NEW TEST FOR THE SHEAR TRANSFER CAPACITY OF HORIZONTAL SLIP JOINTS IN LOADBEARING MASONRY

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ABSTRACT

Masonry structures in Australia 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 consist of one or two layers of membrane type material placed between the 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 - slip under long term loads and transmit short term dynamic load through the structure. Tests at the Universities of Newcastle and Adelaide have indicated that these types of joints 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 drying shrinkage tests have been performed at the University of Newcastle. In these tests the frictional load in the joint between a shrinking concrete slab and a masonry wall was recorded over a three month period. It was found that the low tensile strength of concrete slabs and long test duration limit the applicability of these tests. A new low velocity slip test has been developed. In this test method the concrete slab on the slip joint is pushed at a constant speed by controlled thermal expansion of the calibrated metal rod. Each test takes about ten days. This paper presents a description of the new test and preliminary tests results.

KEYWORDS: slip joint, membrane, shear transfer, differential movement.

INTRODUCTION

A large proportion of masonry in Australia is un-reinforced. 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 three or four storey apartment building. In these buildings, masonry walls are typically combined with 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

Figure 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.

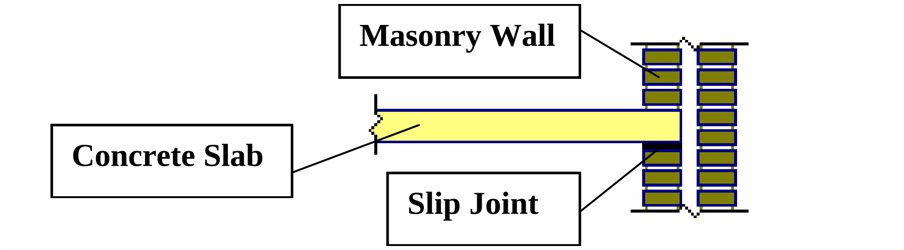


Figure 1 - Slip Joint in Load-Bearing Masonry Wall

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 [1]. In the majority of cases the slip joints were found to possess significant shear capacity under short-term loading and therefore are able to transfer seismic forces. Unless the same joints are capable of accommodating long-term differential movements, their use as slip joints (as in common practice) is very much open to discussion. Therefore the connection shown in Figure 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”.

A number of researchers have studied the behaviour of slip joints previously. Schubert [2] 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 ~10 mm/hour) and reported that the strain rate did influence the drag resistance.

Page et al. [3] and Griffith et al. [4] 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. [5], Rajakaruna [6] and Zhuge et al. [7] 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. [3] and Griffith et al. [4].

Simundic et al. [8] 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.

Trajkovski and Totoev [9] performed shear tests on masonry panels with damp proof courses varying the sliding velocity. They confirmed that the friction between masonry and a damp proof course depends on sliding velocity. Therefore the shear strength of a joint varies with different rates of load application.

Totoev et al. [10, 11] developed a long-term test to measure the frictional forces generated between a shrinking concrete slab and a masonry wall. They found that some types of slip joints exhibit the pseudo viscosity and are able to 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. In those tests differential movement between masonry and concrete was achieved through the drying shrinkage of a specially designed concrete. Unfortunately, the tensile strength of that concrete was found to be too low to perform tests with vertical compression in the joint greater than 0.3 MPa. Other disadvantages of those tests were their long-term nature and uncontrolled sliding velocity. Each test took approximately three months to complete.

OBJECTIVES FOR THIS STUDY

It is clear from the literature on slip joints that:

(i) there is strong evidence that some slip joints exhibit pseudo viscosity,
(ii) most slip tests were performed at high strain rates, representing short-term loading,
(iii) a limited number of tests have been performed at the realistically low strain rates, representing the differential movements in a slip joint due to the long-term dimensional changes within the concrete and masonry,
(iv) long-term tests which use shrinking of concrete to drive the differential movements in a slip joint have limited applicability and a number of inherent disadvantages.

The objectives of this study follow logically from the analysis of the literature and the 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. Hence, the objectives are:

(i) to improve the test for measuring the shear forces transferred through a slip joint at realistically low strain rates, which are representative of 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 an improved low velocity slip test, some preliminary results of this study, and comparison of the older long-term test based on concrete shrinking with the new improved test.

TESTING RIG

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

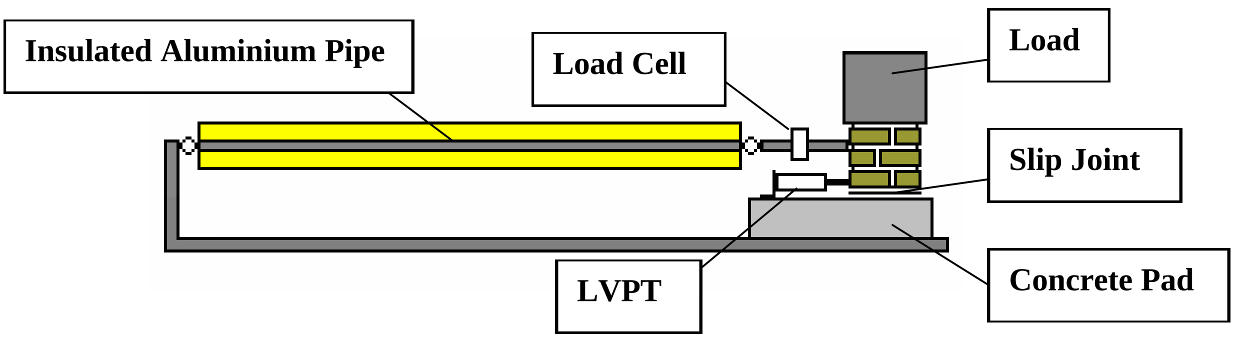


Figure 2 - Schematic Rig Configuration for Low Velocity Slip Tests

The slip driving force is provided by longitudinal thermal expansion of an insulated aluminium closed pipe. It is 3 m long, 63.5 mm in external diameter and has 6.35 mm thick walls. This pipe is filled with water. The water temperature is controlled by an automatic heater. Preliminary tests indicated a thermal elongation in the order of 4 mm for a temperature increase of 60^{o}C. The pipe has several supports uniformly distributed along its length in order to alleviate bending. As can be seen from Figure 2, a "closed loop system" was created by connecting the far end of the pipe to the concrete pad, with the slip between the concrete and brick being monitored continuously.

A half of a standard dry pressed clay brick (114 mm x 110 mm x 70 mm) 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 imposed strains 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.

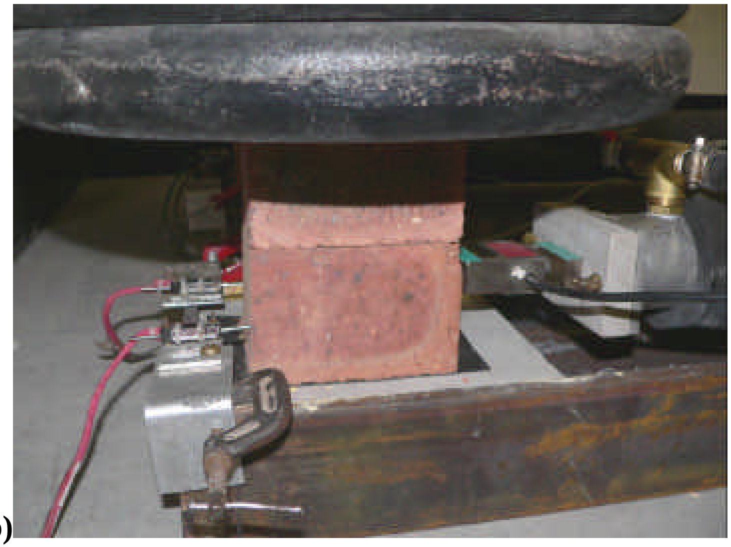
a)  b) 

Figure 3 - Instrumentation Set Up: a) Testing rig; b) Specimen being tested

A slip joint was formed between the brick and the concrete pad by inserting the appropriate membrane detail. The shear transfer area of the joint of 0.0125 m^2 was equal to the area of the bed face of the half 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 10 mm travel capacity. A load cell of 10 kN capacity has been incorporated into the "closed system" to measure the shear force induced in the slip joint by elongation of the aluminium pipe. Output electric signals from the LVPT and the load cell were monitored constantly and recorded by a data-logger.

TEST SPECIMENS

Three types of common Australian slip joints were tested previously:

- 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.

Joint Types 2 and 3 are also commonly used in damp-proof courses. It was previously found that only joint Type 3 exhibited some pseudo viscosity, presumably because it is made of plastic material. It was decided to continue testing joint Type 3 and joint Type 2 mainly for comparison purposes.

TESTING PROCEDURE

The testing procedure was similar for all cases. Slip joints are being tested at different levels of vertical compression (0.08 MPa, 0.16 MPa, 0.3 MPa, and 0.6 MPa), although in this paper only results for the first three compression levels are reported. The first of these compression levels is typical for roof slabs, the second level is typical for roof slabs with parapet walls, and the third level is chosen to represent typical compression of a slip joint/damp proof course in a single storey masonry building. An average test takes about ten days to complete. Two tests for joint Type 3 have been completed to date at the first three compression levels and two tests for joint Type 2 have been performed at 0.08 MPa compression. Differential movements up to 4 mm and shear forces up to 2 kN were recorded. It was assumed that if a joint possessed any pseudo viscosity, ten days of low strain rate should be sufficient time to give a good indication of the shear stress relaxation.

EXPERIMENTAL RESULTS AND DISCUSSION

The first series of tests was performed to compare results of the newly developed low velocity slip test with the previously developed concrete drying shrinkage test [10].

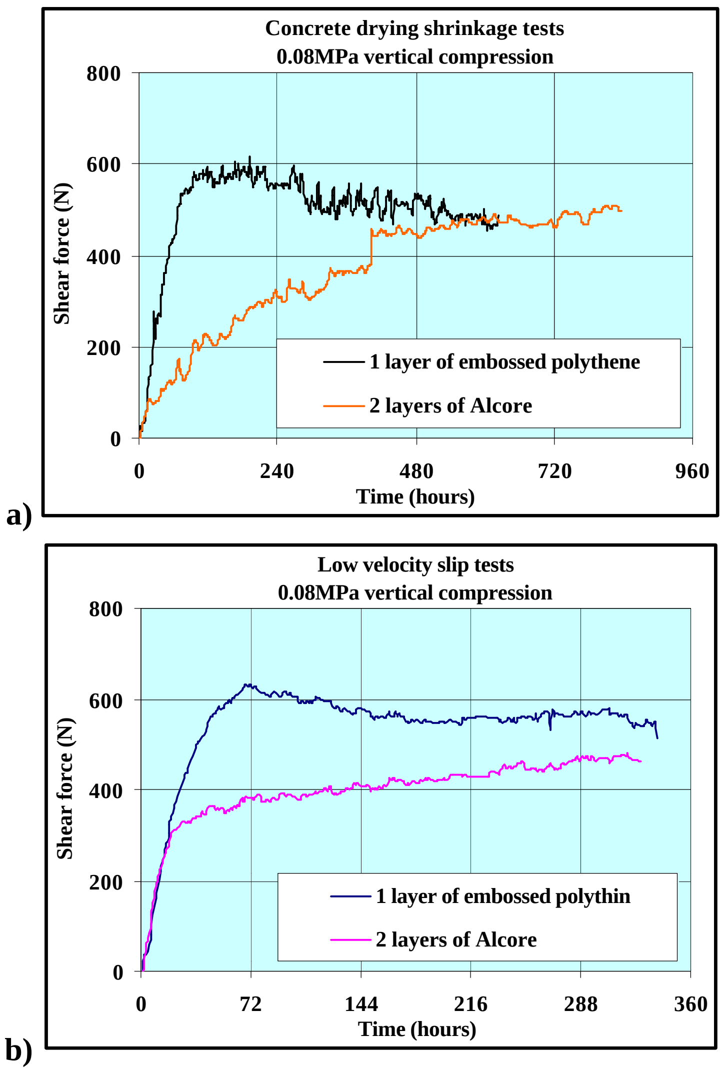
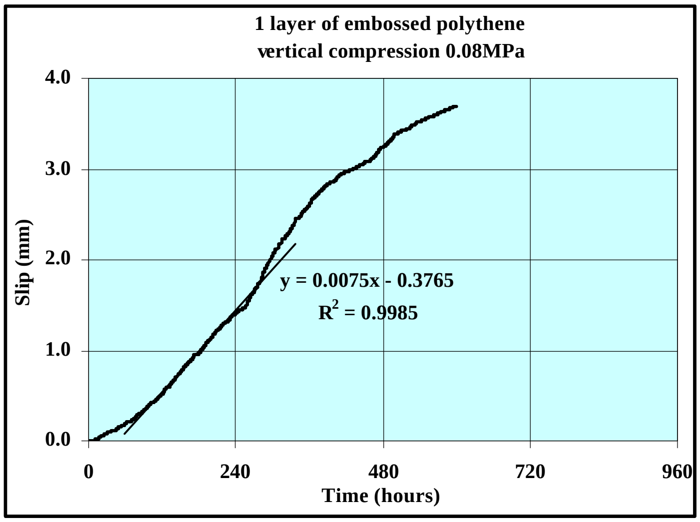


Figure 4 – Typical Shear Force Evolution Curves from a) Concrete drying shrinkage test [10]; b) Low velocity slip test

Figure 4 shows typical shear force evolution curves for both tests. They are essentially similar. The Type 2 joint (with Alcore) did not show any tendency for shear relaxation over the testing time regardless of the test duration. This suggests that joint Type 2 is not pseudo viscoelastic at a vertical stress level of 0.08 MPa and this is apparent from both tests. Unlike the Type 2 joint, the shear force evolution curves for the Type 3 joint (with polythene) clearly indicates some relaxation of the shear stress. This confirms that the Type 3 slip joint is pseudo viscoelastic at this level of vertical stress. It is also important that the difference in the long-term shear capacities of slip joints determined from both tests is less than 7%. One considerable advantage of the low velocity slip test is the controlled slip. It is obvious from typical slip evolution curves (shown in Figure 5) that calculation of the pseudo viscosity from the new test results is more reliable.



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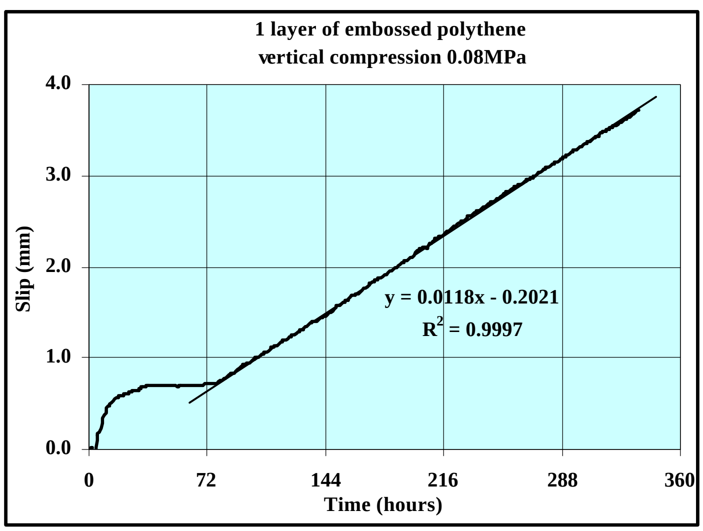

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Figure 5 – Typical Slip Evolution Curves from
a) Concrete drying shrinkage test [10]; b) Low velocity slip test

For calculation of the viscosity using the Maxwell stress-strain model for viscoelastic materials [12], a constant stress at a constant strain rate needs to be determined. It can be seen from the results of the concrete shrinkage tests shown in Figures 4-a and 5-a that the only period of the relatively constant slip rate was from 120 h to 240 h of testing. An average strain rate of 2.63 microstrain/hour and an average shear stress of 22609 Pa were recorded during that 5-day period. The pseudo viscosity of 0.019 MPa·s has been estimated for this joint at 0.08 MPa compression. A comparable value of 0.018 MPa·s for the pseudo viscosity of this joint type was also calculated from the results at 0.3 MPa compression [11]. In the low velocity slip test the slip is controlled. Therefore, almost the entire slip evolution occurs at a constant slip rate. The fluctuation of the corresponding shear force/stress is also much less in the low velocity slip test than in the concrete shrinkage tests. This explains why we consider results of the new test more reliable.

The results of the low strain rate tests for the Type 3 slip joints at three levels of vertical compression are presented in Figure 6 in the form of shear force evolution curves.

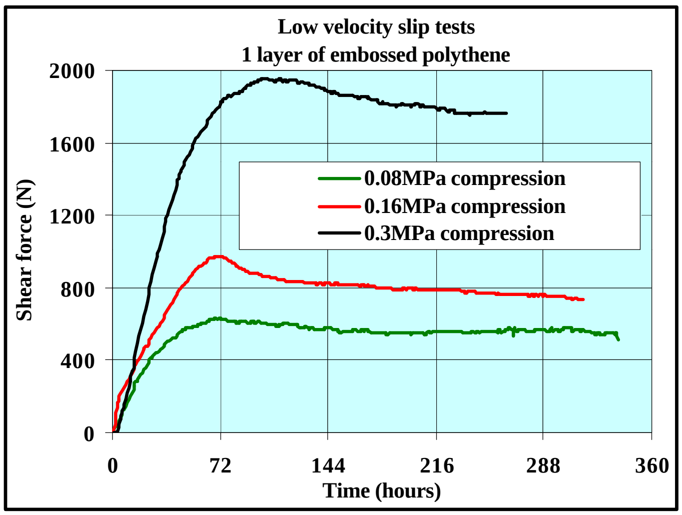

Figure 6 – Shear Force Evolution Curves

All evolution curves in Figure 6 are similar. This joint type exhibits relaxation of shear force/stress typical for viscoelastic behaviour at all three levels of vertical compression. The calculated pseudo viscosity of the joints is approximately the same regardless of the level of vertical compression and is ~0.018 MPa·s. This value is considerably smaller than the viscosity of polythene itself. It is also important that the shear capacity of this joint type under low velocity long term loading is on average 30% lower than the shear capacity of similar joint observed in shaking table tests [3, 4].

CONCLUSIONS

To complement previous short-term shear tests on slip joints, a study of their long-term performance is now underway at the University of Newcastle. Results of the concrete drying shrinkage tests have been found unsatisfactory. A new low velocity slip test has been developed instead. Preliminary results from the new test 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 satisfactorily;

- The test captures all the important aspects of the joint behaviour including the shear force and shrinkage strain evolutions and the shear stress relaxation. This test can therefore be used to estimate the pseudo viscosity of joints;
- A common Australian slip joint made of embossed polythene was tested at realistically low strain rates at three levels of vertical compression (0.08 MPa, 0.16 MPa, and 0.3 MPa);
- A pseudo viscosity of ~0.018 MPa·s was confirmed for this joint;
- The test program is continuing, both at higher levels of vertical compression and replicating tests at lower compression levels to allow design recommendations to be made.
- The increase in the level of vertical compression appears to cause proportional increase in the maximum shear stress in a joint. However, the long-term shear capacity of this slip joint type is found to be significantly lower than their short-term capacity. This should be investigated further before the "friction coefficient" approach to the estimation of the shear transfer capacity can be assessed with some certainty.

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