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REVIEW OF THE PROGRESS IN THIN BED TECHNOLOGY FOR MASONRY CONSTRUCTION

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ABSTRACT

Thin bed technology for clay/ concrete masonry is gaining popularity in many parts of the developed economy in recent times through active engagement of the industry with the academia. One of the main drivers for the development of thin bed technology is the progressive contraction of the professional brick and block laying workforce as the younger generation is not attracted towards this profession due to the general perception of the society towards manual work as being outdated in the modern digital economy. This situation has led to soaring cost of skilled labour associated with the general delay in completion of construction activities in recent times. In parallel, the advent of manufacturing technologies in producing bricks and blocks with adherence to specified dimensions and shapes and several rapid setting binders are other factors that have contributed to the development of thin bed technology. Although this technology is still emerging, especially for applications to earthquake prone regions, field applications are reported in Germany for over a few decades and in Italy since early 2000. The Australian concrete masonry industry has recently taken keen interest in pursuing research with a view to developing this technology. This paper presents the background information including review of literature and pilot studies that have been carried out to enable planning of the development of thin bed technology. The paper concludes with recommendations for future research.

KEYWORDS: Structural Masonry; Thin Bed Joints; Failure Mechanisms; Interface; Ductility.

INTRODUCTION

Construction of traditional masonry is labour intensive. In the developed economies, quality block layers are in high demand, and this situation is forecasted to become worse due to a general skills shortage and attractive choices of jobs for labour in allied industries. Australian masonry industry, like other engineering industries, is adversely affected by skills shortage. The Australian Competition and Consumer Commission (ACCC) made a determination (A90993, 2006), that there will be one-third fewer skilled masons in 2014 relative to 2005. This unmet shortage, even if the demand does not rise, will incur project delays with significant direct and indirect costs to the community. It is estimated that the cost of losing skilled masons to the society is $960M for this decade (2005 – 2014).

Attempts are being made to combat this problem through development of innovative products and/ or construction methods that would require minimal skilled labour. Dry-stack masonry employing vertical self aligning interlocking/ dovetail blocks or blocks with projecting lugs or tongue and groove, and high-stack units (Beall, 2000; Marzahn, 1997; Zeus & Popp, 2000; Dhanasekar et al. 2008) are some examples. These methods employ either reinforced grout filling or surface rendering with fibre reinforcement cement plaster for imparting resistance to out-of-plane loading, in addition to providing protection from weather (including rainwater ingress) requiring another specialised skilled labour essentially to impart ‘strength’.

With the advent of stronger binding materials, it has become possible to retain the benefits and reduce the demerits of the traditional 10mm low bond mortar joints (Dran, 1996; da Porto, 2005; da Porto et al. 2005; Fried et al. 2005; Walliman et al. 2008). The new binders help reduce the thickness of mortar to as low as 1mm and has shown that the thin bed glued masonry have quadrupled the lateral load capacity relative to conventional masonry mainly as it modifies the failure mode close to that of continuum products such as concrete walls, without excessive localisation of the failure path along the joints (Fig. 1). In theory, this would mean that continuum mechanics that do not adequately explain the behaviour of the conventional masonry might well be able to be applied rationally for the analysis and design of the thin bed masonry system as the new technology appears, eliminating the long standing concept of the joints/ interfaces as ‘planes of weaknesses’.

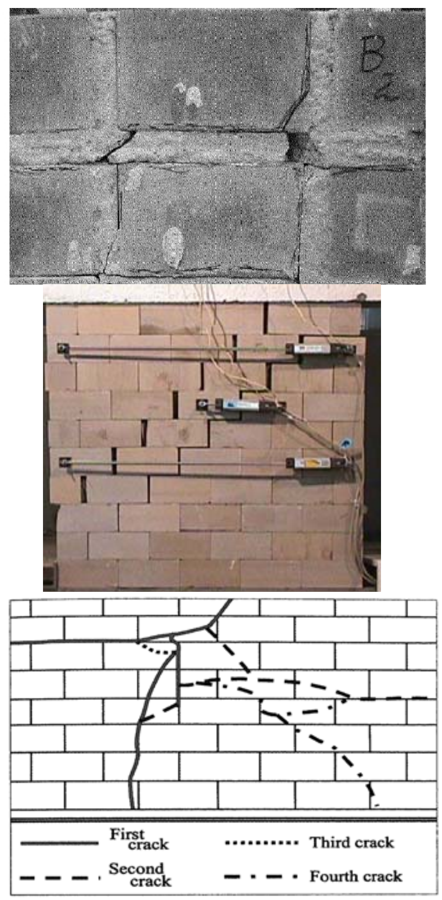

Figure 1: Modes of Failure under Shear: Traditional (10mm joint) Lourenco et al (2004); Dry Stack (0mm joint) Marzhan (1997) and Thin Bed (~2mm joint) Masonry Specimens (Fried et al(2005).

SIGNIFICANCE OF THIN BED MASONRY

The significance of the joint to inplane shear/ out-of-plane flexure can be inferred from the modes of failure of various types of masonry shown in Fig. 1. The 10mm conventional mortar joints fail due to a combined mechanism involving interface, mortar and unit cracking. The dry stack masonry fails entirely due to diagonal stepped mode in interfaces with no distress to the units. The thin bed glued masonry failure exhibits only a limited influence of joints. *Thus it can be inferred that both the conventional and the dry stack techniques exhibit* *significant effect of the interface to the modes of failure of masonry leading to localisation; the thin bed technology, on the other hand, shows that it has the potential to modify the failure mode with no obvious localisation, thus minimising the effect of joints.*

As shear failure mechanism in conventional masonry is rather complex and is dominated by the interface, many ideas have emerged resulting in a varied spectrum of test setups shown in Fig. 2, with none regarded truly applying pure shear (the Australian standards do not provide a standard test for shear strength determination). Identifying an appropriate test method for thin bed masonry shear strength determination will equally be challenging. However, the non-dominance of interface might aid development of some simplified techniques. It therefore appears that it is possible to develop appropriate binder – unit combinations such that the interface bond is maximised to modify the masonry closer to that of a continuum.

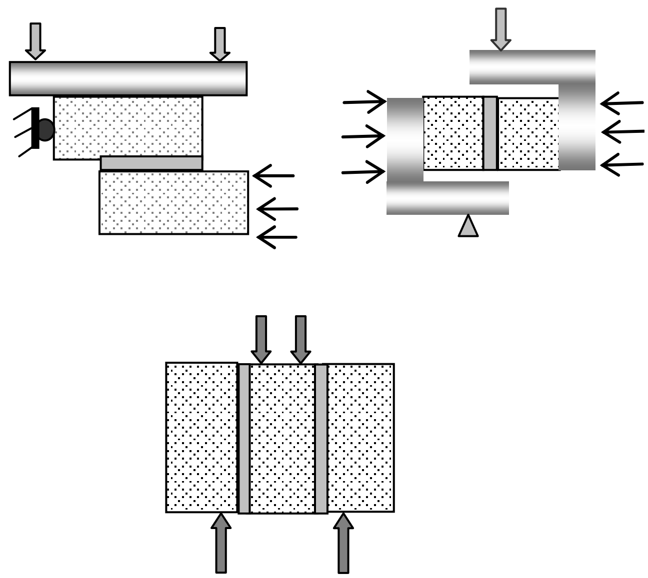

Figure 2. Various Methods of Testing of Masonry Shear

As the proportion of the volume of the joints to the volume of masonry reduces, thin bed joint masonry systems can be proven as lower emission products (due to reduction in Portland cement usage) compared to the conventional masonry system. Where polymer replaces cement, the glue mortar could further improve the emission credentials of the thin bed concrete masonry.

The *significance* of thin bed technology to masonry then may be summarised as follows:

- the technology will minimise the reliance on skilled block layers;
- thin bed masonry, unlike dry stack masonry, will *not* require reinforcing and grouting or external surface rendering to impart structural strength;
- thin bed masonry utilises highly engineered units of higher dimensional tolerance with the resulting product reducing the variability that plagues the design of conventional masonry, thereby enhancing the competitiveness and reliability of masonry as a structural material;
- thin bed technology will promote high levels of quality assured binders and processes of application that will minimise the risks to the health and safety of the semi and unskilled labour that will construct walls;
- the thin bed technology will minimise the effects of interfaces as *planes of weakness*; it will, therefore, be possible to develop continuum mechanics damage theories without resorting to the complexities of localisation and/ or interface characteristics;
- thin bed technology will produce low carbon emission masonry product due to lower usage of Portland cement, especially in binders.

All European research thus far has proven that thin bed masonry is competitive. Attempt is being made such that the Australian communities are provided with this state-of-the-art technology to potentially improve self-build ability and general housing affordability, a pressing social problem, especially amongst the first home buyers market.

STRUCTURAL ASPECTS OF THIN BED MASONRY

The effect of the thickness of mortar joints to the compressive strength of conventional masonry is well established in the literature, and it is well recognised that the joint thickness adversely affects the strength. For modern masonry constructed with bricks/ blocks and mortar, there has been a world wide recognition of standardising the mortar joint thickness as 10mm; for stone and random rubble masonry, the thickness of masonry generally is much larger (20mm ~ 25mm). Autoclaved aerated concrete (AAC) masonry uses glue for connection of one unit with the other, with the average thickness varying from 2mm ~ 5mm. Marzhan (1997) has shown that masonry with bed joints less than 5mm exhibits relatively less scatter compared to the common 10mm joints; this provides scope for developing stronger and *low variability* masonry with the thin bed joint technology.

It is well recognised that mortar (due to incompatible tangential displacements at the interface) is primarily responsible for inducing cracks in the masonry units parallel to the direction of primary compression. By improving the quality of the interface (improved bond due to adhesion), it therefore appears possible to eliminate the incompatibility of tangential deformation between the units and the mortar at the interface, with the resulting product not necessarily inducing tensile failure in units (thus improving masonry strength (Sarangapani et al, 2005). Effect of thickness of mortar joints is thus recognised for compressive strength; however, its effect to the flexural/ shear behaviour of masonry is less well understood with no theoretical framework reported in the literature.

Vermeltfoort (2004) conducted biaxial tests (Fig. 3) on thin bed masonry panels and developed a shear – compression failure envelope. The bed joint was raked to improve the aesthetics; a finite element analysis of the raked joint was shown to have caused a 'notch' effect leading to tensile splitting of the masonry unit. The masonry units were clay shell blocks; the tensile splitting stress was critical for such units. The sensitivity of the Australian concrete masonry units to the effects of raked joints requires careful examination.

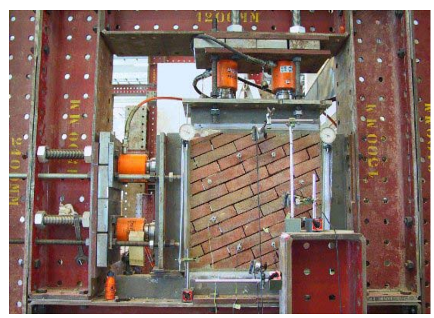

Figure 3: Thin bed masonry under biaxial loading (Vermeltfoort, 2004)

CONSTRUCTION ASPECTS OF THIN BED MASONRY

The advent of thin bed masonry has prompted the European engineers to develop robots for construction of walls either at site or at factory (PritSchow et al. (1996)). Precision and speed were the issues addressed by the robot. In these early days, these robots could be viewed as assistants carrying out straight wall constructions with the experience block layer masters completing more complex corners and openings.

To date many publications report glued thin bed technology for clay shell, where the glue bed is formed using a hand-held gun or a box rolled along the bed discharging the mortar achieving higher tolerance. Alternate technique of forming thin bed includes dipping of the units in a mix of liquid consistency prior to placing in a specific course of the wall. The method of forming thin bed is extremely important, because this technology requires in-depth understanding of the bond, deformation and failure mechanisms of this new product to ensure that both the risks to the structural adequacy of the walls, and to the semiskilled or unskilled labourers who are encouraged to build the walls, are minimised.

One of the minor detailing that could lead to catastrophic failure of thin bed masonry is the potential to fracture at raked joints as they act as notches in a continuum subjected to inplane tension stress field. A finite element analysis of a thin bed assembly by Vermeltfoort (2004) has revealed that the wall with raked thin bed joint has the potential to generate stress intensity factors significant enough for initiation of Mode – I cracks as shown in Fig. 4.

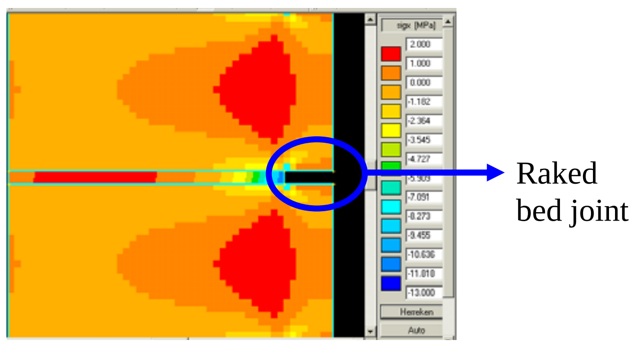

Figure 4: Behaviour of Raked Thin Bed Joint under Inplane Tension

Increase in flexural, shear and compressive strength of masonry is regarded as a significant advantage for the construction of long/ tall walls without the need for regular cross walls/ engaged piers/ bond beams offering lateral support by Walliman et al (2008). They strongly recommended the thin bed brick walls be fabricated in a factory environment rather than leaving it to unskilled/ semi-skilled labour to deal with the high-tech product at site; their main concern was perhaps linked to site supervision and certification of 2mm ~ 3mm thick joints – especially, their uniformity and integrity. Much research is needed to simplify site inspection if the original intention of making this product available as a 'do-it-yourself' system. Detailing of standard width and height door/ window panels within thin bed masonry walling offers much challenge. Need for education of practising engineers on masonry in general is also cited as impediment to larger adoption of this product. It is clear that much research on constructability and site adoption, especially with reference to environmental ambient temperature/ humidity is urgently required if one were to take advantage of the structural and material level advantages the thin bed technology offers to masonry construction in the context of building applications.

RECENT PROGRESS IN AUSTRALIA

The clay masonry industry in Australia has recently developed thin bed technology (known as *slick brick*) through certification from BRANZ (NZ), by carrying out standard tests for design compliance to capacity design provisions in AS3700, the masonry structures standard (Inglis, 2003). No information on deformation/ drift/ ductility could, however, be found.

In Australia, Autoclaved Aerated Concrete (AAC) masonry routinely uses thin bed technology. However, as AAC is a light weight product that could be sawn at site, it is expected that the interface bond issues will be quite different to that of the CMU. Similar technology for concrete masonry is not yet available in Australia.

Several pilot tests on flexural response of thin bed concrete masonry, constructed using thixotropic epoxy resin adhesive mortar and high stack CMU available in the market have recently been performed at QUT's structural engineering laboratory. All beams are constructed as stack bonded prisms using six 'high-stack' blocks of dimension 200mm × 200mm × 200mm as shown in Figs. 5a and 5b respectively. High-stack blocks are precision units manufactured specifically for drystack masonry. Thixotropic epoxy adhesive mortar, commonly avaialble in the market, was used in the construction. It was not easy to use the mortar as the mortar mix was too stiff for ease of spread based on manufacturer specification; it took much time to gain control thickness. The failure surface of some beams is shown in Fig. 5c.

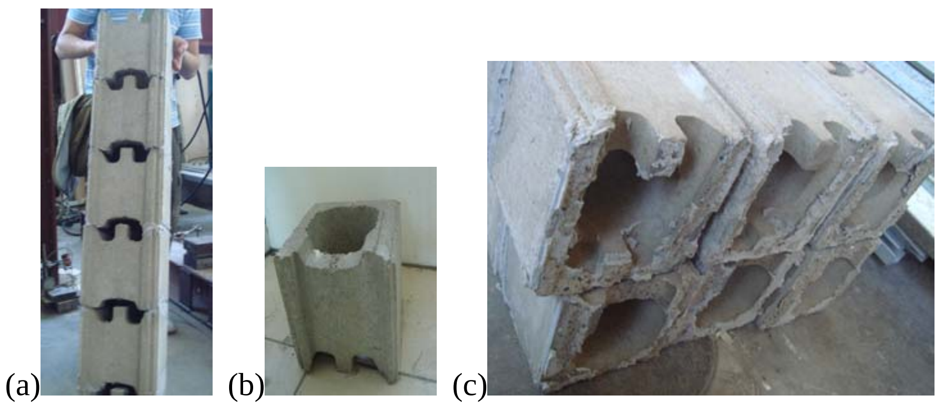

Figure 5: Pilot testing of thin bed concrete block masonry

A typical load-deflection curve obtained from the testing is shown in Fig. 6. In spite of quite ordinary construction quality, the bond failure was not sudden as exhibited by the excellent post peak curve in Fig. 6.

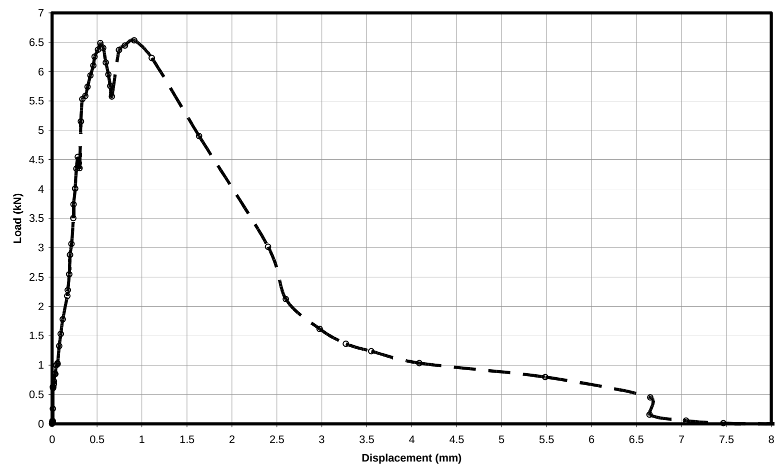

Figure 6: A typical load-deflection curve obtained from the pilot testing

The ductility of the beam specimens tested within 24 hour of fabrication, although much improvement is required to perfect the methods of application of the binder and the control of thickness of joint, has shown remarkable consistency, which encourages further development of the technology, using Australian concrete blocks and binders.

RECENT PROGRESS IN THE EUROPE

Thin bed technology is believed to have been developed in Germany prompting much research in Italy, Netherlands and most recently in the UK. Different thin joint construction systems are used in the various European countries, according to the local practice and traditions: aerated autoclaved concrete units, calcium silicate units, perforated clay units for load bearing walls (but also infill walls), and solid clay bricks for veneer or multi-leaf walls, particularly in the Northern European countries (da Porto, 2005).

Although these new types of masonry are recognized by the Eurocode 6, very often the various national codes lack in the definition of strength characteristics. Moreover, only the construction of masonry made with filled head joints and bed joint of ordinary thickness has been, traditionally, allowed in seismic zones. However, the latest version of the Eurocode 8 defers the permission of using different masonry types in seismic areas, according to the classes of perpend joints, to each country (EN 1998-1, 2004), and does not give any recommendation for thin joint masonry construction in seismic areas. As thin bed technology has been developed in countries not prone to seismic risk, but it is rapidly spreading throughout the seismic prone countries, the current European research is mainly aimed at evaluating its seismic performance. Experimental research is carried out by means of in-plane cyclic shear-compression tests, in order to gather information not only on strength of walls, but also on ductility, displacement capacity, energy dissipation, equivalent viscous damping, and stiffness degradation. Besides tests on masonry panels, also full scale tests on sub-assemblies or model buildings, with pseudo-dynamic or dynamic procedures, are being conducted. Numerical analysis are aimed at calibrating simplified or more advanced seismic design procedures for these masonry types, and at clarifying the effect of the unit and/or joint type on the overall behaviour of the wall.

Extensive experimental research aimed at defining the in-plane cyclic behaviour of load-bearing masonry walls made with vertically perforated clay units and thin bed joints was carried out in Italy. The system was compared to masonry with ordinary bed joints and units with mortar pockets or with tongue-and-groove (da Porto, 2005). Experimental behaviour was reproduced by an analytical model able to predict the lateral load-displacement curve in case of shear failure of the unreinforced walls. Based on this, non-linear dynamic analyses allowed defining values of load reduction factors for the three masonry types, to be used in linear static analysis (da Porto et al., 2009a). Furthermore, non-linear static finite element analyses allowed gathering information on the influence of the bond arrangement and the unit strength on the in-plane cyclic behaviour (da Porto et al., 2009b). Recently, in-plane cyclic tests on different types of clay masonry walls, including thin bed joint masonry, were again carried out in Italy (Magenes et al., 2008b). From both works, it emerges that no dramatic differences are found, at the ultimate limit state, between different types of clay masonry, with thin bed joints or other types of bed and perpend joints, although some slightly lower displacement capacity values can be found for thin bed masonry.

Similar types of tests (in-plane cyclic shear-compression tests) are being carried out also on calcium silicate masonry with thin bed joints (Magenes et al., 2008a), and on AAC masonry with thin bed joints (Penna et al., 2008). In the latter case, both unreinforced and also lightly reinforced AAC masonry specimens, with horizontal trusses placed in unit recesses, have been tested. The results obtained on AAC specimens have been also used to calibrate more modern displacement based design procedures for the seismic analysis of masonry buildings (Costa et al., 2008). Tests on edge-ground perforated clay units and calcium silicate units were also carried out on model buildings by means of shake table. Thin bed masonry was compared with similar masonry, built with ordinary joints, and tested with or without confinement (Tomazevic et al., 2004). Meyer et al. (2008) carried out shaking table tests only on thin bed joints model buildings. Pseudo-dynamic tests on model buildings and sub-assemblies are also being recently carried out (Anthoine et al., 2008).

SUMMARY & RECOMMENDATIONS

The background and the research to date on thin bed technology for masonry walling have been reviewed. Progressive contraction in the skilled labour appears to be the prime reason for the industry bodies to align with the academia in developing thin bed technology for masonry. From purely the point of view of technology, there appears enough evidence that

- constituent materials can be produced at high level of quality and precision for making thin bed masonry a viable construction system
- thin bed masonry attains strength quickly, which makes the system viable for faster construction
- thin bed masonry attains higher strength relative to other forms of masonry, which makes the system viable for long and/ or tall walls eliminating need for many cross walls
- the compressive strength of thin bed masonry tends to approach the strength of blocks
- the shear and flexural strengths of thin bed masonry is not significantly affected by the interface bond behaviour
- thin bed masonry performs similar to continuum under loading without significant influence of the interface
- the ductility of thin bed masonry is quite sound

- much research is ongoing for examining the suitability of thin bed masonry in seismic areas, especially in Europe.

Thin bed masonry can be constructed easily using varied systems of application of the ‘glue’ mortar/ binder. Use of raking in joint, however, appear leading to catastrophic failure due to the Mode – I stress intensity factor potentially exceeding the threshold level. Another matter that puzzles people in construction research is the difficulties associated with site supervision of quite thin joints for uniformity and structural integrity; therefore, suggestions emerge for prefabrication within industry setting.

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