Numerical Simulation of Masonry Structures Under Cyclic Loading Using Applied Element Method
組積造構造の交番載荷実験の応用要素法解析

Masonry Modeling in AEM

In the domain of micro-level modeling of masonry, the Applied Element Method (AEM) is more suitable because of mainly three reasons. Firstly, the AEM is capable to follow complete structural response from initial stage of loading until total collapse behavior with reasonable accuracy so that inelastic response after the cracks occur can be captured. Secondly, brick masonry which is composite of brick units and mortar and its discrete nature can be easily modeled in the AEM by a set of square elements connected at their contact edges either by *'Element springs'* or *'Joint springs'* according to their positions. Discretization of masonry in the AEM is illustrated in **Figure 1**. Thirdly, the progressive nature of masonry failure mode i.e. cracks initiation, propagation and their distribution is better simulated in the AEM.

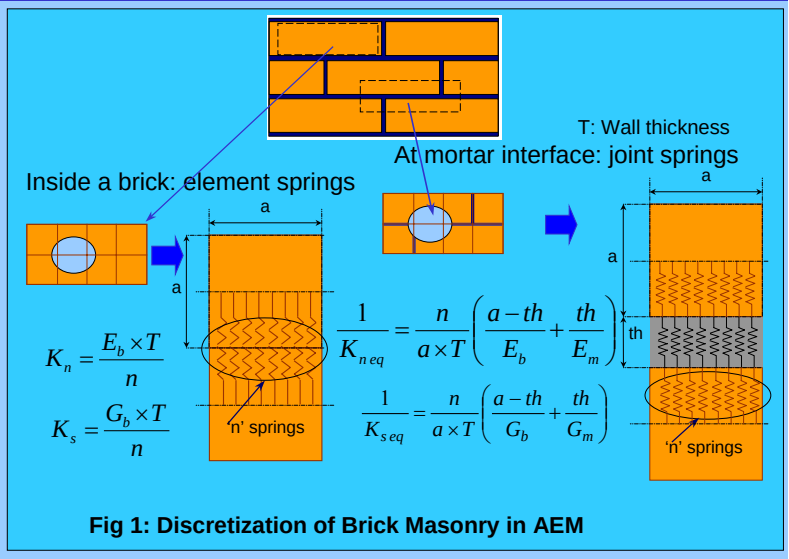


Fig 1: Discretization of Brick Masonry in AEM

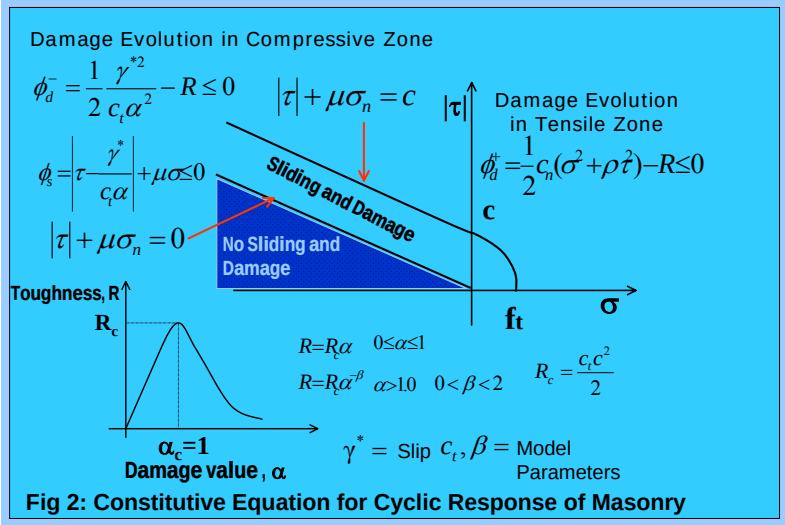


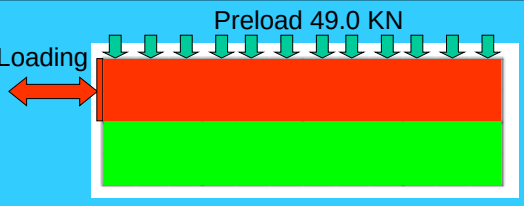
Fig 2: Constitutive Equation for Cyclic Response of Masonry

Material Modeling for Cyclic Response of Masonry

Damage model proposed by **Gambarotta and Lagomarshino, 1997,** was adopted in the AEM as the material model to capture the masonry cyclic response. This constitutive equation is based on damage mechanics and takes into account both the mortar-damage and the brick-mortar decohesion which are considered to take place during crack opening and frictional sliding along the interface. Two internal variables, γ^* and α, represent the frictional sliding and the mortar joint damage, respectively. The sliding and damage variables evolution is ruled both by the frictional sliding and the mortar joint damage. The damage evolution in tensile and compression zones as well as the frictional limit criteria are given in **Figure 2**.

Simulation of Experimental Results

Two experimental cases were simulated for the verification of the material model adopted in the AEM. **Figure 3** gives the boundary condition, material properties and comparison of the results of the experiment conducted by Atkinson et al (1989). **Figure 4** shows the model description, material properties and result comparison of the diagonal shear test carried out by Sathiparan (2005) on masonry wallettes.



Material Properties and Model Parameters

Brick Size (mm³)	E_b (KN/mm²)	E_m (KN/mm²)	f_t (KN/mm²)	c (KN/mm²)	tanϕ	Pre-load (KN)	1/Ct (KN/mm²)	β
193x92 x55	14.7	2.11	0.94e-3	1.0e-3	0.67	49.0	1.25	0.8

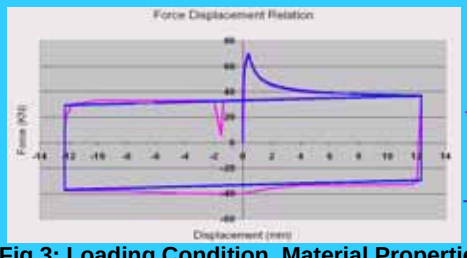
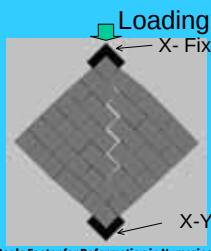


Fig 3: Loading Condition, Material Properties and Result Comparison of Atkinson Experiment (1989)

Simulation results obtained by implementation of the damage model for masonry under the framework of the AEM showed good agreement with the experimental results.

Material Properties and Model Parameters

E_b (KN/mm²)	E_m (KN/mm²)	f_t (KN/mm²)	c (KN/mm²)	1/ct (KN/mm²)	β	tanϕ
15	0.028	5.89e-5	8.6e-5	0.125	1.0	0.75



Model Description
Dimension of the wallet=280mmx280mm
Thickness=50mm
Thickness of Mortar=5mm
Number of Elements=206
Number of Springs per Element Side=10

Scale Factor for Deformation in Numerical result is 10

Comparison of Crack Patterns

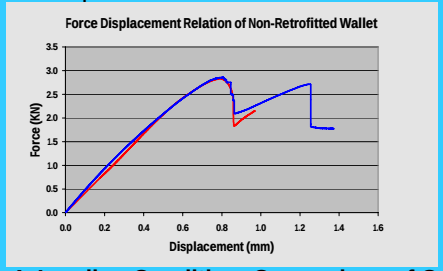


Fig 4: Loading Condition, Comparison of Crack Patterns and Comparison of Force-Displacement Relations of Sathiparan Experiment (2005)

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