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REINFORCED CONCRETE SANDWICH PANELS WITH AUTOCLAVED AERATED CONCRETE INFILL

Abdel-Mooty M.[a], Al Kashif M.A.[b], Fahmy E[c],Abou Zeid M.[d] and Haroun M.[e]
Construction and Architectural Engineering Department, The American
University in Cairo (AUC), Egypt
[a]mamooty@aucegypt.edu, [b]mkashif@aucegypt.edu,[c]ezzat@aucegypt.edu, [d]mnagiba@aucegypt.edu,
[e]maharoun@aucegypt.edu

Abstract

Reinforced concrete sandwich panels are composed of two thin concrete outer layers separated by a lightweight, insulating, and usually weaker inner layer. They provide improved thermal insulation characteristics and are easier to construct due to their reduced weight. The composite action of the panel is achieved mainly through the use of shear connectors between the two outer layers due to the very low shear resistance of the inner insulating layer. However, the shear connectors reduce the thermal insulation property of the panel through bridging the two outer layers with heat conducting media. In this research, the use of lightweight Autoclaved Aerated Concrete (AAC) blocks is suggested to provide shear coupling and maintain the bending capacity of the panel. An experimental program is developed to study the load capacity and deformation of this system through testing full scale RC sandwich panels with AAC blocks infill in 4-point bending test until its failure. Different design parameters are examined in this test program including: the surface roughness of the AAC layer, and the use of steel shear connectors. The results show the efficiency of AAC infill in resisting shear and maintaining the bending capacity.

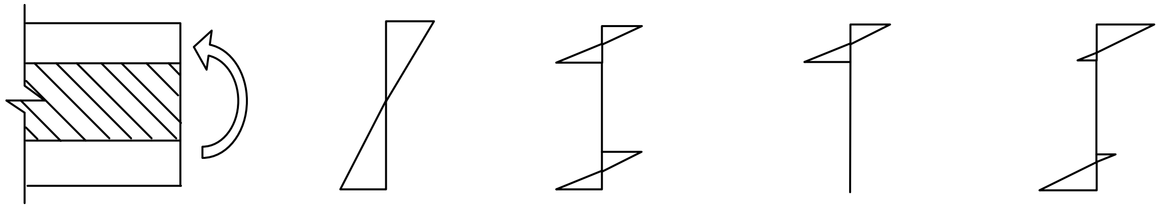
Keywords: Concrete Sandwich Panels, Autoclaved Aerated Concrete, Precast Slabs, Thermal Insulation.

1. Introduction

Concrete sandwich panels are gaining widespread popularity due to the increasing demand for energy efficient structures. Sandwich panels are typically constructed of two concrete wythes separated by an inner layer of an insulating material. This insulating material can take the form of rigid foam or honeycomb insulating core. These panels can be used for walls and slabs. They can be designed to withstand both in-plane and/or out-of-plane forces due to vertical gravity loads and lateral wind and seismic loads (Salmon et al 1997, Benayoune at al 2008). They can provide the needed heat and sound insulation for the structure and they can also provide both interior and exterior architectural finished surfaces. Precast sandwich panels can be prestressed to increase their flexural strength. The several aspects related to the use, design, manufacturing and detailing of such panels have been covered in depth in the report prepared by the PCI committee on Precast Sandwich Wall Panels (Seeber et al 1997).

The behavior of sandwich panels ranges from fully composite to non-composite. The degree of composite action depends on the shear connection between the two concrete wythes. A full composite behavior is achieved when the two concrete wythes are connected together in such a form as to provide full interaction thus 100% composite action is developed. In this case the two wythes work together as one unit as would normally occur in solid slabs. A non-composite panel is theoretically defined as a panel without composite action where there exists no interaction at all between the two concrete wythes hence they act independently. In the case of non-composite panels, one of the two wythes could be non-structural and the load is supported by the structural wythe only. Connection between the concrete wythes is developed through friction between concrete and inner insulating material; use of solid concrete zones; bent reinforcing bars; or metallic and non-metallic shear connectors. The amount and type of connectors determine the degree of composite action. However, it should be noted that such connectors, if they are heat conducting, would lead to thermal bridges and thereby decrease the thermal efficiency of the panels. The bending strain distribution under pure bending is shown in Fig. 1 for the various cases.

In this study, aerated concrete (AAC) blocks are used to replace ordinary rigid foam infill in the sandwich structure. They can provide a much stiffer slab with better shear resistance and thus improve the composite action of the sandwich panels under bending. Aerated concrete blocks are lightweight, environmental friendly, easy to handle, and readily available in the construction market.



Bending moment action in sandwich panel | strain in fully composite action | strain in non-composite two-structural withes | strain in non-composite one-structural wythe | strain in partially composite action

Figure 1: Bending strain distribution in sandwich panels

2. Literature Review

Traditionally, the use of bricks in slabs has been introduced to reduce the cost of expensive concrete. Reinforced brick masonry was developed where bricks were laid together and joined by reinforced concrete ribs and a concrete top layer was used to protect the bricks. Reinforced brick slabs used in this way behave like waffle slabs. This was further developed by adding a ferrocement layer in the bottom surface (Kaushik et al 1991). The behavior of ferrocement sandwich panels with light weight AAC fill was studied (Fahmy et al 2005 and 2006). The composite behavior of precast Composite sandwich panels was experimentally studed by Pessiki et al (2003). A semi-precast floor slab system was introduced where the ferrocement layer formed the precast part and steel shear connectors were embedded in it to provide a shear link to the cast in situ concrete ribs (Thanon et al 2010a). The brick layers and the in situ ribs resisted the bending compressive forces while the precast ferrocement layer resisted the bending tensile forces. Aerated concrete was introduced in place of ordinary bricks to achieve lighter weight slabs. Interlocking between the aerated concrete blocks and concrete ribs was introduced to achieve the shear link without the use of steel shear connectors (Thanoon et al 2010b). However, ferrocement-brick composite slabs were not thermally efficient because of the existence of the concrete ribs. Also this system relied on the thin ferrocement slab to carry the tensile load unlike concrete sandwich panels which make use of the full depth to resist the bending moments.

3. Experimental Programme

Six panels are constructed and tested for flexure and shear under a 4-point lateral loading test. Two panels, A1 and A2, are made with no shear connectors. Two panels, B1 and B2, contain two lines of steel shear connectors. The last two panels, C1 and C2, are provided with two RC web connectors in each panel. The sandwich panels in this study are 1 m wide and 3 m long and spanned 2.8 m between the lines of support. They are made of two 50-mm thick concrete wythes separated by a 100-mm AAC block layer. Panels A1 and A2, shown in Fig. 2, are identical with no shear connection between the two concrete wythe, where friction between the block and wythe is relied upon to transmit shear. The faces of the AAC blocks are scratched to provide better friction and interlocking with the concrete. Panels B1 and B2, shown in Fig. 3, are identical in which 6-mm diameter diagonal steel bars are used as shear connectors between the two concrete wythes. The blocks in panel B1 and B2 are kept without roughening to minimize the effect of friction between the blocks and the concrete wythes. Panels C1 and C2, shown in Fig 4, are identical and contained two reinforced concrete webs 50 mm wide each. All panels are provided with reinforcement in both concrete wythes. A total of six 10-mm diameter reinforcement bars are provided in the longitudinal direction and sixteen 8-mm diameter bars are provided in the transverse direction in the top compression wythe. The bottom tension wythe has six 12-mm diameter reinforcement bars in the longitudinal direction and sixteen 8-mm diameter bars in the transverse direction. The yield stress of the used reinforcement bars is 400 MPa, while the average 28-day cubes compressive strength of the concrete used was 45 MPa. Reinforcement is provided at the top layer to control cracks due to shrinkage and to resist any local bending moments which may arise in the top layer due to lack of full composite behavior. For Panels C1 and C2 steel stirrups of 6-mm bars diameter are placed at a spacing of 100 mm in the concrete webs.

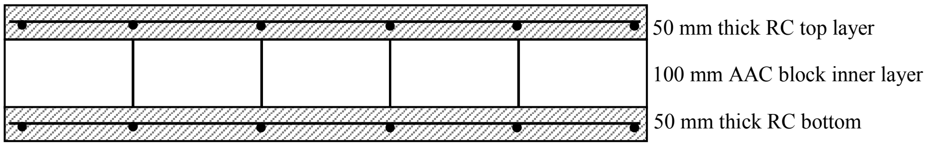


Figure 2: Panel A1 and A2 using no shear connectors

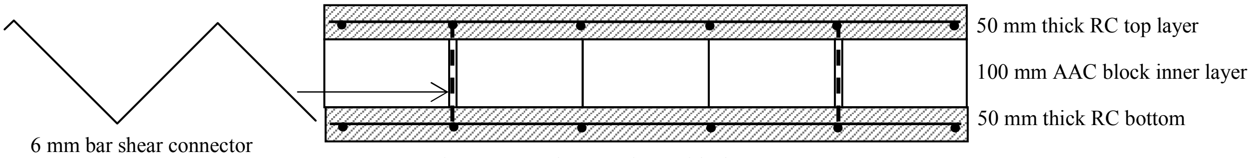


Figure 3: Panels B1 and B2 with shear connectors

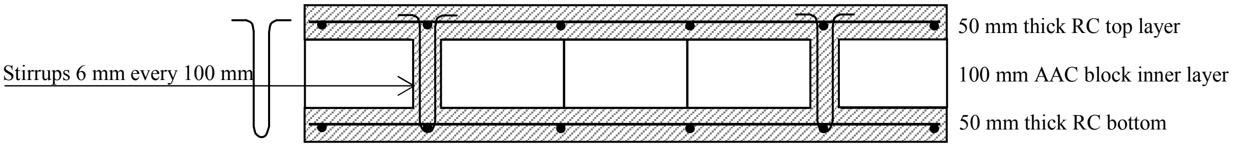


Figure 4: Panels C1 and C2 with concrete web connectors

4. Test Set-up

The panels were tested in a horizontal position with simply supported end conditions. A 4-point line loading test was conducted to study both the flexural and shear capacity of the panels. The AAC blocks are readily provided in the local market in standard sizes of 600×200 and different thicknesses of 100, 150, 200, and 250 mm. The layout of the blocks is shown in Fig. 5 below. A full size AAC panel of dimension 1.0×3.0 m can equally be used in place of the AAC blocks which would avoid having joints between individual blocks.

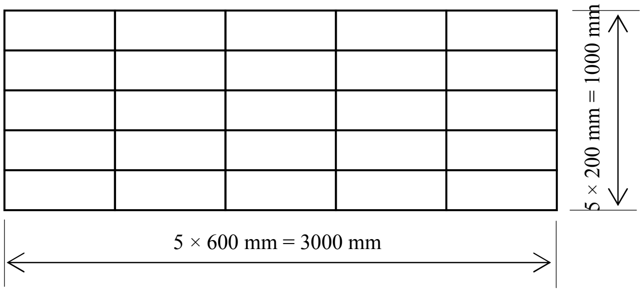


Figure 5: Plan view of infill panels of AAC blocks

Load was applied through a hydraulic jack using a hydraulic pump with a pressure regulator to adjust the loading at slow rate which also allows for good observation of the behavior of the panels during testing. The loads were transferred from the jack through I-beams to other two beams 1.0 m apart applying two equal line loads to the specimens as shown in Fig. 6. The panel rests on steel line rollers to allow for horizontal movement due to bending deformation thus avoids local stresses due to friction at the support lines. Strain and deformation at selected locations are measured to evaluate the composite action of the sandwich panels. The measured response is digitized and recorded using high speed data acquisition system. Instrumentation layout and details are discussed in the next section.

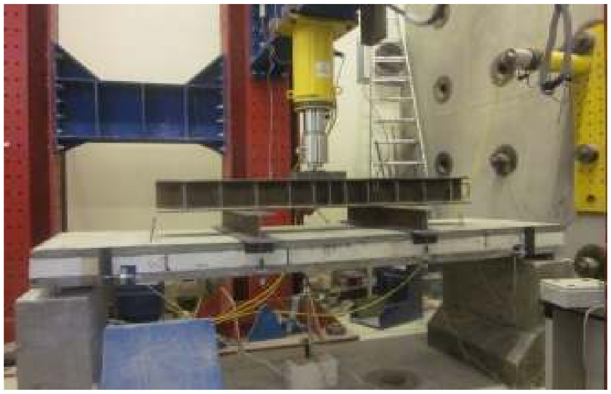


Figure 6: RC sandwich panel with AAC infill during a 4-point load bending test.

5. Instrumentation

The total applied load is measured using a 200 ton capacity load cell connected to the hydraulic actuator of the same capacity. The vertical deflection of the panel during testing is measured using LVDT connected to the mid-span point of the lower RC layer. The differential movement between the two outer concrete wythes in both vertical and horizontal direction are measured using LVDT's. Two LVDTs were used to measure the relative vertical deflection at the two locations of load application. To measure the relative shear movement between the two concrete wythe, a steel angle was fixed to the upper wythe and an LVDT was mounted horizontally on the lower wythe to measure the movement of the steel angle connected to the upper wythe relative to the lower wythe. The longitudinal strains in both RC wythes are also measured at mid-span using 4 surface mounted electrical strain gauges two on each surface. The strain gauges are placed on both sides of the panel as shown in Fig. 7. Electrical strain gauges are also attached to the steel shear connectors in case of panels B1 and B2 to measure strain in the shear connectors.

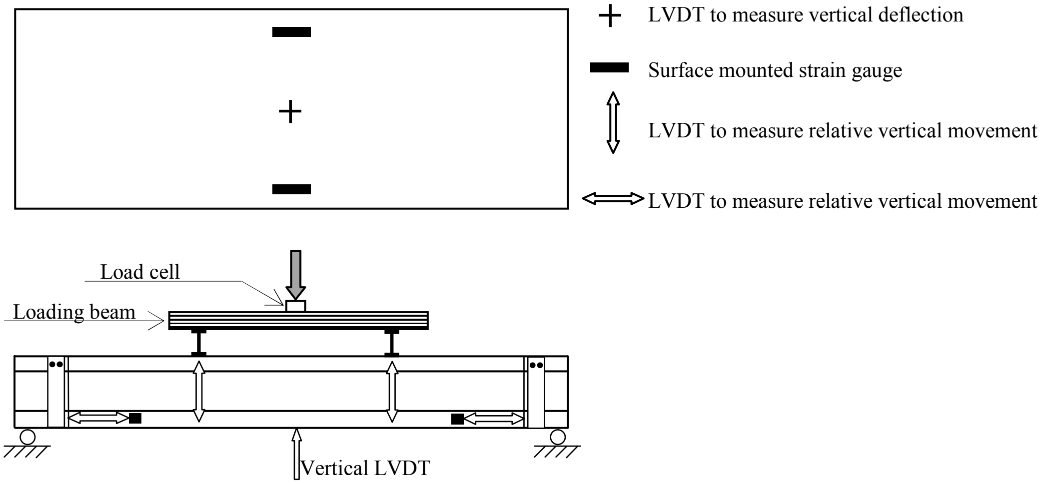


Figure 7: test set-up and instrumentation layout

6. Results and Discussion

The panels are monotonically loaded in a four-point load bending test until failure. Failure is marked by a decrease in the load capacity of the panels, indicated by a drop in the load deflection curve, accompanied by excessive deformation. The load deflection curves for the tested panels are shown in Fig. 8. It can be seen that the presence of shear connectors whether in the form of steel truss or concrete web connector enhances the performance of the slabs.

The stiffness of the slabs is largely dependent upon the composite action of the panels presented by the shear resistance of the inner layer and the shear connectors. It can also be seen that all slabs exhibit an initial full composite behavior to before they start to gradually lose the composite action and thus their stiffness. For slabs A1 and A2, the full composite behavior is limited to a very small load range, lower than 0.5 tonnes. As a matter of fact, slab A1 in particular witnessed a lower stiffness from the beginning of the load testing due to the presence of an initial separation between the concrete wythes and the AAC blocks which had possibly occurred during handling of the specimen in addition to the weak bond between the concrete and AAC. This weak bond indicated an improper compaction of the AAC blocks when placed against the lower concrete wythe.

Slab A2 showed a reasonable stiffness compared to A1 and it started to lose its stiffness gradually until eventually it attained the same stiffness of A1. Loss of stiffness is attributed to the poor shear transfer between the concrete wythes. Measurement of the relative sliding between the two wythes as shown in Fig. 9 clearly indicates that there is a close correlation between the relative sliding and the ultimate capacity of the panels. Failure of panels A1 and A2 was driven by relative sliding of the concrete layers and AAC followed by tensile cracking and crushing of the two concrete wythes.

For panels B1 and B2, there was some improvement in both the stiffness and the load capacity of the panels. Slab B1 showed a full composite behavior until a load of almost 5 tonnes which signifies the effectiveness of the steel connectors. However, further to this load a drop in the stiffness was noted which possibly occurred as a result of the disconnection of the steel connectors from the concrete wythe. The performance of Slab B2 was similar to B1 except that there was no dramatic drop in the stiffness of this slab as was the case with B1. Fig. 10 shows the strain in the shear connectors in both slabs B1 and B2. It can be observed that the shear connectors were working effectively for slab B1 until there was a release of load due to disconnection of the shear connectors which caused the stress in the connectors to vary direction. For Slab B2, the shear connectors did not carry considerable stress as shown by the low measured strain which is a result of the small embedment of the connector in the upper concrete wythe. Hence, failure of B1 and B2 was caused by disconnection of steel connectors from concrete wythe followed by shear cracking in AAC blocks and ultimately tensile cracking and crushing of the two concrete wythes.

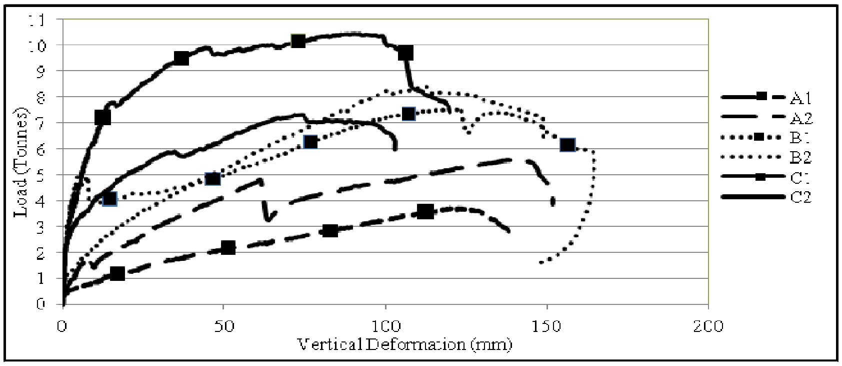


Figure 8: Load Deflection for all test panels

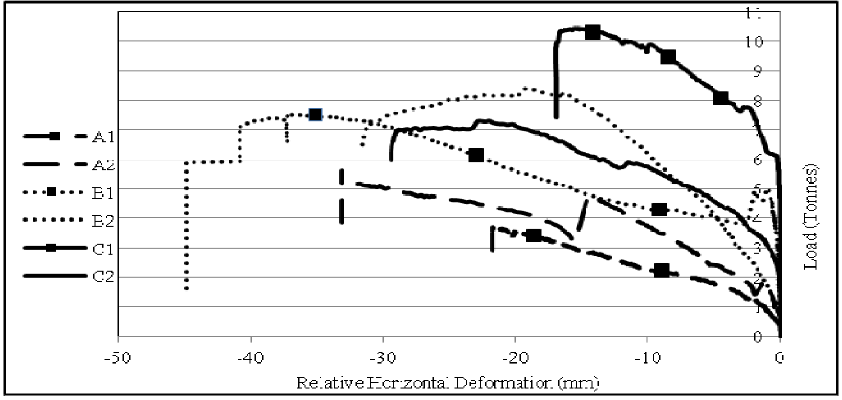


Figure 9: Relative Horizontal Deformation for all test panels

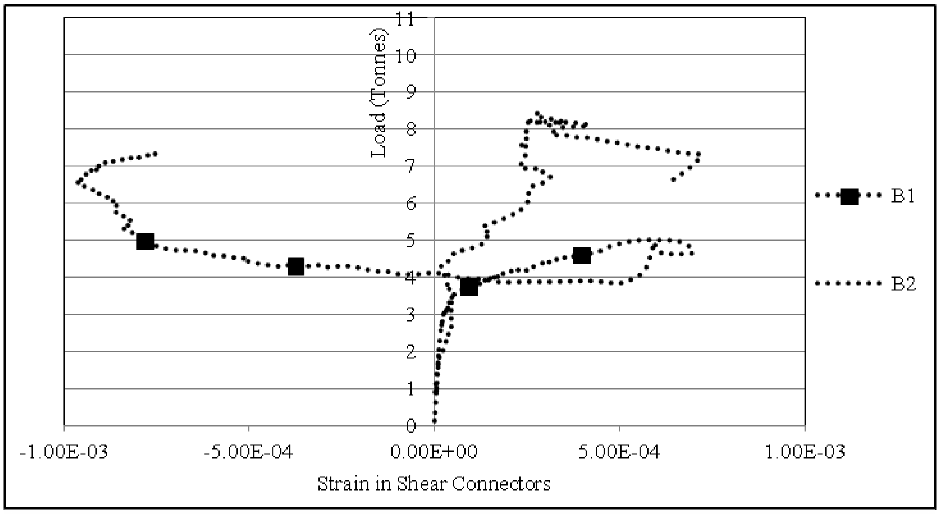


Figure 10: Strain in Shear Connectors in Panels B1 and B2

The sandwich panel C1 with concrete web connectors showed a full composite behavior up to a load of 8 tonnes. The performance of Panel C2 was not as good as C1 and it failed at a relatively lower load. Again this could be due to disconnection of steel stirrups from concrete wythe as a result of insufficient embedment length. Failure of panels C1 and C2 occurred due to failure of the shear web leading to relative sliding of the sandwich panel layers followed by shear failure in the AAC and ultimately tensile cracking and crushing of the two concrete wythes.

7. Conclusions and Recommendations

This paper introduces a new hybrid system which employs the concept of sandwich panels with the use of AAC blocks in place of the conventional foam insulation. The test results showed that the panels can resist loads up to 10 tonnes under a 4 point loading test which amounts to a bending moment of 4.7 tonnes m/m. The slabs also showed good ductility. The specimens with shear connectors showed a significant improvement over the specimens which relied merely on the friction bond between the AAC and concrete. The panels with no shear connection withstand a low of as low as 3.8 tonnes. The use of steel shear connectors increased the panel load capacity to 8 tonnes. While with the use of reinforced concrete webs the failure load of the sandwich panel is increased to approximately 10 tonnes. The reliability of the shear connection between the panel layers plays a significant role in determining the load capacity of the panel. From the strain measurements of the steel shear connectors, it can be concluded that the embedment length of the steel connectors and stirrups into the concrete layer is a critical factor. Enough embedment length should be provided and the steel connectors should better be interlinked with the slab reinforcement to prevent disconnection of the connectors. The AAC blocks should be well soaked in water before placement to prevent absorption of water from concrete and improve bond between AAC blocks and concrete.

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References

Benayoune, A., Abdul Samad, A., Trikha, D., Abang Ali, A. and Ellinna, S. (2008). Flexural Behaviour of Precast Concrete Sandwich Composite Panel – Experimental and Theoretical Investigations, *Construction and Building Materials Journal*, *Vol. 22*, pp 580-592

Fahmy, E., Abou Zeid, M,. Shaheen, Y., and Gaafar, H. (2005). *Behavior of Ferrocement Panels Under Axial and Flexural Loadings*, Proceedings of the 33rd CSCE Annual Conference, The Canadian Society for Civil Engineering, Toronto, Ontario, Canada, June 2005.

Fahmy, E., Shaheen, Y., Abou Zeid, M., and Gaafar H. (2006). Ferrocement Sandwich and Hollow Core Panels for Wall Construction, *Journal of Ferrocement, Vol. 36, No. 3*, Thailand, July 2006.

Kaushik, S., Gupta, V., Anuj, and Singh, K. (1991). Behavior and Performance of Composite Ferrocement Brick Reinforced Slabs. *Journal of Ferrocement, Vol. 21, No.3,* pp 215-222

Salmon, D., Einea, A., Tadros, M. and Culp, T. (1997). *Full Scale Testing of Precast Concrete Sandwich Panels*, *ACI Structural Journal*, July-August, pp 354-162

Seeber, K. et al. (1997). State-of-the-Art Report on Precast/Prestressed Sandwich Wall Panels- PCI Committee Report, *PCI Journal, Vol.42, No.2*, pp 1-61

Thanoon, W., Yardim, Y., Jaafar, M. and Noorzaei, J. (2010a). Structural Behaviour of Ferrocement-Brick Composite Floor Slab Panel, *Construction and Building Materials Journal, Vol. 24,* pp 2224-2230

Thanoon, W., Yardim, Y., Jaafar, M. and Noorzaei, J. (2010b). *Composite Aerated Concrete and Ferrocement Lightweight Slab,* Proceedings of the 14th European Conference on Earthquake Engineering (ECEE), Ohrid, Macedonia