

SPATIAL CORRELATION OF FLEXURAL BOND STRENGTH FOR MASONRY WALLS: AN EXPERIMENTAL AND STATISTICAL STUDY

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SUMMARY

The unit flexural bond strength in clay brick unreinforced masonry (URM) walls is a key material property that affects their lateral load capacity. It is well known that the flexural bond strength of individual units (one unit is defined as a brick and the underlying mortar bed that brick is attached to) varies considerably between units, and that this variability might significantly affect the structural performance and reliability of URM walls in flexure. The paper describes an experimental program where six full sized clay brick URM walls were constructed to replicate field conditions. The walls were constructed by four masons to represent a range of mason workmanship. The timing and placement of different batches of mortar were closely monitored. The flexural bond strength of each unit in each wall was obtained using the bond wrench test. This provided the data for a statistical analysis to assess the spatial correlation of unit flexural bond strengths – i.e. the degree of correlation between units within and between courses, and how such correlation may depend upon the placement of each mortar batch and mason workmanship. It was found that there is little correlation between units either within or between courses. It is thus recommended that flexural bond strengths between units are statistically independent. The study also found that the clay brick wall unit flexural bond strengths best fit a truncated Normal probability distribution.

INTRODUCTION

Limit state specifications for design of clay brick unreinforced masonry (URM) in Australia, US, Canada and Europe have not been developed from reliability-based calibration methods but rather calibrated to past experience. Although it is commonly believed that current design models are conservative, the actual level of safety and reliability of masonry structures is unknown.

Very few studies have considered computational methods for calculating the structural reliability of masonry structures, and of the majority that have, the simplest loading condition only was considered; namely, vertical loading. Stewart and Lawrence (2002) developed preliminary ‘proof of concept’ techniques to estimate the structural reliability of masonry walls in one-way bending and showed that, based on structural configurations designed to the Australian Masonry Structures Code AS 3700-2001, the reliability indices obtained for masonry structures in flexure have a reliability that is somewhat higher than other structural materials. Stewart and Lawrence (2008) conducted a reliability-based code calibration of structural masonry in compression designed to Australian Standards and recommended that the capacity reduction factor for walls loaded concentrically in compression be increased from 0.45 to 0.75, resulting in a 66% increase in the compressive design capacity of structural

masonry. It is not unreasonable to presume that a rational reliability-based code calibration of structural masonry in flexure could also result in a recommended increase in the capacity reduction factor for the design of structural masonry walls in flexure.

A need clearly exists for developing theoretical and computational models to enable the accurate calculation of reliability for new and existing masonry structures in flexure. Although extensive work has been directed at developing predictive strength models for masonry, very little effort has so far been directed towards the issues of model error, unit strength and uncertainty, unit-to-unit spatial strength correlation and their effect on wall strength and reliability in flexure. A unit is defined as a brick and the underlying mortar bed that brick is attached to.

Stewart and Lawrence (2002) showed the significant effect that unit-to-unit spatial variability can have on flexural strength prediction and structural reliability. Spatial variability can be represented by the correlation length, which intuitively speaking, refers to the length over which strong correlation persists. Stewart and Mullard (2007) state that for some concrete material properties, a correlation length of approximately 2 m exists. Due to the repetitive use of one type of mortar and brick which is normally used to build a masonry structure, it is reasonable to presume that a significant correlation length could exist for some masonry material properties. In particular, it could exist for unit flexural bond strength, which Willis et al. (2004) identifies as one of the most important local mechanisms contributing to the moment capacity of masonry walls in flexure.

This paper reports findings from an experimental program and subsequent analysis of the data, conducted with the objective being to examine whether there exists any spatial correlation between unit flexural bond strengths in a clay brick URM wall, taking into account mortar type, mortar batch and workmanship factors. Four full sized walls were built at The University of Newcastle (Australia), and two full sized walls were built at the University of Sao Paulo (Brazil). After a minimum mortar curing period (specific times are presented below), each individual unit in each wall was bond wrench tested. This provided unit flexural bond strength data for each wall, which enabled a statistically significant spatial correlation analysis of unit flexural bond strengths and for characterization of the bond strength probability distribution. This probabilistic information can be used in the development of a reliability-based calibration method to determine the limit state specifications for structural clay brick URM walls in flexure.

WALL MATERIALS AND CONSTRUCTION

For the experimental program, two sets of experiments were conducted. The first set, conducted in Newcastle, Australia (NA), used four single leaf clay brick URM walls, each with dimensions of 4 m long and 2.4 m high. The second set of experiments were conducted in Sao Carlos, Brazil (SCB) and used two single leaf clay brick URM walls both with dimensions of 4 m long and 2.5 m high.

Newcastle, Australia Experiments

The four walls were built with one type of brick; namely an extruded clay brick with no holes and the absence of any type of indentation. The brick dimensions were nominally 230 mm long \times 110 mm wide \times 76 mm high and the mortar joints nominally 10 mm in thickness (standard practice in Australia). Each wall was 16.5 bricks in length and 28 courses high.

Two types of mortar were used. Walls NA1 and NA3 (Newcastle, Australia, walls 1 and 3) were constructed using standard 1:1:6 mortar with no additives (Type M3 mortar in AS 3700-2001). Walls NA2 and NA4 were constructed with a non-standard mortar mix (1.5:1:6 + "Mortar Mate" air entrainer (see <http://www.geocel.co.uk>)). This mortar is used extensively by masons in the Newcastle region in order to increase the workability of mortar; as beach

sand sourced from the region is notorious for its narrow grading, which makes the mortar unworkable.

All four walls were constructed by professional masons. Walls NA1 and NA2 were constructed by a reputedly high quality mason and walls NA3 and NA4 were constructed by a fair quality mason. The walls were built sequentially in the laboratory (indoors) over a one month period. Each wall was constructed to a height of 1.6 m the first day, and to completion the second day. As per Australian practice, two or three “mud-boards” were located equidistance along the proposed length of the wall. A mud-board is a flat board on which shovels of mortar from the initial mixing tub of mortar are placed, to facilitate ready access to the mortar. In the Newcastle built walls, because different amounts of water were added to each mud-board in the process of retempering the mortar, this produced sub-batches from the main mortar batch, with a sub-batch being considered as the mortar with a unique amount of water, located on a mud-board.

Sao Carlos, Brazil Experiments

Two walls were made with one type of brick; namely a pressed clay brick containing a frog on one face. The brick dimensions were nominally 210 mm long \times 100 mm wide \times 45 mm high and the mortar joints nominally 15 mm in thickness (standard practice in Brazil). Each wall was 17.5 bricks in length and 40 courses high.

One type of mortar was used to build the two walls, namely a 1:2:9 mortar with no additives. The 1:2:9 mortar was chosen for its low average flexural bond strength to ensure joint rather than brick failures during bond wrench testing. Clay bricks manufactured in Brazil are very low in strength, hence the need for low strength mortar. Wall SCB1 (Sao Carlos, Brazil, wall 1) was constructed by a reputedly high quality mason and wall SCB2 was constructed by a fair quality mason. The two walls were constructed outdoors, simultaneously over a five day period. Approximately ten courses of each wall were constructed per day. Mud-boards were not used during construction, so the mason trowelled mortar from the same tub of mortar.

Table 1 shows a summary of mortar types and mason quality used to build each of the experimental walls.

Table 1: Summary of mortar type and mason quality for the experimental walls

Location	Wall Reference Number	Mortar Mix	Mason Quality
Newcastle, Australia	NA1	1:1:6	High
	NA2	1.5:1:6 + air entrainer	High
	NA3	1:1:6	Fair
	NA4	1.5:1:6 + air entrainer	Fair
Sao Carlos, Brazil	SCB1	1:2:9	High
	SCB2	1:2:9	Fair

METHOD OF TESTING

The Newcastle, Australia walls were cured for a minimum of 28 days, but no more than 40 days before they were tested. The Sao Carlos, Brazil walls were cured for 3 weeks before testing. The flexural bond strength for each unit in each wall was then tested using the bond wrench test in accordance with AS 3700-2001. All units in one wall were tested before moving onto the next wall. For each wall, starting at the top course of the wall, the perpendicular (vertical) joints were cut through the depth of the course, down to the top face of the brick on the underlying course using a hack saw. The bond wrench was then used to remove each brick, one by one, recording its flexural bond strength and location in the wall. Once the top course was removed, the process was repeated for the second course from the top, and so on, until the entire wall was dismantled. The unit flexural bond strengths for the bottom course of

units attached to the underlying concrete base were not recorded as the flexural bond strength for those units would not have been representative of a common unit flexural bond strength due to the difference in extruded clay brick and concrete suction properties.

During the bond wrench testing of a course, the course beneath it was not restrained. However, in the SCB tests, it was found that in a small number of cases, the joint of the unit being tested did not fail but rather a small section of wall which included several bricks failed. Still pertaining to the SCB tests, in other units, it was found that the flexural bond strength of the joint was so low that the self weight of the bond wrench could not be supported by the joint and therefore the joint failed before a reading could be taken.

STATISTICAL APPROACH TO SPATIAL CORRELATION ANALYSIS

Generally speaking, correlation indicates the strength and direction of a linear relationship between two random variables. In order to conduct a spatial correlation analysis of units within and between courses in all of the six walls tested, each course of a wall is considered as a series of unit flexural bond strengths. The mathematical tool used to measure spatial correlation for a series of equispaced data points in the space domain is the autocorrelation function ρ_k , which is calculated for lag k using all pairs of values in a series separated by k . The number of units separating two points in a series is defined by k and can take on a value in the integer set $\{0, 1, 2, \dots, (N-2), (N-1)\}$, where N equals the number of equispaced data points in the series.

Intuitively, the autocorrelation function ρ_k is interpreted as a measure of the “similarity” or degree of correlation between each value in the series and a value located k units away from it. The value for the autocorrelation function ranges between 1 and -1. A correlation function value of $\rho_k = 1$ indicates that each value in the series is perfectly correlated with a value in the series k units away from it. A correlation function value of $\rho_k = 0$ indicates that each value in the series is not correlated with a value in the series k units away from it (i.e. statistically independent). A correlation function value of $\rho_k = -1$ indicates that each value in the series is perfectly negatively correlated with a value in the series k units away from it.

For a series of N observations z_1, \dots, z_N measured at locations i_1, \dots, i_N , Priestley (1981) shows that there are a number of estimates for the autocorrelation function but states that the bias estimate is the most popular variance estimator in time series analysis. Moreover, Fenton (1999) states that the bias estimate produces a slightly smaller expected error variance than that of the unbiased case. For these reasons, the bias estimate of the autocorrelation function is used for the spatial correlation analysis. The bias estimate of the k^{th} lag autocorrelation function value is defined by

$$\rho_k = \frac{\frac{1}{N} \sum_{i=1}^{N-k} (z_i - \mu(z))(z_{i+k} - \mu(z))}{\sqrt{\frac{1}{N} \sum_{i=1}^{N-k} (z_i - \mu(z))^2 \frac{1}{N} \sum_{i=1}^{N-k} (z_{i+k} - \mu(z))^2}}, \quad k = 0, 1, 2, \dots, N-1 \quad (1)$$

where $\mu(z)$ is the mean of the series. When calculating autocorrelation function values for a course of unit flexural bond strengths in a wall, N is the number of whole units in a course (e.g. for wall NA2, $N = 16$ for each course), z_1 is equal to the first unit flexural bond strength value in the course and z_N is equal to the last unit flexural bond strength value in the course. When examining correlation between courses in a wall, the value N used in Equation (1) is equal to the total number of courses that were bond wrench tested in the wall (e.g. For wall NA2, $N = 27$), z_1 is equal to the unit flexural bond strength value at a certain location in the second course of the wall (note that course 1 bond strengths were not tested), z_N is equal to the unit flexural bond strength value at the same location in the 28th course of the wall. Taking wall NA2 as an example, the correlation between unit bond strengths for each course

in wall NA2 were represented by 27 corresponding correlograms, one for each course, and the correlation between bond strengths between courses in wall NA2 were represented by 16 correlograms. A correlogram is a plot of the autocorrelation function value ρ_k versus the lag k for a series.

When examining correlation within a course of unit flexural bond strengths in a wall, if $\mu(z)$ is taken to be the mean of the unit flexural bond strengths (z_1, \dots, z_N) in the course, this mean will reflect the variation amongst values in the course. Using this course mean to calculate the autocorrelation function value for lag k , will result in seeing a less than expected level of correlation for a course. This can also be seen by examining Equation (1) more closely. Observe that approximately half the bond strength values in a course are above the course mean and approximately half of the values are below the course mean. This could, in many instances, result in positive and negative terms in Equation (1) cancelling each other out to a large extent, providing a correlation function value much closer to zero. Therefore, to avoid this “local” mean effect when calculating the autocorrelation function values for each course and between courses in a wall, the mean $\mu(z)$ will be taken as the mean unit flexural bond strength (μ_{unit}) for the wall.

Priestley (1981), Fenton (1999) and others suggest that autocorrelation function value estimates lying within a band of $\pm 2\sqrt{1/N}$ are deemed to be not significantly statistically different from $\rho_k = 0$. For the purpose of examining spatial correlation, the upper band (hereafter referred to as the limiting value for correlation) location of $2\sqrt{1/N}$ was plotted on each correlogram. This is used to establish if there exists unit flexural bond strength correlation within a course after this band has been taken into account, and the corresponding correlation length. For example, given a course of unit flexural bond strengths, if the autocorrelation function value falls below $2\sqrt{1/N}$ at $k=4$, then units may be taken as statistically correlated for up to 3 adjacent units.

RESULTS

The experimental testing program resulted in a set of data for each wall consisting of the location of the unit in the wall, its corresponding flexural bond strength, and the batch from which the mortar for that unit came. Walls NA1, NA2, NA3 and NA4 produced full wall data sets. However, as discussed earlier, the SCB1 and SCB2 wall data sets lack some unit flexural bond strength values.

Probability Distribution for Unit Flexural Bond Strengths

A range of probability distributions are fitted to wall NA1, NA2, NA3 and NA4 data sets. Note that a truncated Normal distribution instead of a Normal distribution is considered because unit flexural bond strengths are relatively low (when measured in MPa) and cannot assume negative values. Due to the fact that SCB1 and SCB2 did not produce full data sets, it is not meaningful to calculate the statistical parameters for these walls. The maximum likelihood method is used to fit the distributions to wall NA1, NA2, NA3 and NA4 unit flexural bond strength data. The histogram and fitted probability distributions for NA2 are shown in Figure 1. A Kolmogorov-Smirnov test at the 5% significance level is also performed on NA1, NA2, NA3 and NA4 in order to check whether the flexural bond strength data set for a wall can be obtained from any of the hypothesized distributions.

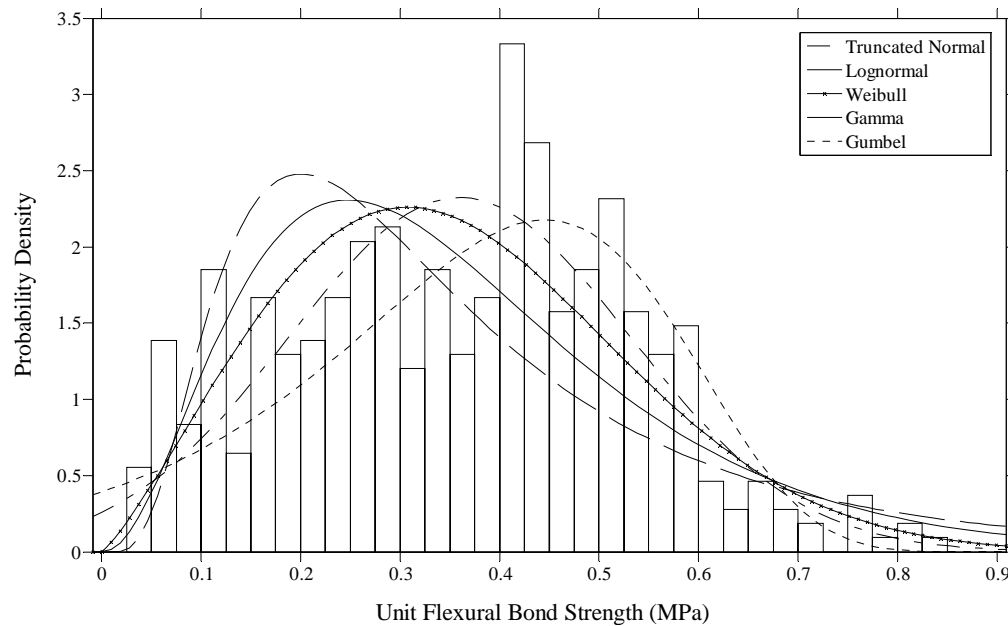


Figure 1: Probability distribution fits for wall NA2

An Inverse Cumulative Distribution Function (CDF^{-1}) plot is also used to infer a goodness-of-fit for the probabilistic models. When the CDF^{-1} of a particular probabilistic model sits on the 1:1 line, this indicates that the probabilistic model fits well to the data (see Figure 2). On the CDF^{-1} plot, when a value is below the 1:1 line, the probability density is higher than that exhibited by the data. By overestimating the lower tail of the histogram (when the CDF^{-1} values are plotted below the 1:1 line) for a material strength, the resulting probability of failure will be over-estimated and therefore provides a conservative result. The statistical parameters for Newcastle walls NA1 to NA4 are summarised in Table 2.

Table 2: Statistical parameters for NA wall data sets

Wall	Number of Data Points	Kolmogorov-Smirnov Test 5% Significance	Best Fit Distribution	Mean Unit Flexural Bond Strength (μ_{unit}) (MPa)	Coefficient of Variation (COV)
NA1	432	Truncated Normal, Weibull	Truncated Normal	0.51	0.41
NA2	432	Truncated Normal	Truncated Normal	0.36	0.47
NA3	432	Truncated Normal	Truncated Normal	0.56	0.45
NA4	427	Truncated Normal	Truncated Normal	0.40	0.42

In the case of wall NA2, the Kolmogorov-Smirnov test at the 5% significance level indicates that only the truncated Normal distribution could not be rejected as the underlying distribution for the wall unit flexural bond strengths. By examining the CDF^{-1} plot for wall NA2 (Figure 2), the lower tail of the truncated Normally distributed histogram is slightly below the 1:1

line, which provides a slightly conservative estimate for the probability of failure when this distribution is used to generate random variables of unit flexural bond strength for a reliability analysis. For all four NA wall data sets, a truncated Normal distribution appears to be the best fit. The confidence with which a truncated Normal distribution can be adopted to represent the variability in unit flexural bond strength data is high because the number of data points in the sets used to obtain this distribution is large.

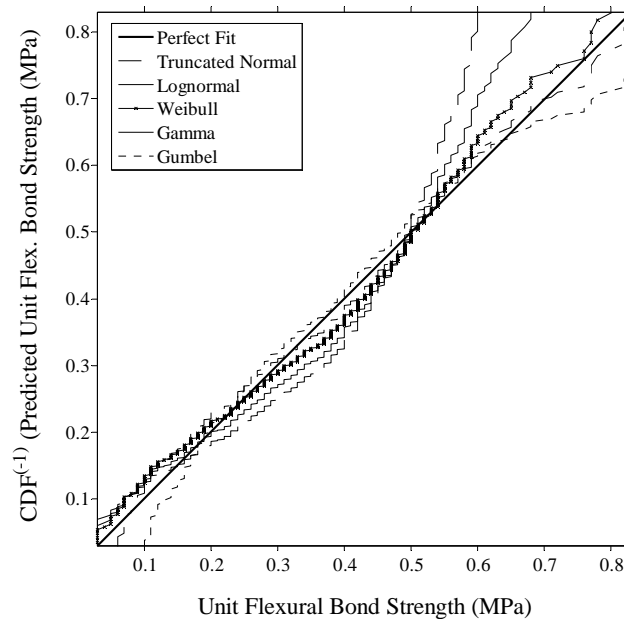


Figure 2: Inverse cumulative distribution functions for NA2

The wall unit flexural bond strength means and coefficients of variation in Table 1 are within the limits reported by McNeilly et al. (1996) recorded for 19 building sites in Melbourne (Australia); where means varied from 0.21 MPa to 0.85 MPa and coefficients of variation from 0.16 to 0.49. Using the truncated Normal distribution to represent variability in unit flexural bond strength is consistent with findings by Baker (1981). Lawrence (1983) also found that although the Lognormal, Normal and Weibull distributions were not rejected for the Kolmogorov-Smirnov test at the 20% significance level, the Normal distribution gave the lowest statistic and was used for subsequent analysis in that research.

It is observed that the mean unit flexural bond strength for wall NA1, built by the high quality mason, is slightly less than for wall NA3, built by the fair quality mason. Both walls used 1:1:6 mortar with no additives. A similar result can be seen between walls NA2 and NA4, where the mortar was 1.5:1:6 + air entrainer. This result seems counter-intuitive. One would expect the high quality mason to produce a higher mean unit flexural bond strength than that produced by the fair quality mason. The reason for this result might be attributed to the fact that walls NA1 and NA2 were built shortly after very heavy rainfall. The bricks used to build these two walls were exposed to the torrential downpour before being brought into the laboratory (indoors). The bricks used in walls NA3 and NA4 were left outside to dry in the fine weather conditions that followed the storm for several weeks afterwards. Due to the mild conditions within the laboratory, the bricks used in walls NA1 and NA2 may not have dried out to the extent that bricks used in walls NA3 and NA4 were able to. Using relatively moist bricks for walls NA1 and NA2 would have had the effect of reducing the suction potential between bricks and mortar, which if too low, can in some circumstances reduce the unit flexural bond strength produced (Sugo 2007).

Spatial Correlation of Unit Flexural Bond Strengths

An autocorrelation analysis using Equation (1) is performed on units within each course and between courses for all walls. For walls SCB1 and SCB2, there were flexural bond strengths for units located at various locations in the wall that were not recorded. When conducting a spatial correlation analysis on a course which contains non-recorded unit flexural bond strength values, the following approach is taken. Within a course (series) of unit flexural bond strength values, if there are non-recorded locations which isolated two or less values, these values are discarded from being included in the spatial correlation analysis for that course. If spatial correlation between unit flexural bond strengths were to exist in a course, it will be most evident within 3 adjacent units, and a minimum of three adjacent values in succession are required to calculate the autocorrelation function value at $k = 3$.

The 27 course correlograms are plotted together for walls NA1 and NA2 and are shown in Figures 4(a) and 4(b) respectively. Between course correlograms are not shown. The horizontal dotted line in each plot is the limiting value for correlation defined by $2\sqrt{1/N}$ for which autocorrelations below this line are not significant.

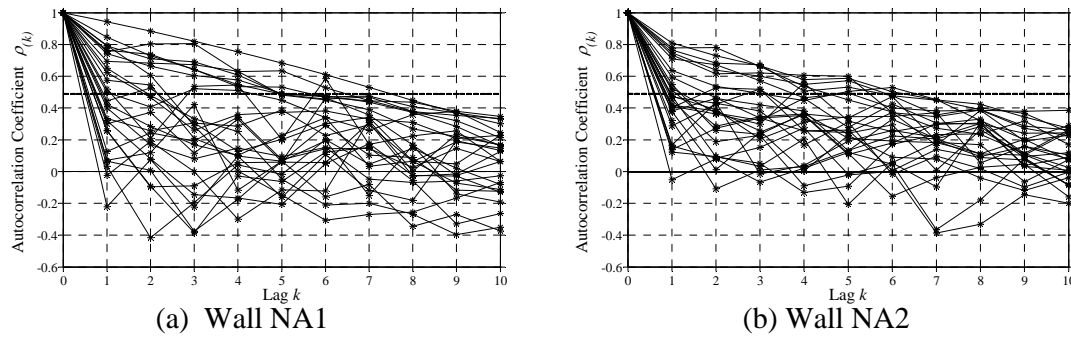


Figure 4: Autocorrelation function values plotted for each course in NA1 and NA2

Initially, the percentage of courses and between courses in a wall which contain some adjacent unit (i.e. when $k=1$ in Equation (1)) correlation, and the wall average of $\rho_{k=1}$ for courses and between courses are examined to see if there is consistently observed correlation between adjacent unit flexural bond strengths within a wall. If correlation between adjacent units is consistently seen throughout the walls, and autocorrelation function values at $k=1$ are relatively high compared with other construction materials, then further autocorrelation lags will be examined in more detail. If the autocorrelation function values at $k=1$ are relatively low compared with other construction materials, and if correlated units within and between courses are not consistently seen and predictably locatable within the walls, then further autocorrelation lags will not be examined in more detail, because for the sake of a probability or reliability analysis, unit flexural bond strengths can be considered statistically independent for clay brick walls.

Weak adjacent unit correlation (i.e. $\rho_{k=1} > 2\sqrt{1/N}$) exists for between 16% and 48% of courses in a wall, and for between 0% and 44% of between courses in a wall. The average autocorrelation function value at a lag of $k = 1$ (i.e. $\rho_{k=1}$) for each wall ranges between 0.22 and 0.50 within courses and 0.09 and 0.36 between courses. Table 3 summarises the correlation statistics for adjacent unit correlation within and between courses. Note that for all but one wall the average course and between course adjacent unit autocorrelation function values are less than the limiting value for correlation ($2\sqrt{1/N}$). The one exception is marginal, as the average course adjacent unit autocorrelation function value in this case is only 0.01 greater than the limiting value for correlation. This result means that adjacent unit correlation is not significant. Note that even an autocorrelation function value of 0.5 to 0.7 is not considered a strong correlation but rather a weak correlation.

Table 3: Within and between course statistics for adjacent unit correlation (i.e. when $\rho_{k=1}$)

Wall	Percentage of courses where $\rho_{k=1} > 2\sqrt{\frac{1}{N}}$ (%)	Average of $\rho_{k=1}$ for courses in wall	Limiting value of correlation for courses in wall	Percentage of between courses where $\rho_{k=1} > 2\sqrt{\frac{1}{N}}$ (%)	Average of $\rho_{k=1}$ between courses in wall	Limiting value of correlation between courses in wall
NA1	41 %	0.44	0.49	13 %	0.24	0.38
NA2	37 %	0.46	0.49	0 %	0.23	0.38
NA3	48 %	0.50	0.49	44 %	0.36	0.38
NA4	41 %	0.44	0.49	37 %	0.35	0.38
SCB1	28 %	0.26	0.48	12 %	0.12	0.34
SCB2	16 %	0.22	0.48	6 %	0.09	0.34

The majority of courses which did show weak adjacent unit correlation were situated one course after another in the wall. Other weakly correlated courses within the walls were randomly situated. Between course weak adjacent unit correlation was not consistently situated at any particular location in the walls. During the construction of the walls, there was nothing in particular that was done differently with the preparation of the mortar batches where sequential weak course correlation was found, compared with all the other batches. The weakly correlated courses did not contain unit flexural bond strengths which were consistently higher or lower than the mean for the wall (e.g. weak course correlation was not only found in courses which had consistently high unit flexural bond strengths within the course).

Reasons for seeing a higher number of courses which contain weak correlation in the NA walls compared with the SCB walls might be due to the effect that differing ambient environmental conditions had on the mortar during construction, differences in brick suction properties between the bricks used in Australia and Brazil, and the general quality of workmanship produced by the Australian masons compared with the Brazilian masons. It can also be observed that the conditions present for the building of the SBC walls were closer to what one would expect to find on most construction sites, compared to those that existed for the construction of the NA walls. Given that on construction sites, there is a higher possibility for incorrect batch mixing and several masons with different skill levels all working on the one wall, and noting that there is a very low incidence of adjacent unit correlation within the SCB walls, one would expect to see reduced presence of unit flexural bond strength correlation in walls built under normal construction conditions.

In conclusion, taking a first glimpse at the correlograms in Figure 4, one may be lead to conclude that unit flexural bond strength correlations are high. However, upon closer examination, it has been shown that average adjacent unit correlation for the experimental masonry walls is low (between $\rho_{k=1} = 0.22$ and $\rho_{k=1} = 0.50$ for courses in a wall), with a low incidence rate (between 16% and 48% of courses in a wall) and unpredictably situated within a wall. For all but one wall which gave only a slightly higher average, the average adjacent unit correlation is less than the limiting value for correlation ($2\sqrt{1/N}$), thus indicating statistically insignificant correlations. Given that controlled laboratory experiments showed relatively little adjacent unit correlation, for the purpose of conducting a probability or reliability analysis, it is recommended that flexural bond strengths for all units in a masonry wall are statistically independent, with each unit flexural bond strength being modelled as a truncated Normal distribution.

DISCUSSION

The most obvious and well known factors for high unit-to-unit flexural bond strength variability (i.e. lack of spatial correlation) are changes in mortar and brick batch, frequency of water addition and the use of additives in the mortar, variations in weather conditions during construction, and variations in brick suction rates due to factors like location of each brick in the kiln during production and its location and exposure to weather conditions on a pallet. Other factors which were thought to have contributed to the high unit-to-unit flexural bond strength variability witnessed in these experiments were:

- The thickness of the mortar bed laid along a course and the number of taps applied to the brick in order to align the unit to the finished level may have affected its flexural bond strength. In practice, for each unit in a course, it is possible that the mason laid a marginally different thickness of mortar bed before adding each brick and tapped each brick a different number of times.
- In order to realign a brick already laid, the mason detached the brick from the mortar that it was initially bonded to. The brick's ability to effectively rebond with the mortar at the new location was thought to have diminished.
- Each brick on a pallet potentially possessed different amounts of surface dust due to factors like varying exposure to weather conditions because of its location on a pallet, which in turn may have affected its suction rate.
- Elapse times between mixing the mortar, spreading the mortar and laying the bricks onto the mortar bed may have affected each unit's flexural bond strength.

Based on the results of the analysis and observations during the testing program, it would appear that although the mortar itself may possess spatial correlation (as has been observed for concrete), it is the brick/mortar interface that predominately governs the strength of a clay brick URM wall (Sugo et al. 2001). It was observed during testing, that the strength of the brick/mortar interface is governed by factors relating to workmanship and variability in brick suction rate. Therefore, although somewhat counter-intuitive, the results clearly indicate that statistically significant correlation between adjacent unit flexural bond strengths is not likely to be observed.

CONCLUSIONS

This paper describes an experimental program developed to examine the extent of spatial correlation between unit flexural bond strengths within clay brick walls, taking into account mortar type, batch location and mason workmanship. It was found that there is very little spatial correlation between clay brick wall unit flexural bond strengths either within or between batches. It is thus recommended that each unit has a flexural bond strength that is statistically independent of its neighbour. The study also found that the clay brick wall unit flexural bond strengths best fit a truncated Normal probability distribution.

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