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A non-linear interface element model for thin layer high adhesive mortared masonry

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ABSTRACT

A nonlinear interface element modelling method is formulated for the prediction of deformation and failure of high adhesive thin layer polymer mortared masonry exhibiting failure of units and mortar. Plastic flow vectors are explicitly integrated within the implicit finite element framework instead of relying on predictor–corrector like approaches. The method is calibrated using experimental data from uniaxial compression, shear triplet and flexural beam tests. The model is validated using a thin layer mortared masonry shear wall, whose experimental datasets are reported in the literature and is used to examine the behaviour of thin layer mortared masonry under biaxial loading.

1. Introduction

Masonry is extensively used in engineered structures despite its complexities as an anisotropic, low tensile and highly variable material. Masonry exhibits complex failure modes even under simple stress states. Non-linear behaviour of mortar joints plays a crucial role in the response of masonry structures under the lateral loading due to earthquake or wind. In the masonry systems containing strong units – weak mortar combination, failure of units is virtually non-existent and the failure is limited to mortar joints that act as the planes of weakness and usually cause large variability in the conventional masonry with 10 mm cement–sand mortar joints; the variability is primarily caused by the workmanship, which is hard to control under the 10 mm joints. As mortar is applied tool-assisted in the thin layer mortared masonry, the variability is found lower [2]. Use of high adhesive, polymer–cement mortar also aids in the reduction in the variability [1,3–8].

Depending upon the level of the accuracy required and the simplicity desired, several modelling methods have been developed in recent times [8–36]; these are largely classified as "micro" or "macro" modelling methods which are shown to adequately predict the failure of the meso scale wallettes and the macro scale structural walls respectively. The micro modelling methods often use individual properties of the constituent materials and their interfaces separately [8–13,24–26], whilst the macro modelling approach uses the properties of the homogenised blocks and mortar [14,16,17,24,27,29–35]. Homogenised macro modelling method is efficient due to less demand of computational effort compared to the micro modelling and hence is suitable for large structural analysis [16,17,19]. On the other hand, the micro modelling can provide an insight into the localisation of the block–mortar interfaces depending on the levels of detail required [11,12].

Micro modelling approach based on contact or interface elements are reported in the literatures [8–13]. The modelling of interfaces in masonry is commonly handled through interface elements by various researchers [9,18,19,21] which are also used widely in other fields, for example soil and rock mechanics [37–39]. The interface can exhibit damages due to normal (tensile/compressive) stresses and tangential tractions, which are modelled using different strategies; for example, Nazir and Dhanasekar [8] have formulated a plastic surface contact model for thin layer mortared masonry. Mahaboonpachai et al. [11] have used a damage failure criterion; Spada et al. [13] and Haach et al. [9] have used the non associated plasticity theory for shear–tension regime with a tension cut-off and Mohr Coulomb type failure criteria for shear–compression regime. In the micro models, the clay brick or the concrete block is generally kept elastic in most publications [8,9,11] and in some even as rigid [18], which are acceptable to replicate the behaviour of the conventional, low adhesive mortared masonry

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Nomenclature

Symbols and notations

Π_1	concrete masonry block
Π_2	mortar
Π_3	combined concrete block and mortar
t_j	thickness of mortar joint
n	normal to bed joint
s	tangential to bed joint
$\bar{t}$	stress matrix
$\bar{k}$	stiffness matrix
$\bar{u}$	displacement matrix
σ	normal stress
τ	shear stress
k_n	normal stiffness
k_s	shear stiffness
u_n	normal displacement
u_s	tangential displacement
h_u	height of concrete masonry unit
E_u	modulus of elasticity of unit
E_m	modulus of elasticity of masonry
υ	Poisson's ratio of mortar
β_{1t}	tolerance for tension failure
β_{2t}	tolerance for shear failure
u_{no}	normal displacement correspond to peak normal stress
u_{so}	shear displacement correspond to peak shear stress
f_1	tension failure criteria
$\bar{r}_1(p_1)$	tension softening stress
f_t	tensile strength of masonry
G_{f_t}	tensile energy
p_1	normal plastic displacement in tension
h	slope of post-failure response curve
β_{1c}	tolerance for compression failure
β_{2c}	tolerance for shear–compression failure
f_2	shear failure criteria
p_2	tangential plastic displacement
$\bar{r}_2(p_2)$	shear softening stress
c_o	shear strength of masonry
G_{f_s}	shear energy
$\mu = \tan\varphi$	coefficient of friction
f_3	compression failure criteria
p_3	compression plastic displacement in tension
$r_3(p_3)$	compression softening stress
f_c	compressive strength of masonry
p	generalized plastic displacement
f	generalized failure function
σ_e	generalized effective stress
r	generalized post failure stress
σ_y	generalized failure stress
σ_{tn}	tensile stress normal to bed joint
σ_{cn}	compressive stress normal to bed joint
σ_{tp}	tensile stress parallel to bed joint
σ_{cp}	compressive stress parallel to bed joint
δ_{tn}	tensile displacement normal to bed joint
δ_{cn}	compressive displacement normal to bed joint
δ_{tp}	tensile displacement parallel to bed joint
δ_{cp}	compressive displacement parallel to bed joint

and may not be suitable for thin layer, high adhesive mortared masonry.

A detailed modelling method can be cost effective as the other alternative of experimental method to determine the properties of masonry can be quite expensive – particularly where complex stress state behaviour is desired. This paper reports an ongoing research on the response of thin layer mortared masonry under complex states of stresses.

The modelling method reported in this paper considers concrete blocks as a plastically damaging nonlinear solid element similar to the formulation by Lee and Fenves [40] and Lubliner et al. [41]. The body of the mortar layer and the interfaces are included in the interface element formulation reported in this paper. The main novelty in this model is the determination of the nonlinear post-peak plastic deformations using explicit derivatives of the constitutive equations. This approach is used to update the plastic displacement vectors, interfacial stress tensors and the Jacobian matrices. This approach, therefore, provides very large nonlinear plastic deformation without any convergence problems unlike the commonly used predictor–corrector integration schemes where prediction of large deformations under very small load increments is problematic. Furthermore, the explicit integration scheme is easy to formulate as narrated in Section 3. Another novelty is the ability of this model to reproduce the failure of this masonry through joints as well as the masonry units, the details of which are given in Section 9.

The effect of mesh and load increment size is reported in this paper. These studies present the calibration of the model through compression, flexural tension and shear tests reported in Thamboo et al. [42]. Orthotropy of thin layer mortared masonry has been studied using uniaxial tensile and compressive loading applied parallel and perpendicular to bed joints. Finally the model is verified using the results of a thin layer mortared masonry shear wall the result of which is available in da Porto [1].

2. Interface model

Let us consider a masonry wall constructed using concrete blocks and thin layer of polymer mortar as in Fig. 1(a) where two blocks (top and bottom, denoted by Π_1) sandwiches a mortar layer (Π_2) of uniform thickness t_j as shown in Fig. 1(b).

The static and kinematic fields of the mortar layer (Π_2) are defined in its local Cartesian coordinate system (n, s) in which n and s are normal and tangential axes (to bed joints), respectively, as shown in Fig. 1(b).

Fig. 1(c) shows a joint which consists of two components: (i) mortar layer and (ii) block–mortar interface. Tensile and shear failures in masonry commonly occur through the joints; with thin layer mortar, it is very difficult to assess whether or not the failure plane cut through the body of the mortar layer or the mortar–block interface plane. Even in traditional masonry employing 10 mm joints, failure is usually a combination of mortar body cracking and delamination of block–mortar interface. It is, therefore, sensible to consider both the mortar–block interface and the mortar body as one equivalent system for modelling purposes as shown in Fig. 1(d). Concrete blocks are considered plastically damaging deformable solid. The model of unit-joint assembly is shown in Fig. 1(e).

2.1. Elastic response

Initially the interface behaves elastically as defined in Eq. (1):

$$\bar{t} = \bar{k} \times \bar{u} \tag{1}$$