LONG-TERM SHEAR TRANSFER PROPERTIES OF HORIZONTAL SLIP JOINTS IN LOAD-BEARING MASONRY

Yuri Z. Totoev[1], Adrian W. Page[2], Goran Simundic[3]

ABSTRACT

Masonry structures contain slip joints between concrete slabs and their supporting masonry walls to accommodate differential movements due to concrete slab shrinkage, thermal effects and masonry moisture expansion. Traditionally slip joints in Australia consist of one or two layers of a membrane type material placed between masonry and concrete. According to Australian Standards all structures must be designed for earthquake loading. Therefore the slip joints must satisfy two apparently conflicting requirements – to slip under long-term loads for adequate serviceability performance and to transmit short-term dynamic loads from earthquake in order to create effective load paths through the structure. Recent work at the Universities of Newcastle and Adelaide has indicated that these types of joint do exhibit substantial shear capacity under short-term load. There is an urgent need to establish their behaviour under long duration induced strains (i.e. differential movement effects) to clarify their potential to behave as slip joints for the serviceability limit state. Long-term tests are currently underway at the University of Newcastle to investigate this behaviour. In these tests the frictional forces generated in the joint between a shrinking concrete slab and a preloaded masonry wall have been monitored over a three month period for a selected range of joints. This paper presents preliminary results of this experimental project.

Key words: load-bearing masonry, slip joints, concrete slab shrinkage

[1] Lecturer
Department of Civil, Surveying, and Environmental Engineering
The University of Newcastle, Callaghan, NSW 2308, Australia
E-mail: ceyuri@civeng.newcastle.edu.au

[2] CBPI Professor in Structural Clay Brickwork and Dean
Faculty of Engineering
The University of Newcastle, Callaghan, NSW 2308, Australia
E-mail: apage@mail.newcastle.edu.au

[3] Laboratory Manager

INTRODUCTION

A large proportion of masonry in Australia is unreinforced. It is widely used as a veneer, as an infill in framed structures, and also as load-bearing walls. The most common form of load-bearing masonry in Australia is the 3 or 4 storey apartment building. In these buildings masonry walls typically support reinforced or prestressed concrete slabs. Differential movements between the slab and the wall can arise from thermal and long-term dimensional changes within the concrete and masonry. Normally a low-friction slip joint separates the slab and the wall to reduce the drag force applied to the masonry wall and thus prevents cracking (see Fig. 1). One or two layers of a membrane type material are used for this purpose. The most commonly used materials are damp-proof-course membranes of embossed polythene or bitumen-coated aluminium. In some cases joints consisting of two layers of greased galvanized steel are used.

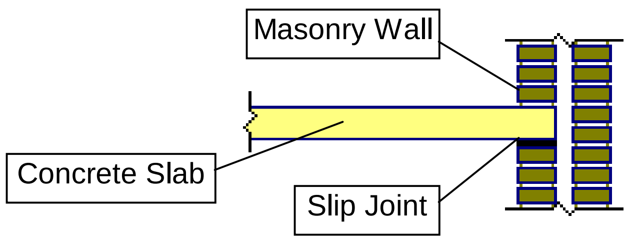

Figure 1. Slip Joint in Load-Bearing Masonry Wall

A number of researchers have studied the behaviour of slip joints previously. Schubert (1983) studied the effect of adhesion, friction, and mechanical interlock on the drag resistance of a number of different slip joints. He conducted his tests at different strain rates (some as slow as ~10mm/hour) and reported that the strain rate did influence the drag resistance.

Page et al. (1998) and Griffith et al. (1998) performed a series of monotonic unidirectional shear tests, cyclic shear tests and dynamic shaking table shear tests for a selected range of slip joints. Two sets of friction coefficients (static and dynamic) were determined. They also reported a noticeable difference between the two coefficients for some joints. Importantly, the difference between the respective coefficients was quite variable: for some types of joints the dynamic coefficient was lower than the slow strain rate coefficient; for other types of joints the dynamic coefficient was higher; and for some joints there was no difference between the two.

Suter et al. (1992), Rajakaruna (1997) and Zhuge et al. (1998) performed a number of monotonic shear tests of masonry containing joints with damp-proof-course membranes and reported results comparable with those of Page et al. (1998) and Griffith et al. (1998).

Simundic et al. (2000) reported results of long-term shear tests for several slip joints. In these tests the shear force on the joint was maintained at a constant level and the differential movement (slip) was monitored. These results demonstrate that slip joints do have the potential to exhibit some creep.

Definition of the problem

Historically slip joints have been developed to provide a discontinuity between the concrete slab and the masonry wall to allow some freedom of differential movement. The frictional resistance of slip joints has been studied after introduction of the Australian Earthquake Loading Code AS1170.4 (Standards Australia, 1993). In the majority of cases the slip joints were found to possess significant shear capacity under short-term loading and therefore able to transfer seismic forces. Unless the same joints are capable of accomodating long-term differential movements, their use as slip joints (as in common practice) is very much open to discussion. Therefore the connection shown in Fig. 1 has to satisfy two apparently conflicting requirements:

(i) the ability to allow slip under long-term differential movements between the materials and hence to alleviate any build-up of stresses, particularly in the masonry;
(ii) the ability to transfer the short-term earthquake induced forces by friction in the joint.

The difference between these two types of internal effects lies in the time scale involved and thus the corresponding strain rates. To be able to satisfy the two requirements the shear stresses developed in the joint should be high if the strain rate is fast and, in contrast, when the strain rate is slow, the induced shear stresses should be low. The dependence of a material response on strain rate is typical for viscoelastic materials. A similar behaviour is required in a slip joint, which can be referred to as “the pseudo viscosity of a joint”.

It is clear from the literature on slip joints that:
(i) there is some evidence that slip joints exhibit pseudo viscosity,
(ii) most slip tests were performed at high strain rates, representing short-term loading,
(iii) no tests have been performed at the realistically low strain rates of 1or 2 mm/month, representing the differential movements in a slip joint due to the long-term dimensional changes within the concrete and masonry.

Objectives of this study

The objectives of this study follow logically from the analysis of the literature and the urgent need to determine the performance of various types of slip joints under short and long-term loads. This will then allow the design of joints which can provide effective serviceability performance as well as transfer seismic loads (Page (1995)). Hence, the objectives are:

(i) to develop a test for measuring the shear forces transferred through a slip joint at realistically low strain rates, representing the differential movements in a slip joint due to the long-term dimensional changes within the concrete and masonry,

(ii) to test a selected range of common slip joints at low strain rates to determine the pseudo viscosity of the joints,

(iii) to identify those types of common slip joints, that best satisfy the dual requirements of short and long-term performance.

A range of long-term tests is underway at the University of Newcastle to clarify the above issues. This paper presents some preliminary results of this study.

EXPERIMENTS

Test specimens

Three types of common Australian slip joints were tested:

- Type 1: two layers of greased galvanized steel,
- Type 2: two layers of bitumen-coated aluminium, often referred to by its commercial name "Alcore",
- Type 3: one layer of embossed polythene, often used in damp-proof courses.

Joints Type 2 and 3 are also commonly used in damp-proof courses.

Testing rig

A purpose built testing rig was developed for the concrete shrinkage slip tests. The schematic testing arrangement is shown in Fig. 2 and the instrumentation set up in Fig. 3.

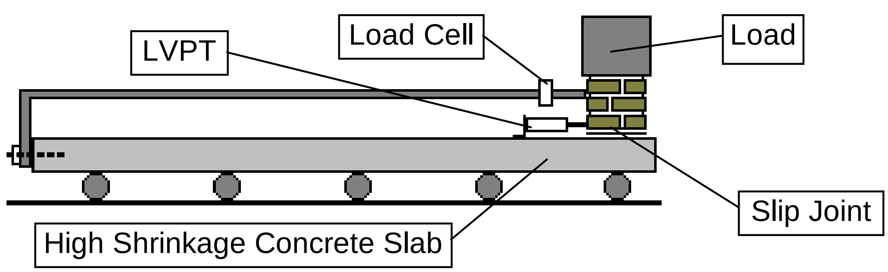

Figure 2. Schematic Rig Configuration for Shrinkage Tests

The concrete slabs or rather beams were 3m long, 300mm wide and 100mm thick. They were made of unreinforced concrete with properties deliberately chosen to maximize shrinkage. Preliminary tests indicated a total shrinkage in the order of 1600 microstrain. The beam was supported by a number of rollers in order to alleviate bending of the beam and to allow its unrestrained shrinkage. As can be seen from Fig. 2, a "closed system" was created by connecting the far end of the beam to the masonry sample, with the slip between the concrete and brick being monitored continuously.

A single standard dry pressed clay brick (230mm X 110mm X 70mm) was used to simulate the underside of a single leaf of a load-bearing masonry wall. It was placed horizontally and perpendicular to the direction of the beam shrinkage, which means that the “out-of-plane” slip normal to the masonry wall was being measured. A steel cap was placed over the brick to ensure that the brick remained horizontal during the test and also to ensure uniform distribution of vertical load.

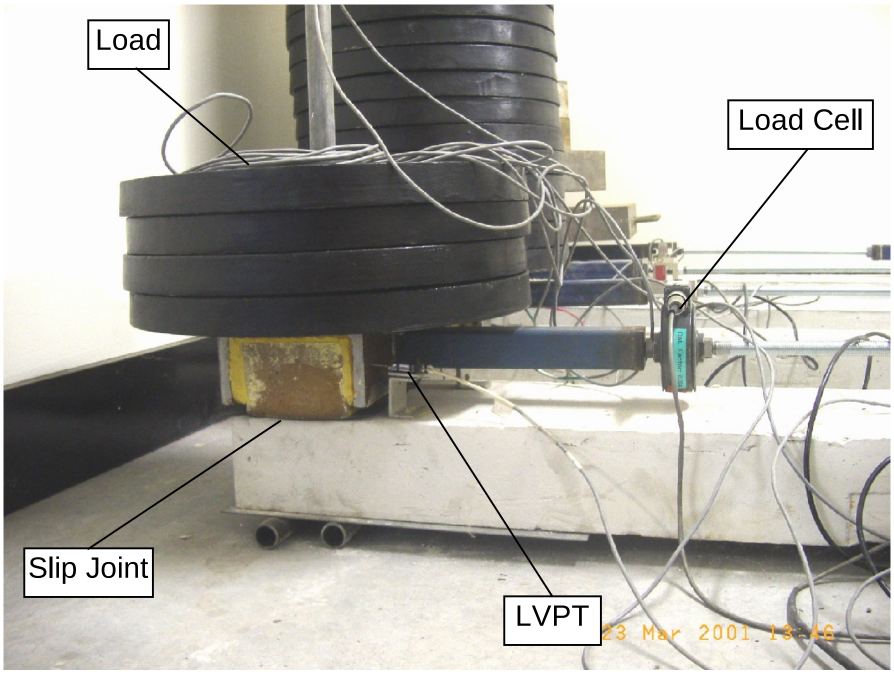

Figure 3. Instrumentation Set Up

A slip joint was formed between the brick and the concrete beam by inserting the appropriate membrane detail. The shear transfer area of the joint of $0.0253m^2$ was equal to the area of the bed face of the brick. Metal weights were placed on top of the steel cap to simulate vertical load in the masonry wall.

The differential movement between the brick and the beam was measured by a linearly varying potentiometric transducer (LVPT of 10mm travel capacity). A load cell of 10kN capacity has been incorporated into the “closed system” to measure the shear force induced in the slip joint by shrinkage of the concrete beam. Output electric signals from the LVPT and the load cell were monitored constantly and recorded by a data-logger.

Testing procedure

The testing procedure was similar for all cases. The concrete beams were cast and cured for two weeks before mounting them in the rig. From a preliminary study, a tensile strength of 0.29MPa was obtained for the concrete at two weeks, an adequate level of strength to avoid premature cracking of the beam. This strength increased to 3.0MPa after 4 weeks. Slip joints are being tested at different levels of vertical compression (0.08MPa, 0.3MPa, 0.6MPa), although in this paper only results for the 0.08MPa compression level are reported. This compression level is typical for roof slabs. An average test takes about three months to complete because most shrinkage in concrete occurs during the first three months after construction. One test for each joint type at the 0.08MPa compression level has been completed to date. Differential movements up to 4.5mm and shear forces up to 1100N were recorded. When there was no increase in the average shear force for two months it was assumed that the long-term shear capacity of the tested joint had been reached. It was also assumed that if a joint possessed any pseudo viscosity, two months of low strain rate should be sufficient time to give a good indication of the shear stress relaxation.

THEORY

A slip joint which has no pseudo viscosity can be simply modeled as perfectly elastic-plastic. In the elastic range, at low strain, the shear stress can be predicted from the following equation:

$$\tau = G\gamma \tag{1}$$

where τ is the shear stress in the joint, G is the modulus of resistance of the joint to the shear strain, and γ is the shrinkage strain. The shear stress in this model is neither a function of time, nor a function of the strain rate. The joint slips when the shear stress has reached its maximum value, which should be the same for both static and dynamic tests.

A slip joint which has pseudo viscosity can be modeled employing the Maxwell stress-strain model for viscoelastic materials (Maxwell (1867)). In this model the shear stress in the joint is time dependant and can be predicted, at low strain rates, from the following equation:

$$\tau = \eta\dot{\gamma}, \quad \dot{\gamma} = \frac{\partial \gamma}{\partial t} \tag{2}$$

where η is the pseudo viscosity of the joint, and $\dot{\gamma}$ is the strain rate. The total strain in this joint is the sum of the elastic strain and the time dependent viscous strain. There is no definite point of slip in this model, since some residual strains are developed from the very beginning of loading. The strain rate is higher in dynamic tests than in static tests. Therefore, the maximum shear stress transferred by the joint should also be higher under short-term loading compared to the long-term effects. The Maxwell model combines elastic and plastic components represented by a spring and a dashpot. In this model, the strain increases (creeps) under long-term constant stress and the stress reduces (relaxes) under long-term constant strain. It is expected that pseudo viscous slip joints, such as those in this study, should exhibit similar tendencies.

RESULTS AND DISCUSSION

The results of the low strain rate tests for the three selected types of slip joints under a precompression of 0.08MPa are presented in Figs. 4 to 6 in the form of shear force evolution curves. Some data (the second half of the first month of testing) for joints Type 1 and Type 2 was lost due to a power failure during a holiday period. Fortunately, the results for this period can still be inferred.

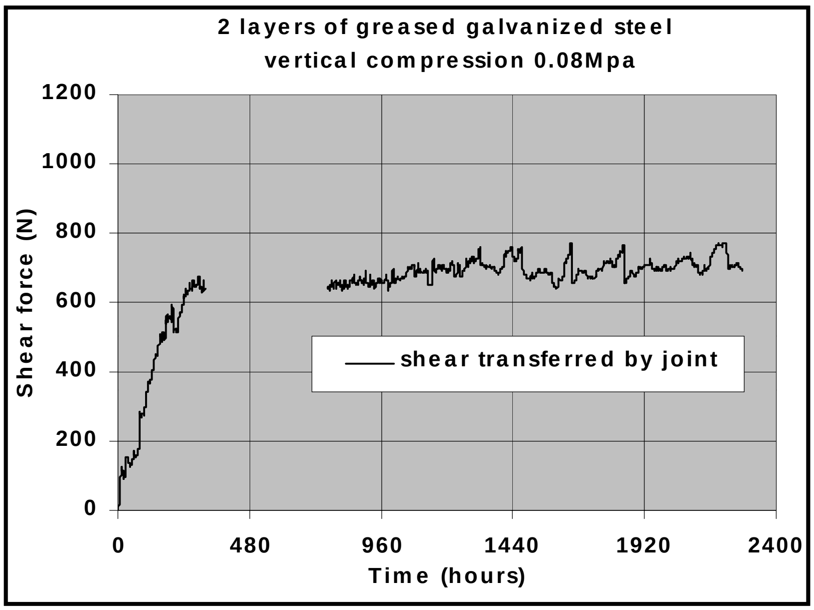

Figure 4. Shear Force Evolution in Joint Type 1

It can be seen that joint Type 1 exhibited a quite definite point of slip with the shear force remaining stable after initial slip. There was no tendency for shear relaxation. These two facts suggest that the Type 1 joint is not pseudo viscoelastic at this level of vertical stress.

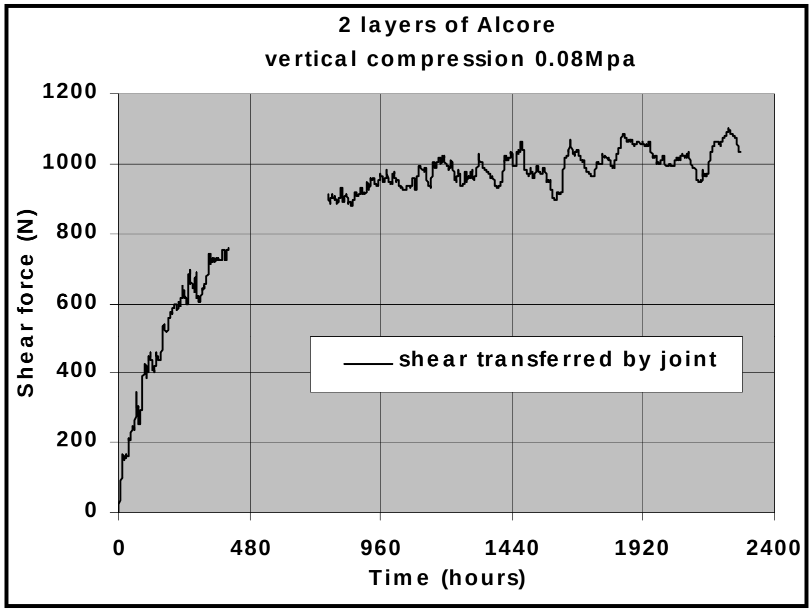

Figure 5. Shear Force Evolution in Joint Type 2

The Type 2 joint did not exhibit a definite slip point (see Fig. 5). It also did not show any tendency to shear relaxation over the three months of testing. This again suggests that, like Type 1, joint Type 2 is not pseudo viscoelastic at a vertical stress level of 0.08MPa.

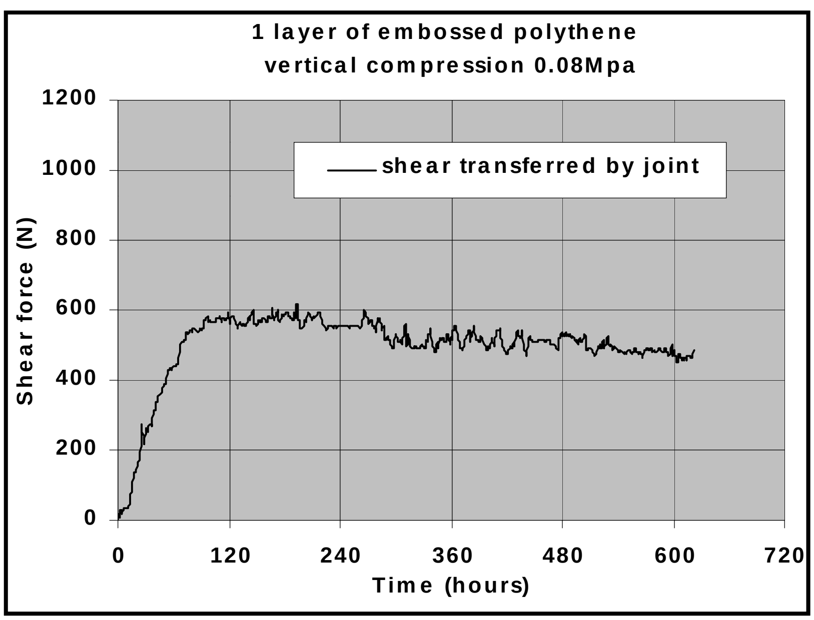

Figure 6. Shear Force Evolution in Joint Type 3

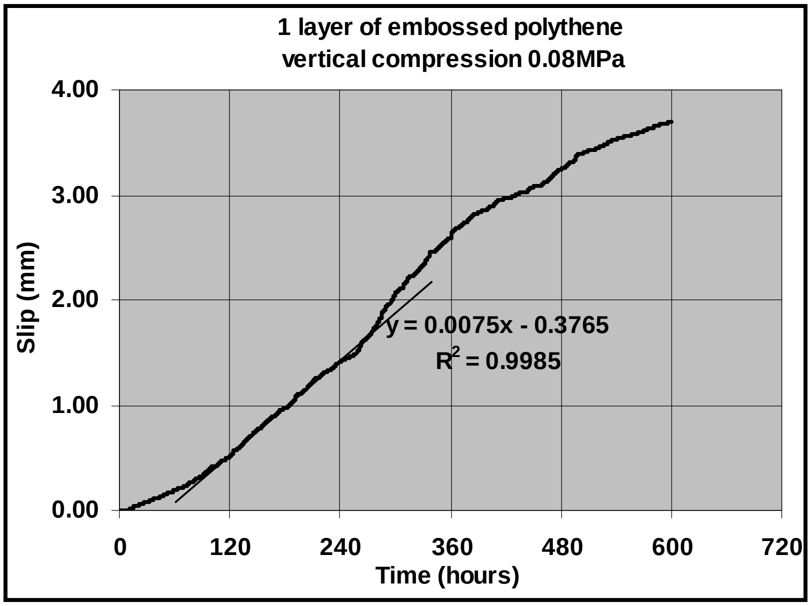

Figure 7. Slip Evolution in Joint Type 3

Unlike the first two joint types, the shear force evolution curve for the Type 3 joint clearly indicates some relaxation of the shear stress, which began after 10 days of testing. This confirms that the Type 3 slip joint is pseudo viscoelastic at this low level of vertical stress. The pseudo viscosity of 8.6 GPa has been estimated for joint Type 3 from the results presented in Figs. 6 and 7. This value was calculated from an average shear stress of 22609 Pa and an average strain rate of 2.63 microstrain/hour during the 5-day period (120h to 240h), when the stress was stable and the strain was almost constant.

SUMMARY AND CONCLUSIONS

To compliment previous short-term shear tests on slip joints, a study of their long-term performance is now underway at the University of Newcastle. Preliminary results of the first three long-term shrinkage tests have been summarized in this paper. After analysis of these results, it is possible to draw a number of conclusions:

- The test and the purpose built rig developed for studying the shear forces which are induced in a slip joint between a masonry wall and a concrete slab due to the long-term dimensional changes within the concrete and masonry appears to be working satisfactory;
- The test captures all the important aspects of the joint behaviour including the shear force and the shrinkage strain evolutions, the point of slip and the shear stress relaxation. This test can therefore be used to estimate the pseudo viscosity of joints;
- Three types of common Australian slip joints were tested at realistically low

strain rates at a level of vertical compression typical for roof slabs (0.08MPa);

- It was found that for the three joint types tested, only one, made of embossed polythene, exhibited viscoelastic behaviour at 0.08MPa vertical stress. A pseudo viscosity of 8.6 GPa was determined for this joint;
- From this first set of preliminary results, it appears that only embossed polythene membranes exhibit viscoelastic behaviour at low levels of compression, and thus would be most suitable for these applications. However, further study is required before recommendations can be made;
- The test program is continuing, both at higher levels of precompression and replicate testing at lower compression levels to allow design recommendations to be made.

ACKNOWLEDGMENT

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REFERENCES

Griffith, M.C. and Page, A.W., (1998). On the Seismic Capacity of Typical DPC and Slip Joints in Unreinforced Masonry Buildings. Australian Journal of Structural Engineering, The Institution of Engineers, Australia, Vol.1, No.2, pp 133-140.

Maxwell, J.C., (1867). Philosophy Transactions R. Soc., London, Vol.157, p. 49.

Page, A.W. and Griffith, M.C., (1998). A Preliminary Study of the Seismic Behaviour of Slip Joints Containing Membranes in Masonry Structures. The University of Newcastle and University of Adelaide, Research Report 160.02.1998.

Rajakaruna, M.P., (1997). Effect of the Damp Proof Course on the Shear Strength of Masonry. Proceedings of the 15th Australasian Conference on the Mechanics of Structures and Materials, Melbourne, Australia, pp 633-637.

Shubert, T.J., (1983). Slip Joints Under Concrete Roof Slabs. Experimental Building Station, Department of Housing and Construction, Chatswood, NSW, Technical Record 502.

Simundic, G., Page, A.W., and Chen, Q., (2000). The Cyclic and Long Term Behaviour of Slip Joints in Loadbearing Masonry Construction. Proceedings of the 12th International Brick/Block Masonry Conference, Madrid, Spain, Vol.2, pp 1409-1420.

Standards Association of Australia, (1993). AS1170.4 Minimum Design Loads on Structures, Part 4: Earthquake Loads. Standards Australia, Sydney, Australia.

Suter, G.T. and Ibrahim, K.S., (1992). Shear Resistance of Damp-Proof-Course

Materials in Brick-Mortar Joints. Proceedings of the 6th Canadian Masonry Symposium, Saskatoon, Canada, pp 119-130.

Zhuge, Y. and Mills, J., (1998). The Behaviour of Masonry Walls Containing a Damp Proof Course under Cyclic Loads. Proceedings of the 2nd Australasian Structural Engineering Conference, Auckland, New Zealand, Vol.2, pp 655-661.