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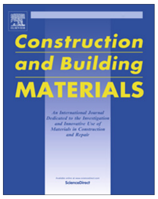

Characterisation and strategies for mitigation of the contact surface unevenness in dry-stack masonry

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HIGHLIGHTS

- Drystack masonry suffers from surface unevenness related stress concentration.
- Matrix based tactile surface sensors were used to quantify contact pressure.
- Micro finite element for surface unevenness was formulated and validated.
- Strategies for mitigating stress concentration examined.

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ABSTRACT

Contact surface unevenness of the dry-stackable, interlocking blocks adversely affects the constructability of the drystack system. This paper presents the contact surface characteristics of these blocks and strategies for mitigating the unevenness through systematic experimental and numerical studies. First, the contact surface characteristics of the dry-stackable blocks have been examined experimentally using matrix based tactile surface sensors (MBTSS). High peak pressure locations on the contacting interfaces have been identified; these locations have remained unaffected by the level of the applied load in the experiment. A micro finite element modelling method incorporating the uneven contact surface has been formulated and the parameters calibrated using the experimental data. Two strategies for minimising the contact surface unevenness are then proposed (1) grinding of the surfaces of the blocks and (2) embedding a packing material between the surfaces. Both strategies have been analysed through the finite element model. The peak contact pressure is shown to have reduced considerably for the grinding strategy and when an auxetic fabric is used as an insert between the contacting surfaces of the blocks.

1. Introduction

Masonry is, perhaps, the oldest construction material in the market. Its performance is highly dependent on the quality of the skilled labour laying the mortar joints. To reduce the costs of labour, several approaches have been trialled in recent years; laying thinner mortar joints through semi-skilled labour using hand-held tools [1–4] and eliminating the mortar layers through the use of interlocking blocks and relatively low skilled labour [5–10]. Drystacking also eliminates shrinkage cracking of the mortar joints typical of the mortared masonry [11].

On the negative side, the units must be manufactured with higher precision of their height and surface evenness. Projections of hard particles as random interstices on the contacting surfaces can adversely affect the constructability as these interstices could act as pivots leading to rocking, which would be safety hazard and drag on productivity at site.

The strength of the drystack hollow masonry is shown to be affected by the surface unevenness of the bed joint in [8]. Reduced stiffness and strength was observed due to the uneven interfaces in experimental investigations [8–10].

The surface unevenness (presence of random interstices) prevents the conformal contact between the contacting interfaces of the blocks. Experimental and numerical predictions of the joint closure characteristics of drystack masonry is reported in [9,12] and [13–14] respectively; however, the contact area and the contact pressure of the drystack blocks have not been examined widely. In [15] the characteristics of the dry joints have been examined through a sheet of carbon paper laid between two dry-stack blocks. They visually inspected the carbon paper impressions for inferring the distribution of the pressure. They reported that under

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the compressive load, the interstices collapsed, which indicated presence of either low strength particles or poorly compacted surrounding matrix. Had the interstices been of high strength coarse aggregates surrounded by well compacted cement matrix, they would have resisted much higher stresses without collapse. In [16] carbon paper impressions are used to estimate the contact area of dry surfaces of sun dried interlocking blocks. The current literature is limited to only the contact surface area characterisation of drystack masonry as the carbon paper impression could not quantify the contact pressure distribution.

In this study, matrix based tactile surface sensors (MBTSS) were employed for the first time in masonry research to ascertain the contact pressure and contact area of the dry interfaces under uniform compressive loading. MBTSS sensors are very flexible and thin like a fabric. Early work at University of Illinois on rail – sleeper contact has shown quite consistent results (Greve et al., [17]; [29]) with no evidence of the effect of the sensor stiffness to the results. MBTSS is shown to precisely determine the contact area and the contact pressure with the progressively increasing compression normal to the interfaces. The results presented in this paper also conforms to the University of Illinois' experience with the MBTSS for contact area and contact pressure determinations. In this study the contact pressure distribution along the face shell of the hollow interlocking block was shown highly non-uniform. These results were validated in this research using a micro FE modelling technique.

The validated model was then employed to examine two strategies of mitigating the unevenness of the surfaces of the blocks, namely: (1) grinding of the blocks and (2) embedding a filler auxetic fabric material between the bed joints. Grinding requires value adding in the factory, whilst inserting packing material can slow down the construction productivity at site; although these economic parameters are acknowledged, this research was solely focussed on the effectiveness of these strategies to the reduction in the high levels of contact pressure for improved structural efficiency.

One of the drawbacks of the mortar layer in the traditional masonry is its higher lateral expansion (which subsequently induce vertical cracking in the blocks) due to their higher (relative to blocks) Poisson's ratio. With a view to avoiding lateral expansion, auxetic materials with negative Poisson's ratio (NPR) were selected as embedding materials in this research. Effectiveness of auxetic materials in civil engineering applications is emerging and improved structural behaviour has been reported in [19–21]; a finite element method of analysis of composites is presented in [18].

The mechanical properties obtained from the testing of the PU and auxetic foam in [21] were used in the FE analysis of foam/fabric embedded bi-stacked prisms. From the results of bi-stacked prisms analyses, an optimum strategy was selected.

This paper is structured as follows: Section 2 presents the experimental investigation on the surface characterisation of drystack blocks. Section 3 reports the experimental results. Sections 4 and 5 present the formulation and validation of the numerical modelling technique respectively for the uneven contact surface in the dry-stack masonry. Strategies for mitigation of uneven contact interface are presented in Section 6. FE analysis of drystack wallettes with optimal strategies are described in Section 7. Conclusions are presented in Section 8.

2. Experimental investigation of the contact surface unevenness

The contact area and the contact pressure were determined using two matrix based tactile surface sensors (MBTSS) inserted between the two symmetrically located contacting surfaces of the face shell under monotonically increasing vertical compressive load. Hollow concrete interlocking blocks supplied by the local manufacturer were used in this investigation. Half and full blocks of gross dimensions 200 mm wide × 200 mm high × 190 mm thick and 400 mm wide × 200 mm high × 190 mm thick respectively as shown in Fig. 1 were used.

Two course (bi-stacked) prisms were used in the experiments. To measure the contact area and contact pressure, MBTSS sensors were inserted between the symmetric face shells of the blocks as shown in Fig. 2. Maximum load in each test was limited to well below the ultimate load of the blocks.

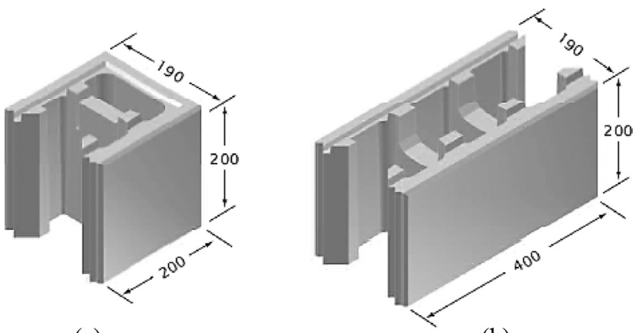
The MBTSS equipment is shown in Fig. 3, which contains a handle 'data acquisition electronics', a sensor and a software. For this experiment, two sensors each of which had dimensions sufficient to cover a face shell (30 mm wide × 200 mm long) of the concrete half block were selected. The sensor model having size of 264.2 mm × 33.5 mm and resolution of 25.8 sensels/cm^2 – shown in Fig. 3 was used. This sensor could record a maximum pressure up to 100 MPa. The sensor consists of an array of sensels that record the pressure and the area of contact during the test. There were 2288 sensels in each tactile sensor used in the tests.

2.1. Calibration of the MBTSS sensors

The sensors were calibrated for different loads to reduce the chances of error in the readings before carrying out the actual tests. Calibration correlates the digital output from the sensels to engineering units of force and pressure. A multi-point calibration method for multiple loads was used for improved accuracy and the process was repeated for ensure repeatability of the data. In this process, the sensor was inserted between the blocks and the specimen was subject to axial compression under displacement control; the Instron load cell reaction was monitored and the loading was stopped when the reaction attained approximately 20 kN. The test was repeated for increased load levels of 40 kN, 60 kN and 80 kN; thus, four sets of load tests were performed on each specimen. The maximum load in the tests was kept well below the expected failure load of 200 kN. The actual maximum load read from the Instron load cell and that obtained from the MBTSS software (integral of the pressure) are shown in Table 1. It can be seen that the error was less than 1%.

2.2. Testing

The calibrated sensors were inserted between the blocks – one on each face shell of the block. The assembly was tested using a 300 kN INSTRON machine as shown in Fig. 4. The specimens were subjected to monotonically increasing compression at a loading rate of 60 kN/min. The maximum load was kept as 100 kN to



(a) (b)

Fig. 1. Hollow concrete interlocking blocks (all dimensions are in mm). (a) Half block (b) Full block.