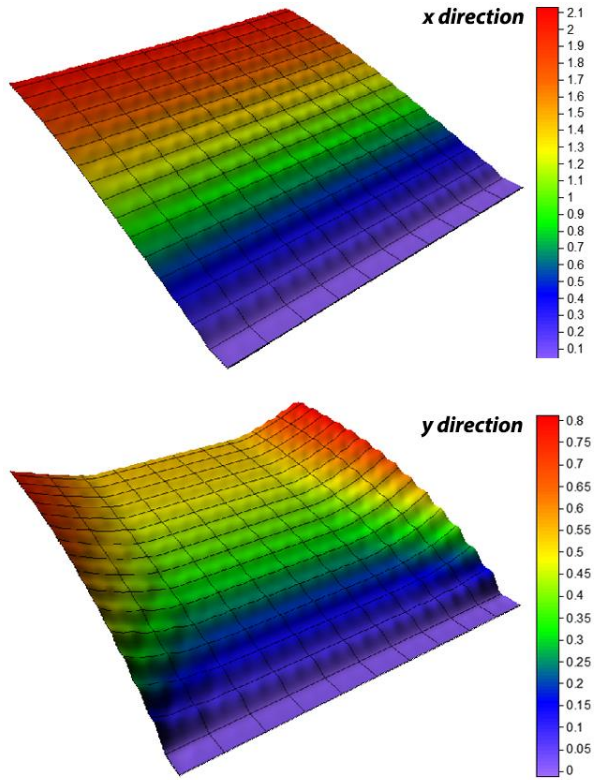

Fig. 10. Indonesia peak displacements in *x* and *y* directions (cm).

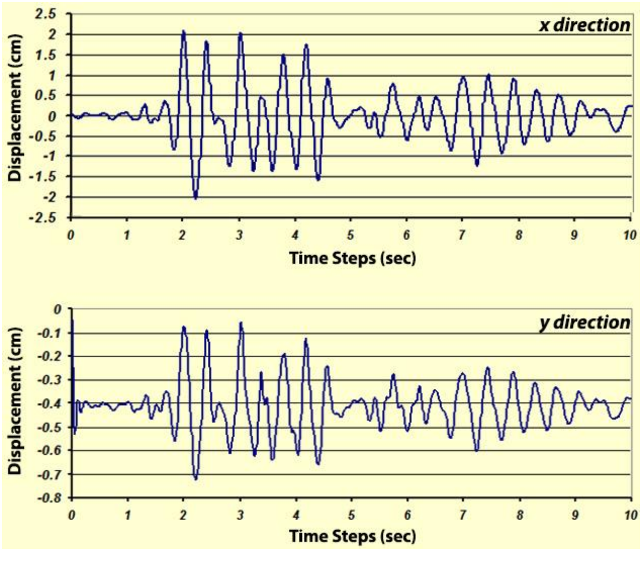

Fig. 11. Time-displacement history of top node of wall in *x* and *y* directions (cm).

The values of maximum displacements of wall are exceeded from allowable displacement for masonry wall, and then it is not acceptable.

Fig. 12 shows stress distribution in the wall subjected to Indonesia earthquake record. The maximum principle stress in *x* and *y* directions at bottom of wall is equal to 0.072 and 0.19 MPa.

Variation of stress at bottom of wall in duration of subjected earthquake has been shown in Fig. 13. Apparently the value of stress is small value and less than strength of hollow blocks.

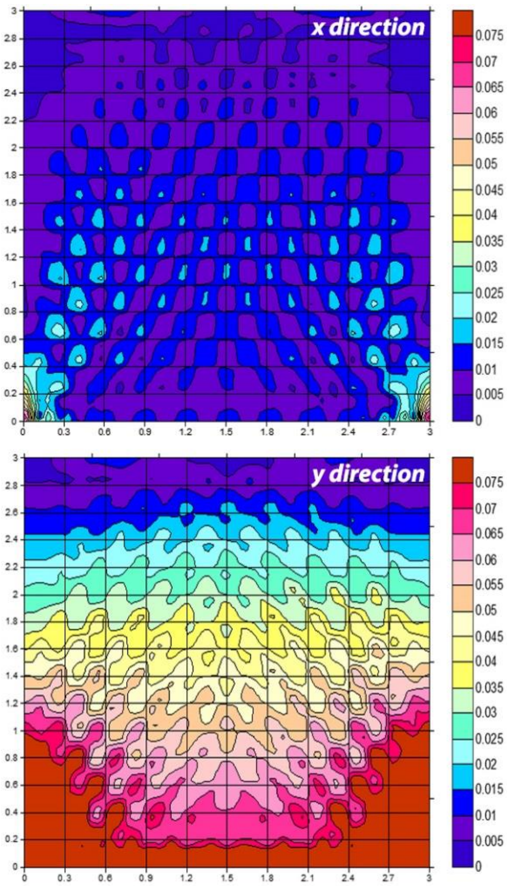

Fig. 12. Peak stresses in *x* and *y* directions (MPa).

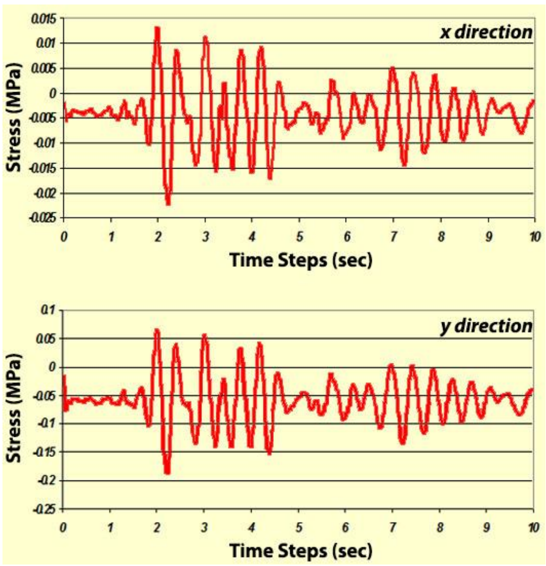

Fig. 13. Time-stress history of corner element in bottom of wall (MPa).

Therefore the wall can resist the stress but displacements of wall exceed the allowable values and it cannot satisfy the deformation limit.

5. Conclusions

Based on the foregoing analysis and discussion of the test results from this investigation, several conclusions can be drawn as follows.

- Finite element model of mortarless block masonry system has been developed. The model is at micro-level which includes the modeling of masonry materials, mortarless dry joint and block-grout interface behavior.
- The interlocking keys provided for this system were able to integrate the blocks into a sturdy wall and can replace the mortar layers that are used for conventional masonry construction in low seismic area.
- Considered wall system can be resist in Malaysia earthquake record excitation (PGA=0.15g, low seismic hazard level) but in Indonesia earthquake record excitation (PGA=0.39g, high seismic hazard level), displacement of wall is exceed allowable values. Therefore this type of wall that constructed by explained hollow blocks just resist low seismic excitation.

References

Ali SS, Page AW (1988). Finite element model for masonry subjected to concentrated loads. *ASCE's Journal of Structural Engineering*, 114(8), 1761-1784.

Alpa G, Gambarotta L, Monetto I (1998). Dry block assembly continuum modelling for the in-plane analysis of shear walls. *Proceeding of the 4th International Symposium on Computer Methods in Structural Masonry,* E & FN, Spon, 111-118.

Alwathaf AH, Thanoon WAM, Noorzaei J, Jaafar MS, Abdulkadir MR (2003). Analytical models for different masonry systems. *Critical Review, Proceeding of IBS2003 Conference.*

Cerioni R, Doinda G (1994). A finite element model for the nonlinear analysis of reinforced and prestressed masonry wall. *Computer and Structures,* 53, 1291-1306.

Lotfi H, Shing P (1991). An appraisal of smeared crack model for masonry shear wall analysis. *Computer and Structures,* 41, 413-425.

Oh K (1994). Development and Investigation of Failure Mechanism of Interlocking Mortarless Block Masonry System. *Ph.D. thesis,* Drexel University, Philadelphia.

Riddington JR, Noam NF (1994). Finite element prediction of masonry compressive strength. *Computer and Structures*, 52(1), 113-119.

Suwalski P, Drysdale R (1986). Influence of slenderness on the capacity of concrete block walls. *Proceeding of 4th Canadian Masonry Symposium*, 122-135.

Zhuge Y, Thambiratnam D, Coreroy J (1998). Nonlinear dynamic analysis of unreinforced masonry. *ASCE's Journal of Structural Engineering*, 124(3), 270-277.