How Mud Bricks Work- Using Unsaturated Soil Mechanics Principles to Explain the Material Properties of Earth Buildings - A year of research

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Abstract
This paper presents work which has been carried out between January 2009 and January 2010 in the field of mud brick construction. At the 2009 Engineers Without Borders UK research conference I presented a paper entitled ‘Using Unsaturated Soil Mechanics Principles to Explain the Material Properties of Earth Buildings’. That paper outlined some of the ideas formed during my PhD thesis, and this paper describes some of the work which has been carried out in this field during the past year. I am not directly involved in the vast majority of this work, but have been consulted on some aspects of it and present this paper as a review of the state-of-the-art of the work, with the hope that it will continue in the future.

Keywords
Earth building, mud brick, unsaturated soils

Introduction
Research presented at the 2009 EWB research conference (Jaquin 2009a) outlined work which had been carried out over the previous three years as part of a PhD at Durham University (Jaquin 2008). This work showed that the strength and stiffness of mud bricks is a function of the negative pressure of water in the pores (suction) and that this negative pressure is a function of the relative humidity of the pore air.

At the time of last year’s conference, the PhD research was completed, and a number of undergraduate and Master’s students were beginning to develop work in this area. This paper outlines the research which has been carried out since. I do not claim credit for any of this research, but it is research into which I have had some direct input. There are also research projects into earth building with which I am not involved, and so this paper represents a fraction of the current research ongoing into earth building.

The state of current research
The field of earth building is probably both the oldest and youngest research area. Earth buildings have been constructed for thousands of years, and the techniques are simple to learn and easy to implement. However the science behind these structures is only now being uncovered, and there are still huge gaps in the understanding of earth as a building material.

Earth building occupies a relatively unique niche in structural engineering terms - non-engineered earth buildings have existed for thousands of years, indeed around 20% of UNESCO World Heritage sites are constructed in earth. Only recently have guidelines been developed to allow the engineering of earth buildings (NZS:4297 1998 in New Zealand and the Lehmbau Regeln (Volhard and Röhlen 2009)) in Germany. A review of international design codes for rammed earth building was undertaken by Walker and Maniatidis (2003) and a guidance book has recently been published (Walker, Keable et al. 2005). However development of such design codes has been held back by the lack of engineering understanding of the construction material and this still lags behind more common construction materials such as steel and concrete. This is now being addressed by researchers around the world. The fundamental understanding of the physics and chemistry which are at play in dried mud bricks is only now being uncovered. Therefore there remain relatively few field implementations of the current research.

This paper presents current academic research under three discrete subject areas. Materials testing and structural mechanics - understanding the properties of the soil from which the walls are constructed, and the structural behaviour of the walls; Low Carbon and building physics - investigating the in-situ behaviour of earth walls, and developing the use of earth as a low embodied energy building material; research into the protection of Heritage structures - research has presented methods to improve the analysis and repair techniques used.

Materials testing and structural mechanics
There are currently a number of researchers delving into a deeper level of understanding of the fundamental processes at play in earth walls. This work lays the foundations for the understanding of how earth behaves structurally, which will enable its adoption as a more mainstream building material.
Lead by Charles Augarde at Durham University, Chris Beckett is undertaking a PhD researching the microstructure of rammed earth and the compaction of soil, using Particle Image Velocimetry (detailed in Beckett and Augarde 2010). At Imperial College London, Harriet Kirk investigated the behaviour of low plasticity soils for rammed earth (Kirk 2009).

In Australia, cement stabilised rammed earth is a relatively mainstream building material. Research is continuing at the University of Western Australia, with a research group having been recently set up under Daniela Ciancio. The group is working with rammed earth contractors in Western Australia to develop structural understanding of the material. Research undertaken by this group includes wind loading on rammed earth walls (Wijewardane 2009) and the use of steel reinforcement in rammed earth (Robinson 2009 and Ho 2009). Dawn Feddersen is undertaking a research master’s degree investigating the water:cement ratio in stabilised rammed earth.

Whilst being a visiting research fellow at Bath University, I was able to arrange an undergraduate project using the shaking table at Bristol University. Early aspects of this research are presented in Hardwick and Little 2010. This research compares the behaviour of earth bricks to those of fired bricks in seismic situations. Current guidelines (e.g. Minke 2000) propose that masonry design guidelines can be adapted for earth buildings. There is however little experimental evidence of the behaviour of unreinforced earth bricks compared to fired masonry, and this project aims to fill that gap.

Low carbon building and building physics

Earth buildings are construction methods which do not require a high energy input, such as is needed in a blast furnace for the production of steel, or in a kiln for the production of cement. An earth wall may have a lower embodied energy than the same wall made in steel or concrete. Therefore in the correct context, earth walls may be a lower carbon alternative to traditional construction.

In addition to the low embodied carbon in earth buildings, earth walls are known for their ability to balance the relative humidity inside buildings and to provide thermal mass, reducing the heating and cooling requirements for the structure. Celia Macedo is undertaking a PhD Oxford Brookes University investigating the Thermal performance of earth buildings, and it is hoped that this will allow earth buildings to be incorporated into design guidelines as an alternative to high energy input Heating, Ventilation and Air Conditioning systems.

During my time at the University of Bath in the summer of 2009 I undertook research into the movement of water in earth buildings, developing an understanding of how relative humidity is balanced by earth walls. Aspects of this work are available in Jaquin 2009b.

Antonio Borges, supervised by Andrew Heath is undertaking a Research Masters degree investigating this subject in much more detail, to enable better prediction of the movement of water in earth buildings.

Heritage structures

Around 20% of UNESCO world heritage sites are earthen construction, and there are many other historic structures made from earth. The preservation of these structures has previously been haphazard and with a varying quality of results. Recent work (e.g. Jaquin, Gerrard et al. 2010 and Canivell, Jaquin et al. 2010) proposes methodologies for the analysis and repair of these structures. A recently begun European research project (New Integrated Knowledge Based Approaches to the protection of cultural heritage from Earthquake induced Risk) aims to look at using some of the understanding being developed to protect heritage structures from seismic risk.

Hopes for future research

There is much research which still needs to be carried out in this field. The final aim of such research is to bring the standard of mud brick building to that of more common modern building materials such as steel and concrete. In order for this to occur, the volume of research must dramatically increase, and standards from bodies such as ISO must exist for earth building materials. However, such codes cannot be written without the scientific understanding which underpins them.

With such research, and the development of internationally recognised codes and standards, it becomes much easier for organisations such as Engineers without Borders to present solutions to problems such as emergency and permanent shelter provision using mud bricks; assessment and repair of earthquake damaged structures; and the development of low carbon building technologies around the world.
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