# Experimental and numerical analysis of mechanical interaction of masonry bricks and mortar

Reza Amiraslanzadeh, En Rin, Toshikazu Ikemoto and Masakatsu Miyajima

*Earthquake Engineering Laboratory, Kanazawa University, Japan*

**Abstract:** Unreinforced masonry (URM) buildings represent a large portion of the buildings around the world. As we know large numbers of these structures have not been designed for seismic loads and structural walls of these buildings were primarily designed to resist gravity loads. Therefore moderate to strong earthquakes can devastate entire cities or villages resulting in massive death toll and cause extensive losses. Hence retrofitting of these structures and improving their strength is significant and vital. For retrofitting of any structure it is particularly important to understand mechanical interactions between its components and elements. In this paper, the mechanism of mechanical interaction between brick and mortar is presented. A general modeling and implementation of contact interaction are demonstrated. The contact parameters are defined and the procedures of assessment and evaluation of contact parameters are introduced. Finally, the numerical results are obtained for different bond parameters which show a good agreement with experimental results.

**Keywords:** Brick-mortar interface, Mechanical interaction, Contact parameters, Friction

## 1. Introduction

Because masonry is a layered structure, made of two materials, it is self evident that the interaction of these layers is important for the behavior, especially when subjected to shear loads, which is the main load resistance section of masonry structures. Various test methods to evaluate the shear strength of the brick-mortar interface have been developed over the past few decades.

The shear bind strength of masonry can be determined by using couple or triplet tests. Figure 1 shows the test set-ups for couple and triplet tests. It is usually thought that strength of mortar itself is an indicator of a strong masonry system. Not only properties of the mortar and masonry unit, but also the pressure on the unit mortar interface affect the shear bind strength of masonry. As the pressure increase, the shear bind strength also increase.

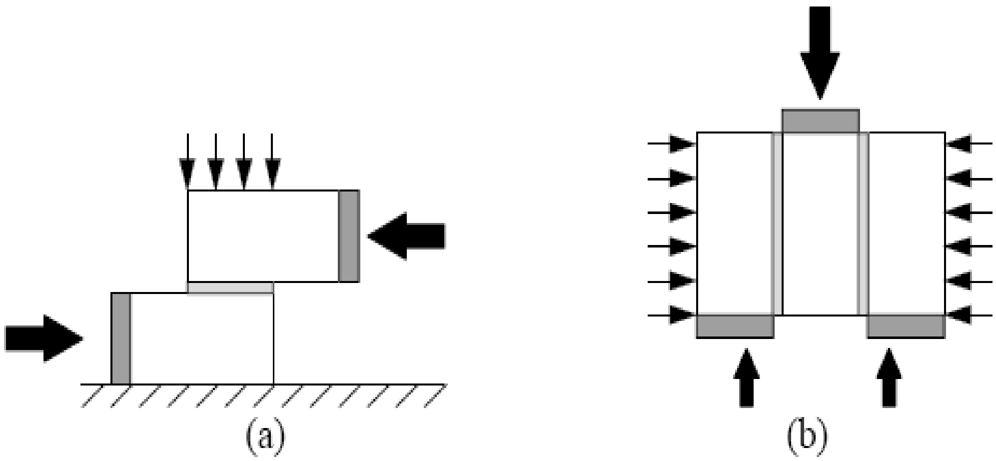


Figure1. Possible test set-ups for determination of shear bind strength: a) couple test b) triplet test.

The maximum shear stress of brick-mortar interface varies between 1 and 8.5 Kg/cm2 with an average value of 4.85 Kg/cm2. The sliding motion at the brick-mortar interface can be considered as a frictional one, described by the evolution of the residual shear stress in function of the confinement stress (Fig 2).

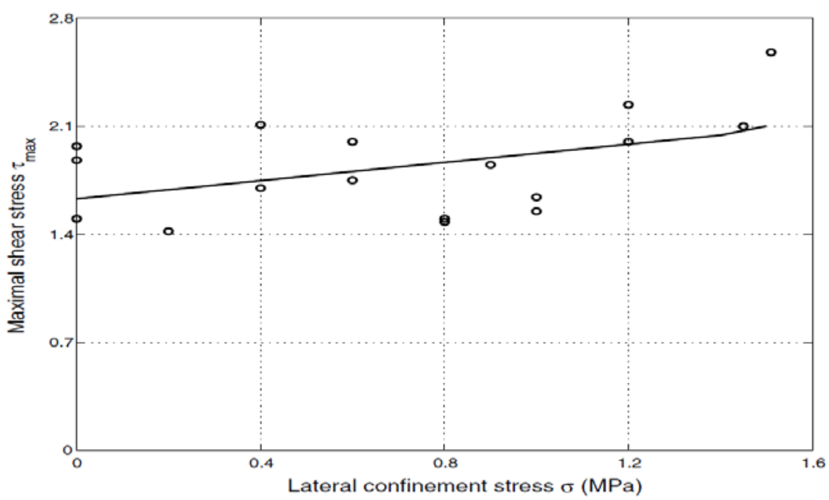


Figure2. Relationship between Maximum shear stress and normal stress.

Some studies [2, 3] propose that the friction coefficient can be deduced upon regression curve and it corresponds to the slope of the regression line between the experimental data. But numerical modeling results showed that it is better to use individual contact pressure dependent friction coefficient to obtain reasonable results.

## 2. Background

Ghazali and Riddington (1988) presented a simple method for assessing the shear strength of the brick-mortar interface by using a triplet test specimen tested without the complication of adding a pre-compression force. From this work it was shown that the Mohr-Coulomb failure envelope could be established by conducting tests with zero pre-compression stress and by then measuring the coefficient of friction at the joint.
For Dynamic shear strength of masonry brick walls Molyneaux (1994) showed that the shear strength obtained under these conditions was strain rate sensitive and strengths of up to three times the quasi-static values could be obtain when the duration of loading was suitably short. This work resulted in developing finite element modeling strategies using LSDYNA3D. For the masonry walls a discrete modeling strategy was adopted whereby individual masonry units were modeled separately. These units were then connected together using special contact surface definitions.

## 3. Description of the test set-up

For the triplet test as shown in the figure 3, specimen consists of three masonry units subjected to a horizontal pre-compression load. The left and right of the masonry courses are kept under constant pressure while a vertical load is applied in the middle masonry unit. Eventually this course slides, providing the value of the shear strength of the joints. In order to define the friction angle of the joints, four various pre-compression load levels were adopted, namely 0.0kN, 5kN, 10kN and 25kN.These stress levels were kept constant during the complete tests duration. For each pre-compression stress level, three specimens were tested, resulting in a total of twelve tests.
Two horizontal rigid supports restricted the movement of the left and right courses of the panel. These supports are covered the full height of the course in order to minimize any bending effect of the panel. The horizontal and vertical loading system consisted of two independent actuators. The horizontal and vertical actuators were applied on a steel beam, so that the load could be evenly distributed in the panel. Initially, the horizontal compressive load was applied by means of the horizontal hydraulic actuator.
As shown in Figure 4, which illustrate the time history of the horizontal load for each panel series it can be observed that the horizontal load was kept approximately constant during the test duration, with the exception of some sudden load variations due to the geometrical irregularities of the failure surfaces of the joints and also dilation angle.

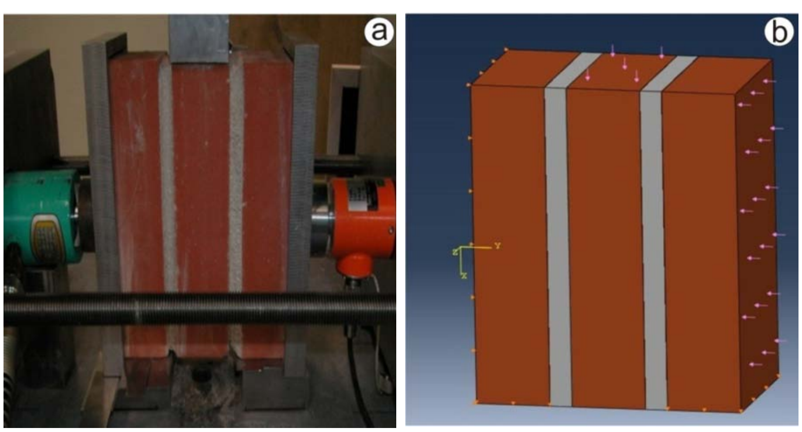


Figure3. Supports and loads condition of the specimen in experimental tests (a) and numerical modeling (b).

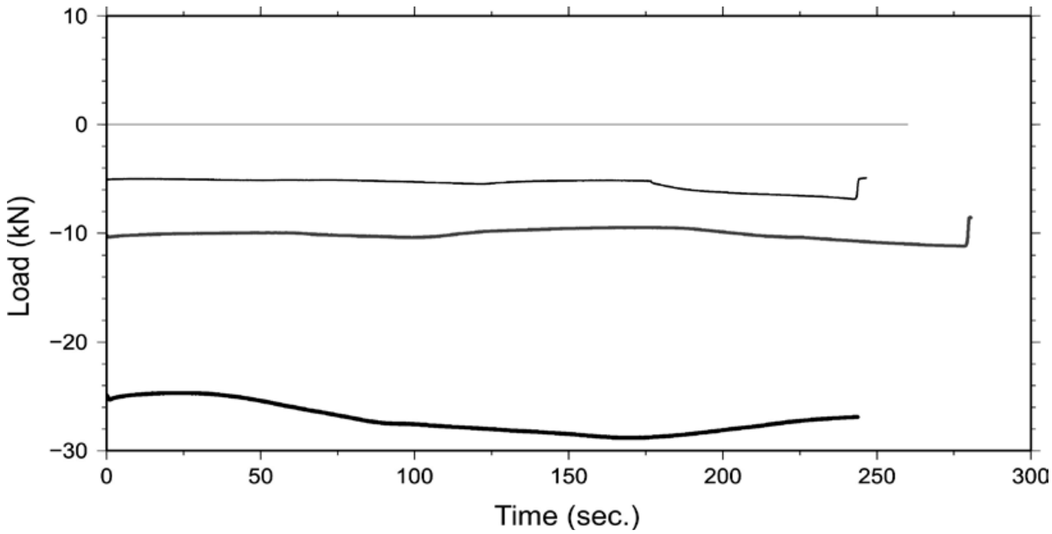


Figure4. Time history of the horizontal load for each panel series.

## 4. Experimental test results

Figure 5 shows the relation between the shear load and displacement of the mid masonry unit. According to the results by increasing pre-compression stress the amount of maximum vertical load to break the specimen was increased. However by this concept we cannot conclude that by increasing pre-compression load the amount of friction coefficient will increase. Calculation of friction coefficient based on the experimental tests as well as numerical modeling results approves this reality.

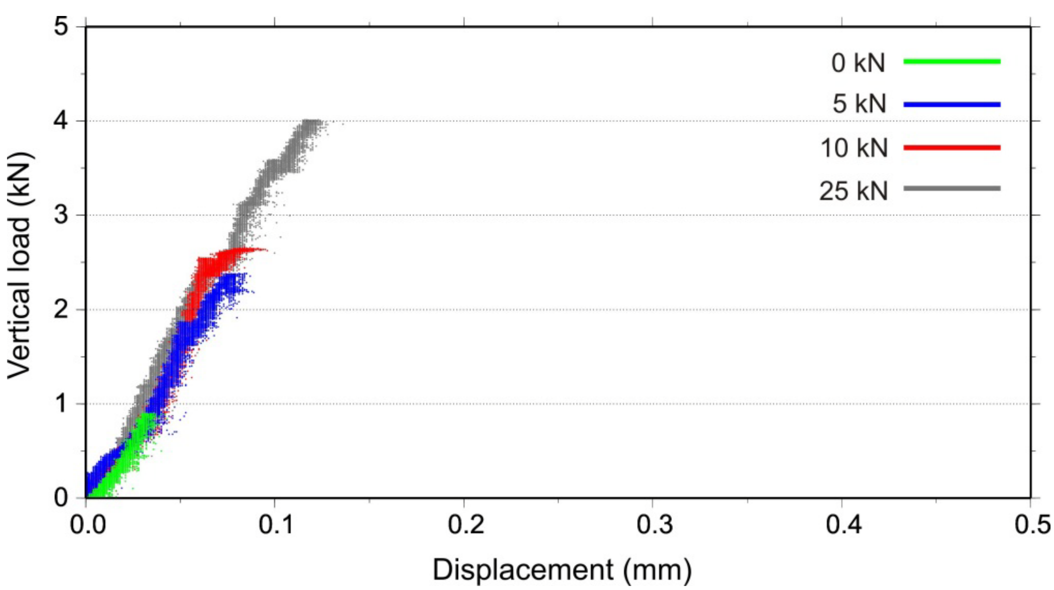


Figure5. Load-Displacement curves for various pre-compression amounts.

**5. Definition of the joint strength parameters**

Friction coefficients for each specimen that was obtained from experimental tests are calculated and shown in the table 1. As we can see in this table by increasing the amount of pre-compression load the amount of interface friction coefficient decrease.

Table1. Summary of the triplet test data to obtain friction coefficient.

| Horizontal Load (Kg) | Horizontal Stress $\sigma_n$ (Kg/cm$^2$) | Vertical Load (Kg) | Vertical Stress $\sigma_V$ (Kg/cm$^2$) | Avg.Vertical Stress $\sigma_V$ (Kg/cm$^2$) | Shear stress $\tau_{xz}$ (Kg/cm$^2$) | $\mu$ $(\tau_{xz}/\sigma_n)$ | Avg. $\mu$ $(\tau_{xz}/\sigma_n)$ |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 893 | 16.24 | 14.42 | 1.69 | - | - |
| 0 | | 585 | 10.64 | | 1.11 | - | |
| 0 | | 901 | 16.38 | | 1.71 | - | |
| 500 | 1.89 | 3271 | 59.47 | 49.85 | 6.20 | 3.28 | 2.75 |
| 500 | | 2569 | 46.71 | | 4.87 | 2.58 | |
| 500 | | 2385 | 43.36 | | 4.52 | 2.39 | |
| 1000 | 3.79 | 2831 | 51.47 | 50.45 | 5.36 | 1.41 | 1.38 |
| 1000 | | 2829 | 51.45 | | 5.36 | 1.41 | |
| 1000 | | 2663 | 48.42 | | 5.04 | 1.33 | |
| 2500 | 9.47 | 4414 | 80.25 | 76.05 | 8.36 | 0.88 | 0.83 |
| 2500 | | 4014 | 72.98 | | 7.60 | 0.80 | |
| 2500 | | 4120 | 74.91 | | 7.80 | 0.82 | |

Figure 6 shows the relation between the normal stress and the shear strength for all specimens, as well as a linear regression that carried out for all series of the specimen. The correlation coefficient (R2) of the linear regression is 0.8, which indicates good correlation between the experimental data. Some studies propose that the slope of linear regression indicates tangential friction for the brick-mortar interface. By this concept the value of friction coefficient will equal to 0.587. But as we demonstrate in table 1 the amount of friction coefficient for brick-mortar is a contact pressure dependent variable and will decrease by increasing the value of pre-compression stress.

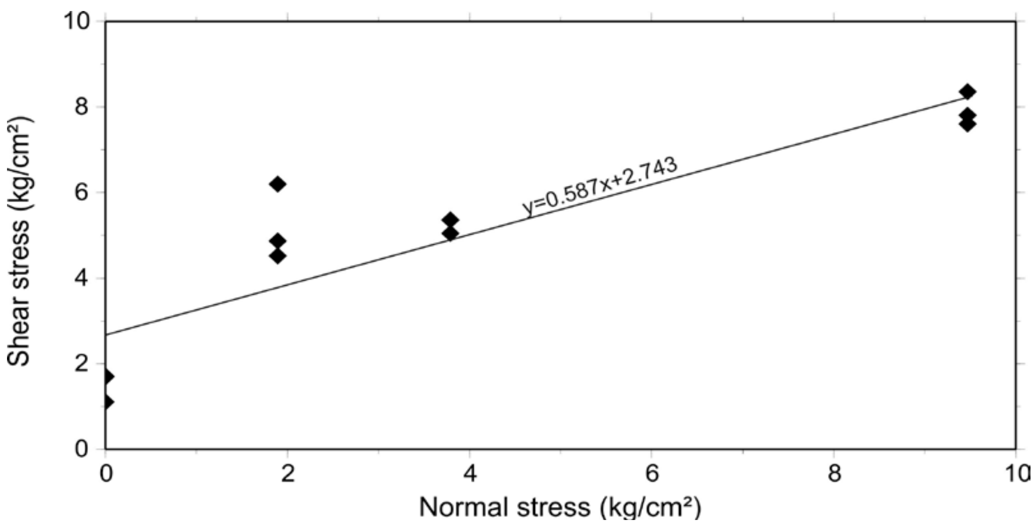

Figure6. Relationship between maximum shear stress and normal stress.

## 6. FEM modeling of brick-mortar interface behavior

Based on the results of experimental tests for interaction behavior of brick-mortar interface FEM model of the triplet test was developed for each panel series with different pre-compression loads. Figure 7 shows the steps of applying vertical and horizontal loads to the specimen. At first confinement load was applied to the specimen after that vertical load was applied to break the specimen. The results of the numerical model of the triplet test that are given in the table 2, shows good agreement with the experimental tests.

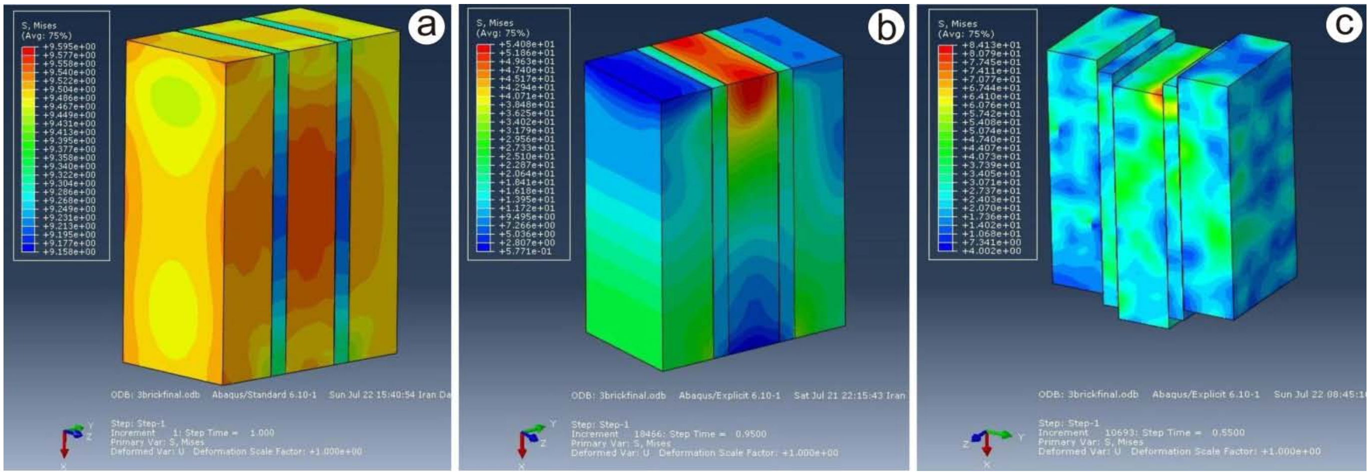


Figure7. a) Stress distribution in step 1 (applying the horizontal stress). b) Stress distribution in step 2 (applying vertical deviator load to break the specimen). c) Stress distribution of the fractured triplet specimen.

Table2. Experimental and numerical modeling results for different pre-compression load.

| **Defined μ in numerical test ($\tau_{xz}/\sigma_n$)** | **Horizontal Load (Kg)** | **Pre-compression Stress $\sigma_n$ (Kg/cm$^2$)** | **ultimate vertical Stress ($\sigma_V$) in experimental test (Kg/cm$^2$)** | **ultimate vertical Stress ($\sigma_V$) in numerical test (Kg/cm$^2$)** |
|---|---|---|---|---|
| 2.75 | 500 | 1.89 | 49.85 | 34.02 |
| 1.38 | 1000 | 3.79 | 50.45 | 50.1 |
| 0.83 | 2500 | 9.47 | 76.05 | 74.9 |

As we can see in the table 2 if pre-compression load was less than the intercept value in Y coordinate of regression line (cohesive), fracture load of numerical model becomes less than the experimental one. Also we can interpret that in case pre-compression load is less than cohesive value, cohesion will be the dominant on fracture criteria otherwise friction coefficient will be the dominant. As shown in figure 8, by increasing the value of pre-compression stress, the amount of friction coefficient will decrease by the power of approximately -0.8. So we can conclude that in masonry structures the value of friction coefficient to make district FEM model using contact pairs with tangential parameters, will have exponentially relationship with the value of pre-compression stress.

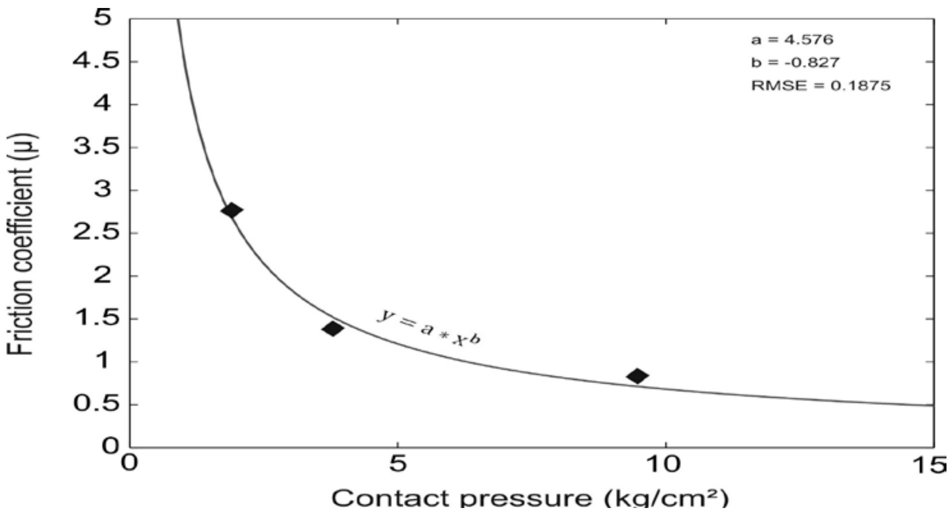


Figure8. Contact pressure and friction coefficient relationship.

**7. Summary and conclusion**

The triplet test was used successfully to assess the shear behavior of brick masonry. In order to define the friction angle of the joints, four various pre-compression load levels were adopted namely 0.0kN, 5kN, 10kN and 25kN. According to the results by increasing pre-compression stress the amount of maximum vertical load to break the specimen was increased. However by this concept we cannot conclude that by increasing pre-compression load the amount of friction coefficient will increase.

By using interface interaction parameters of brick-mortar contacts, finite element model of the triplet test was developed. According to the experimental test data friction coefficient was calculated separately for different per-compression stress levels. These data was used to develop contact pressure dependent friction in order to obtain the most accurate data from numerical modeling. Obtaining reasonable values such as vertical deviator load, proves that using leaner regression of experimental data to obtain friction coefficient as a contact pressure dependent friction in brick-mortar interface, will not be useful in FEM modeling and will lead to non-reasonable data.

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**Reza Amiraslanzadeh[1], En Rin, Toshikazu Ikemoto[2] and Masakatsu Miyajima[3]**

Earthquake Engineering Lab, School of environmental design
College of science and engineering, Kanazawa University
Kakuma-machi, Kanazawa, 920-1192 Japan

[1]E-mail: reza.amiraslanzadeh@gmail.com

[2]E-mail: tikemoto@t.kanazawa-u.ac.jp

[3]E-mail: miyajima@se.kanazawa-u.ac.jp