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Effect of moisture condition on mechanical behavior of low strength brick masonry

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ABSTRACT

The purpose of the research presented in this paper was to determine the influence of moisture on mechanical properties of brick, mortar and masonry. The strength of masonry structure was primarily influenced by a number of factors such as brick/block, bedding mortar, construction quality, pre/post environmental condition, etc. Among the factors affecting such behavior, the presence of moisture plays a key role in the deteriorating state of masonry structures. For this reason, in the present paper the compressive strength of bricks, cement mortars as well as compressive, shear and bond strength of masonry prisms are investigated, in oven-dry, air-dry and wet conditions. The experimental results demonstrate that moisture significantly reduces the compression strength of a brick and cement mortar; the greater the moisture content the lower compression strength. However, the compressive strength of masonry not improve in oven-dry condition, but reduce in wet condition. Moreover, shear and bond strength of masonry reduce with increase in moisture condition.

1. Introduction

Masonry was used widely as the predominant building material before materials such as concrete and steel have been introduced in construction. Brick masonry is still the most popular building material particularly in developing countries due to its easy handling and low costs in construction. Besides, brick masonry provides many additional advantages such as aesthetics, effective heat and sound isolation, fire resistance and economical construction. Due to its many advantages, brick masonry is widely used for the construction of residual houses and infill wall of concrete frame structures that are exposed to the various environmental condition. Also, masonry structures are more vulnerable to extreme natural events like earthquake, windstorms, floods, etc. Therefore, to understand the factors affect the structural behavior of masonry under the different extreme environmental condition, become a critical issue. It was found that the masonry strength was primarily influenced by a number of factors such as brick/block, bedding mortar, construction quality, pre/post environmental condition, etc. The presence of moisture plays a key role in the deteriorating state of masonry structures.

Moisture in external masonry can originate from a number of sources such as;

- Rising damp occurs when groundwater flows into the base of a construction and is allowed to rise through the pore structure [1].
- Rain, particularly when driven by strong winds, can penetrate the masonry walling, typically at mortar joints
- Moisture vapor transmission from activity within a poorly ventilated building.

With unwanted moisture intrusion, masonry units and mortar can crack. When water enters brick or mortar, thermal expansion can cause spalling in the masonry structure. Eventually, spalling can cause large sections of the masonry to crumble and fall off, potentially leading to structural damage. Other adverse impacts include deterioration in strength of masonry and deterioration of the wood or steel, which are part of the masonry structure. In addition, there are some aesthetic impacts such as efflorescence, failure or staining of interior finishes, the growth of biological organisms and worsening odors. For engineering point of view, decreases in the strength of masonry are critical to understand the safety of structure during moisture changes.

The change in moisture content caused by wetting and drying has a considerable effect on the mechanical properties of masonry [2–4]. Masonry contains a great number of voids comprising gel pores, capillary pores and flaws. At the two extremes, these voids may either be fully filled with water (wet saturated) or fully filled with air (dry). Under intermediate conditions, a mixture of water, water vapor and air may be present in the void. More often than not, brick walls are subject to strong moisture during use, and in exceptional circumstances, complete water saturation can be reached in masonry materials. The water

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can have different origins: wind-driven rain, flooding, capillary rise from the ground and hygroscopic salts. An increased moisture content of masonry structures always had a negative impact on the utility value of the particular building. Many studies have been conducted on the evaluation of effect due to environmental in historical masonry structure [5–8]. These studies demonstrate that in historic structures, the increased moisture of vertical masonry structures occurs rather often. Experimental studies by Foraboschi and Vanin [7], Witzany et al. [9] and Amade et al. [10] presented that, a decrease in masonry compressive strength in the water saturation state ranging from a few to over 20% compared to strength in the air-dry state.

Even modern brick masonry walls absorbed water just as old masonry walls. Especially in developing countries, bricks were softer and more porous and tended to take on more moisture. Also, nowadays, joint mortar and surface finishing mortar consisted of less cement content and due to that, the mortar was softer and more porous, all of which increases water absorption. Water absorbed by brick and mortar increases moisture content in the masonry wall and it is the primary element for masonry strength deterioration.

Although a considerable amount of work has been done in the area of brick masonry, most of the work, however, has been performed on masonry at the normal environmental condition, and very few research is performed on the effect of moisture on strength of brick masonry. The effect of water saturation has been investigated for ceramics and concrete, its consequences on the mechanical behavior of brick masonry still require in-depth elucidation [11]. European standard EN 772-1 [12] suggests that compressive strength of masonry units in air-dry condition should be considered as 0.8 times of oven-dry units or 1.2 times of wet units. However, the literature review shows unequivocal results [11].

Franzoni et al. [11] investigated the moisture effect on compressive strength of cement and lime based mortar prisms and masonry triplets with cement mortar layers. Solid fired-clay bricks having size $55 \times 120 \times 250\,mm^3$ were used for these tests. For the manufacturing of the joint mortars, two kinds of the mix were selected: Portland limestone cement and natural hydraulic lime. Compressive strength and static elastic modulus of masonry were investigated under dry, wet and normal environment moisture conditions. The results suggest that the compressive strength and young modulus variations in the wet state quite limited and show low strength in normal environment moisture condition. Masonry prisms subjected to dry and wet condition induce an increase in compressive strength of 17% and 14%, respectively compare with prism subjected to normal environment moisture condition. However, this is a different trend than expected, where compressive strength of masonry prism subjected to normal environment moisture condition in between dry and wet condition. Franzoni et al. [13] investigated the shear strength of masonry prism with cement and lime based mortar subjected to the dry and wet condition. Results show that shear strength depends on the moisture condition and mortar type. Masonry prisms with cement and lime based mortar subjected to wet condition induce a decrease in shear strength of 5.3% and 4.4%, respectively compared with prism subjected to dry condition. These studies were obtained using high strength fired clay brick with compressive strength closer to 30 MPa and elastic modulus around 11 GPa. Also, two types of mortar used for this experiment mainly one of hydraulic lime mortar and one of cement mortar, which is normally not used in developing countries for masonry construction.

Made et al. [14] investigated the moisture effects on masonry prism compressive strength. Masonry cement mortar and Portland cement/lime mortar were used as bed mortar to constructed the masonry prisms. For masonry prisms with masonry cement mortar, the average dry and wet compressive strengths were 37.83 MPa and 32.37 MPa, respectively. There is a 14% strength reduction for wet prisms, compare with a dry one. For Portland cement/lime mortar prisms, the average compressive strength for the dry and wet prisms was 44.53 MPa and 35.32 MPa, respectively. It shows 20% reduction in compressive strength in wet condition compares with the dry condition. The results indicate that the presence of moisture significantly reduces the compressive strength.

Foraboschi and Vanin [7] investigated the compressive strength of bricks subjected to the wet and dry condition by compression tests performed on bricks removed from a historical Venetian building. The results obtained from these tests show that average compression strengths of the dry brick and wet brick are equal to 11.3 MPa and 9.4 MPa, respectively. It demonstrates that wet condition significantly reduces the compression strength of the brick.

Matysek et al. [8] investigated the historical brick (produced in the 1880's) and modern brick compressive strength subjected to water-saturated state and dry state. The compressive strength of the brick in the water saturation state showed strength reduction of 11.3% and 21.4% for historical and modern brick, respectively. This demonstrates that compressive strength of the brick in the water saturation state was worse than in the dry state.

Most of these previous researchers were focus on strong brick units. However, masonry structures in developing countries have a tendency to perform badly due to the low strength of the masonry unit, the low-quality mortar used and the lack of adequate connections between walls. Typically, masonry houses in developing countries are built by house owners themselves or by local masons without any formal engineering supervision. The quality of masonry house construction is often low due to the lack of engineer's supervision involved [15]. Major types of damage patterns observed in masonry buildings are in-plane shear failure, out-of-plane collapse, corner failure and roof collapse. A masonry wall at any point can be under vertical compressive load, in-plane lateral load and out-of-plane load. Mainly, compressive, shear and bond strength are three major mechanical properties of masonry are responsible for these failures. Bricks available in developing countries have a low compressive strength in addition to higher porous. Also, relatively stronger mortar cement-sand mortar used for bed joints instead of natural hydraulic lime mortar. Hence masonry with low-quality bricks and cement-sand mortar considered will be necessary for a better understanding of the mechanical behavior of wet and dry masonry in developing countries. Also, previous research study about the effect of moisture on shear and bond strength of masonry, still scarce.

Therefore, new experimental program, taking into account these aspects, is executed. The purpose of the research presented in this paper was to determine the influence of moisture on mechanical properties of brick, mortar and masonry. This study uses three different types of mortar mixes used for masonry prisms and investigates how moisture affects prism compressive, shear and bond strength. In this research, three different conditions were used which were based on BS EN 772–1 [12] as (a) Oven dry – the samples were dried to constant mass at 105 °C and then left to cool to ambient condition (30 °C) before testing. (b) Air-dry – samples stored in a controlled environment of 30 °C and 90% relative humidity for a minimum of 14 days before testing. (c) wet – samples were fully merged in water for 24 h and left to surface water wipe off before testing. Specimens of single materials (brick and cement-sand mortar) and masonry prisms were tested in oven-dry, air-dry and wet conditions.

2. Experimental program

2.1. Materials used

Commercial solid fired-clay bricks having size $205 \times 105 \times 55\,mm^3$ were used for the tests. For the manufacturing of the mortars, three kinds of binder were selected: Mortar designation (ii), (iii) and (iv) according to BS EN 1996 [16]. For the preparation of mortar, Ordinary Portland cement and river sand was used. River sand with a maximum grain size 3.6 mm was used as fine aggregate. Mortars were prepared in a mixer with a 1:3, 1:5 and 1:7 cement: sand ratio of