

Modeling of Mechanical behavior of Interfaces in Masonry Structures

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Abstract

The purpose of this article, is a numerical modeling of interfaces between the brick and mortar in masonry structures, taking into account the main mechanical phenomena governing their break; such as adhesion, sliding, and the friction. The modeling will be based on an interface coupling laws contact, friction and adhesion originally developed by the group of Michel Raous the LMA (Marseille) and implanted in the GYPTIS code. The study is restricted to a reduced case. The comparison of numerical results with experimental results has been very encouraging in most cases, and showed a good model selection interface is sufficient to properly present the conduct of masonry structures.

**Keywords:** Masonry, Interface, Contact and friction grip.

Introduction

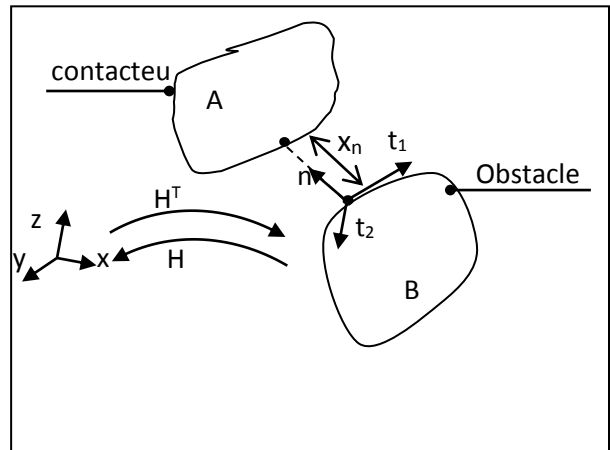
Many studies are devoted to the conduct of building structures. These studies are mainly Italian researchers because of their cultural, social and economic importance to the restoration and preservation of architectural heritage. These studies have established the theoretical and numerical models based on different approaches. Most of them are based on homogenization techniques. The difficulties arise in the application of these techniques to characterize the action of various components especially when all inelastic phenomena developed in the structures (damage, break ...) are taken into account. Due to the nonlinearity in this type of structure, in particular, at the interface between the brick and mortar joints. This last question deals partly in this article. The research started in the national interest framework and proposes to study the conduct of a masonry structure taking into account the main mechanical phenomena governing their break as contact, friction and adhesion.

Laws of contact and classical friction

Consider two bodies A and B into contact (FIG. 1). The orthogonal projection of a point P to A on the surface of B defines a point P' that will be the

origin of the local coordinate system. Let  $v$  the relative velocity of P to A with respect to B, and that undergoes the reaction  $r$  A from B [1]. The laws of friction contact are expressed in the local coordinate system by the relationship between  $v$ ,  $r$ , and the shortest distance between A and B:

$$x_n = \overline{PP'}$$



Landmark local contact

Criteria of unilateral contact

Points belonging to the area of contact must meet the laws governing unilateral contact. They are generally known under the name: Signorini condition

and expressed by the following conditions:

- Impenetrability:  $x_n \geq 0$

State of static contact (non-membership):

$$x_n = 0 \Rightarrow r_n \geq 0$$

- State of non-contact:  $x_n > 0 \Rightarrow r_n = 0$

These three conditions can be condensed in the equivalent form [2]:

$$\forall \rho > 0 \quad r_n = \text{proj}_{R^+}(r_n - \rho x_n) \quad (1)$$

**Friction criterion**

There are many choices; we chose the Coulomb model, which is the most used in the case of dry contact. The model is expressed by the relations:

$$\begin{cases} \|r_t\| \leq \mu r_n & \text{si } u_t = 0 \\ r_t = -\mu r_n u_t / \|u_t\| & \text{si } \|u_t\| \neq 0 \end{cases} \quad (2)$$

Where  $\mu$  denotes the coefficient of friction and the tangential component  $u_t$  of the relative movement (sliding). In the numerical calculation the following equivalent form [2] are used:

$$\forall \rho > 0, \quad r_t = \text{proj}_C(r_t - \rho u_t) \quad (3)$$

Where  $C$  is the cone of the interval limited by Coulomb:  $[-\mu r_n, \mu r_n]$ .

**RCCM model**

The CCR model (Raous-Cangemi-Cocou) was presented for the first time in Raous and al. 1997 [3], Cangemi 1997 [4] and detailed in Raous and al. 1999 [5]. It was developed in its present form, with the consideration of variable friction with the term  $(1-\beta)$  in Monerie, 2000 [6] and Raous and Monerie, 2002 [7]: the RCCM model. In this model, membership is characterized by a variable internal variable  $\beta$ , introduced by Fremont (1987, 1988) [8, 9], which measures the intensity of accession. The introduction of a rigidity of the interface provides good continuity between the two models, and the friction between the adhesion. The conduct of the interface is described by the following equations, where [4] gives the unilateral contact with adhesion [5] gives the Coulomb friction with adhesion and [6] shows the evolution of the intensity of  $\beta$  accession. Initially, when the adhesion is full (total), the interface is so elastic that the energy threshold is not

reached w. Once the threshold is exceeded, damage to the interface and therefore starts, firstly, the

intensity of  $\beta$  adhesion  $\beta^2 C_N$  and  $\beta^2 C_T$  the apparent rigidity decreases, and secondly, the friction appears. When membership is completely broken ( $\beta = 0$ ), the classical Signorini problem is obtained with Coulomb friction.

**Unilateral contact with adhesion:**

$$\begin{aligned} r_n - C_N u_n \beta^2 &\geq 0; \quad u_n \leq 0; \\ (r_n - C_N u_n \beta^2).u_n &= 0 \end{aligned} \quad (4)$$

**Act of friction with adhesion:**

$$\begin{cases} r_t^r = C_T u_t \beta^2; \quad r_n^r = r_n \\ \|r_t - r_t^r\| \leq \mu(1-\beta) |r_n - C_N u_n \beta^2| \\ \|r_t - r_t^r\| < \mu(1-\beta) |r_n - C_N u_n \beta^2| \Rightarrow \dot{u}_t = 0 \\ \|r_t - r_t^r\| = \mu(1-\beta) |r_n - C_N u_n \beta^2| \Rightarrow \exists \lambda \geq 0, \dot{u}_t = \lambda (r_t - r_t^r) \end{cases} \quad (5)$$

**Evolution of the intensity of adhesion:**

$$\begin{cases} b\dot{\beta} = -(Wh'(\beta) - (C_N u_n^2 + C_T u_t^2)\beta)^- & \text{si } \beta \in [0, 1[ \\ b\dot{\beta} \leq -(Wh'(\beta) - (C_N u_n^2 + C_T u_t^2)\beta)^- & \text{si } \beta = 1 \end{cases} \quad (6)$$

The constitutive parameters of the model are:

- $u_N, u_T$ : the normal and tangential components of the relative displacement [u]
- $r_N, r_T$ : the tangential and normal components of the density of contact force

-  $r_N^r, r_T^r$  : parts of reversible tangential and normal density contact force components.

-  $C_N$  and  $C_T$  initial stiffness (Pa / m) of the interface,

- $W$ : the debonding energy threshold (J/m2);
- $\mu$ : The coefficient of friction;
- $B$ : viscosity (Js/m2) associated with changes in membership.

**Examples treated**

In the present work, we will present numerical simulations performed on individual assemblies, triplets composed of solid and hollow bricks bound together by mortar 10mm thick, and

they have been studied experimentally by FaziaFouchal. The simulations were performed under the GYPTIS code developed AML (Marseille) by the group of Michel Raous. GYPTIS is a computer code that incorporates the interface law developed by Raous and al. [3], [5], [7]. It is written entirely in Fortran 90, using 3-node triangles P1, based on the finite element code Modulif. The code GYPTIS resolves static or quasi-static deformation of a planar problem, plane stress or symmetrical and allows communication with the various module Modulif platform. The problem of contact and friction are treated by methods of resolution projection type or methods of mathematical programming Lemke kind.

**Experimental tests on triplets**

Experimental tests are carried out on masonry prisms composed of three bricks (solid and hollow) connected by mortar joints. The samples are placed in the testing machine and subjected to monotonic loading growing evenly distributed to failure. The LVDT strain placed on the center brick allow us to take the relative displacement of the core relative to the other brick bricks. (Fig. 2). The testing machine and the sensor are connected to an acquisition system (PC) that stores the information that is produced during the test. This information is longitudinal deformations and the applied load.



*Shear test on hollow brick triplets [10]*

The different failure modes obtained for triplets tested compounds hollow or solid bricks are shown in Figure 3 Two types of cracks exist, according to the failure mode observed in all trials:

–crack occurs at the interface and grows until it crosses the joint mortar;

– Either the crack occurs and remains localized at the interface, that is what we will discuss in this section.



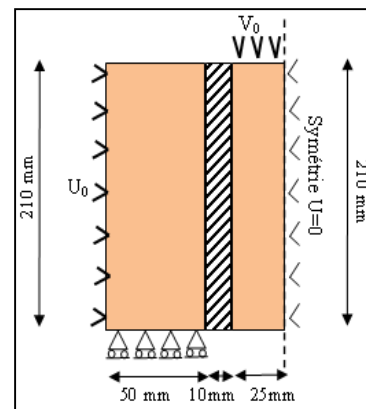
*Strain due to shear test on the triplets [10,11]*

**Numerical simulations on triplets**

To simulate the shear test presented above to the assembly of triplets full brick hollow and in the presence a symmetry relative to the vertical, we restricted our numerical calculation only half of the assembly. This says that we will simulate assembly now consists of an entire brick, a joint mortar and brick half as shown in Figure 4.

The test consists of successively:

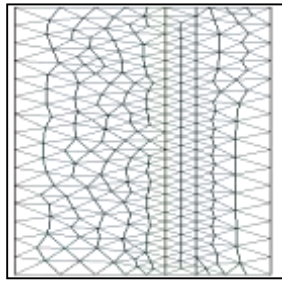
- one displacement containment  $U_0$  in the direction perpendicular to the mortar joint and clamping it to simulate.
- one displacement  $V_0$  imposed on the upper edge of the central bricks to simulate the force applied



*Schematic of shear test on brick triplet*

We used in a triangular mesh element 31 with plane strain on the interface node (fig.5)

In Table 01, it was reported that the mechanical properties we used for modeling various components of the masonry ie brick and mortar.



Mesh triplet composed of brick

Table 1. Elastic mechanical properties used for modeling after FAZIA FOUCHAL [10].

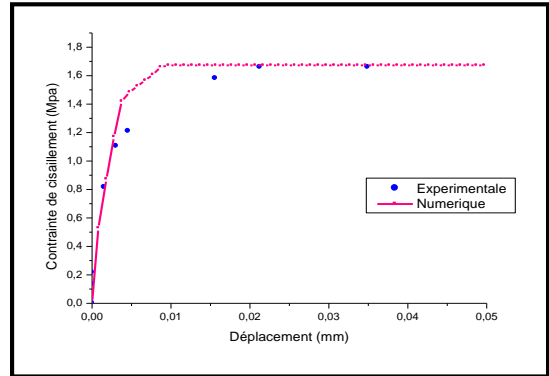
materials	Modulus of elasticity(Mpa)	Poisson coefficient
solid brick	9438.5	0.13
hollow brick	6058.8	0.13
mortar	4000.0	0.3

- Case hollow brick  
 The identification has allowed us to choose the parameters of membership RCCM law that are given in the following table:

Table 2. Parameters law RCCM accession used in the case of verse hollow brick

$\mu$	b (Ns/mm)	w (J/m <sup>2</sup> )	C <sub>N</sub> (N/mm <sup>3</sup> )	C <sub>T</sub> (N/mm <sup>3</sup> )
0.2	0	10 <sup>-7</sup>	0.03x10 <sup>2</sup>	0.03x10 <sup>2</sup>

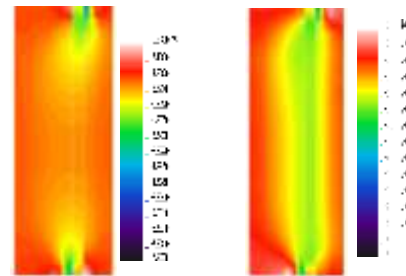
- We were plotted changing the shear stress as a function of relative displacement on the interface brick mortar (fig. 6). It was reported in the following figure curves tangential stresses of the interface according to tangential displacement brick.



Constraint of shear experimental digital

In general, it can be said that the comparison between the experimental and the digital shows good agreement, especially in the elastic part and out of the top of the interface (when the interface begins to crack and  $\beta \neq 1$ ). In the upper part, and damage when the energy becomes larger (when the threshold is exceeded debonding w), an offset is observed between the experimental and digital curve. This can be explained by the arbitrary distribution of the mortar in the hollow brick "the pins" after hardening, and therefore, it is necessary to take in such modeling the effect of the studs" spikes "of the conduct of mortar triplets, stating at the same hollow, as the contact zones.

Figure 7 shows the deformed and the distribution of shear stresses at the beginning of the  $\sigma_{xy}$  out and at the end of the total out of the interface.



Evolution of the deformed. Triplet in the case of hollow brick.

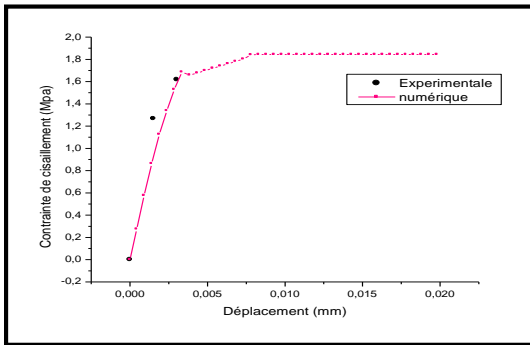
Constraints on the charts, we can see easily that when the adhesive forces are added to the contact reactions, high concentrations appear on the interface and especially the areas likely to be damaged. Once the bond is broken, only the reactions of friction and we will respond within concentrations.

➤ Case of solid brick: Parameters resulting RCCM Act of Accession of identification are shown in the following table:

**Table 3. Parameters Act of Accession RCCM used in the case of triplet solid brick.**

$\mu$	b (Ns/mm)	w (J/m <sup>2</sup> )	C <sub>N</sub> (N/mm <sup>3</sup> )	C <sub>T</sub> (N/mm <sup>3</sup> )
0.2	0	10 <sup>-9</sup>	1x10 <sup>6</sup>	1x10 <sup>6</sup>

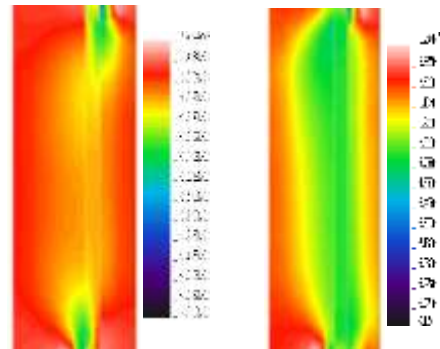
The result of the simulation prepared is shown in Figure 8, where we presented the responses to shear testing, experimental and numerical triplet for solid brick.



**Shear test on a triplet solid brick.**

The results (Fig. 8) are very encouraging with a general shape substantially similar to that of the experimental response curve. Once when exceeded the threshold debonding w ( $\beta = 0$ ), the behavior became more fragile, which is explained by the shape of the curve in the outer part. In this case, there are classic Coulomb's law. As against the resilient portion ( $\beta = 1$ ) behavior is very rigid, the difference in case a hollow brick which is a small curvature that characterizes a softening stage, once the sliding movement between the adjacent brick is activated . In Figure 9 is also presented changes in shear stress, in the case of full brick triplet for movement imposed on the central brick. The two diagrams characterize the beginning and end of the total rupture of adhesive bonds on brick-mortar interfaces. At the beginning of loading, one can clearly notice a kind of stress concentration in areas where the break is triggered. This area is spread as far and until the interface is

totally broken. Once the rupture will be total, only the frictional forces react.



**Evolution of the shear stress  $\sigma_{xy}$**

### Conclusion

In this article, we discussed the modeling of interfaces in masonry structures. Our choice fell on the RCCM model we used a simplified version with zero viscosity.

The comparison of the model with experiments on models, shows a very good agreement. Made in the comparison of numerical results with experimental results that we have done with the software GYPTIS was in most cases very encouraging, and showed a good model selection interface is sufficient to properly present the behavior of masonry structures.

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