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A new strut model for solid masonry infills in steel frames

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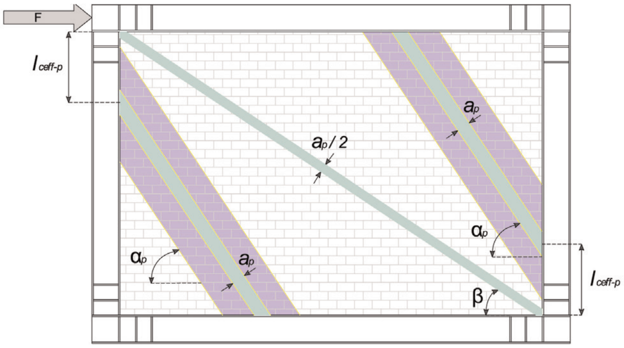
ABSTRACT

This paper presents in-depth results of a proposed strut model for masonry infill walls in moment-resisting steel frames. The proposed model is based on the results of calibrated finite element analyses and hence gives realistic representation of infilled frames behavior. Comparisons are made between the results of the proposed model and other existing strut models; ASCE beam-to-beam, ASCE column-to-column and El-Dakhakhni. The results prove that considerable improvement has been made in capturing the internal forces of the frame members and force-displacement diagram of infilled frames by the new model compared to the existing models. Robustness of the proposed model is also confirmed in predicting performance of several experimental results of infill walls in steel frames.

The model can be observed in the following figure:



$a_P = 0.001a_M(6\theta + 7.5\alpha_p)$ θ and α_p in degrees

$L_{ceff-p} = 0.006h(\theta + \alpha_p - 10\lambda_l h)$ θ and α_p in degrees

$\alpha \cong \tan^{-1}\frac{1}{\mu}$

$\alpha_p = \alpha - \lambda_l h$ α_p and α in degrees

a_{M} is Mainstone proposed strut model and μ is coefficient of friction between bricks of the wall.

1. Introduction

There are numerous attempts in capturing the general behavior of infilled frames; most of them replacing the infill wall with an equivalent diagonal strut. Although accuracy of this modeling has been proved in many studies, this modeling approach seems to

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Nomenclature

a	width of the equivalent strut
a_M	Mainstone proposed strut width
A_{ni}	area of net mortared/grouted section across infill panel
c	mortar cohesive strength
E_m	masonry prism Young's modulus
f_m	infill material compressive strength
f_t	blocks tensile strength
f_y	yield strength of steel
f_{vie}	expected shear strength of masonry infill
F_e	strength demand of the equivalent elastic system
F_y	system yield strength
F_{u-E}	experiential ultimate capacity of infilled frame
F_{u-M}	ultimate capacity of infilled frame based on Mainstone
h	height of frame
h_{inf}	height of infill
k	knowledge factor defined in Section 2.2.6.4 of ASCE 41
l	length of frame
$l_{beff,ceff}$	effective contact length of strut on beam and column
l_{inf}	length of infill
m	component demand modification factor to account for expected ductility associated with this action at the selected Structural Performance Level
$M_{pb,pc}$	plastic moment capacity of beam and column
M_{pj}	plastic moment capacity of frame joint
$M_{beam-cal}$	calculated moment in the beam from the equivalent diagonal strut forces
$M_{col-cal}$	calculated moment in the column from the equivalent diagonal strut forces
G_f^I	tensile fracture energy per unit area
G_f^{II}	shear fracture energy per unit area
Q_{CE}	computed expected strength of infill wall
Q_{UD}	computed demand of infill wall
Q_{ULT}	ultimate strength of infill
r	infill aspect ratio
t	infill thickness
T_i	natural period of i-th mode
t_m *and* t_m^0	normal and shear traction
$t_{s,t}$ *and* $t_{s,t}^0$	normal and shear traction strengths
$w_{c,t}$	compression and tension stiffness recovery factors
Z_{beam}	section modulus of beam
Z_{col}	section modulus of column
β	infill wall height to length ratio
δ_m^f	damage ultimate displacement
δ_m^0	damage initiation displacement
$\delta_m^{\max}$	damage displacement
θ	$\tan^{-1}\frac{h}{l}$
κ	decay rate of cohesive layer in damage evolution
λ_l	Stafford-Smith relative stiffness
$\mu = \tan\phi$	coefficient of friction between blocks
μ_C	ductility capacity
μ_D	ductility demand
μ_{IF}	coefficient of friction between infill and frame
υ	Poisson's ration
ω	constant vertical load on beam
$\sigma_{c,t}$	compressive and tensile stresses

capture global behavior of infilled frames regardless of the internal forces in the frame members. Al-chaar et al. [1] reported observing two parallel diagonal struts in large drifts in their experimental works; while there was a single diagonal strut in the previous steps of loading the specimen. Similar to El-Dakhakhni et al. [2], Chrysostomou et al. [3] suggested modification of the diagonal strut with three equivalent diagonal struts. Rodrigues et al. [4] and Crisafulli and Carr [5] also proposed two strut models for simulation of infilled frames. Therefore, it is concluded that strut direction in infill walls can change to off-diagonal depending on geometrical and mechanical characteristics of the infilled frames, type and material of surrounding frame, and also drift demands.

In a comprehensive study, Asteris et al. [6] pointed out the advantages and disadvantages of the existing macro-models for simulation of infilled frames. They also gave practical recommendations for the implementation of each of these models. They considered the two modes of corner crushing and shear sliding and found that the Mainstone's model, in general, results in a lower-bound equivalent strut width. Among the results of their study is that the single-strut models fail to capture the interaction between the bounding frame and the infill wall, and unless there is a hysteretic model defined, they cannot be used for response history analysis. Also, the same goes for the two-strut models which cannot achieve the accuracy of the three-strut models. Similarly, Crisafulli et al. [7] presented a general review of the available various methods of the two general strategies of modeling infilled frames namely the local or micro-models and the simplified or macro-models. One of the remarkable parts of their studies were comparison of the six existing hysteretic behavior of diagonal struts. Asteris and Cotsovos [8] carried out numerical simulation of unreinforced concrete and masonry infill walls in the reinforced concrete frames by means of nonlinear finite element method. They calibrated their modeling against the results of shaking table tests on a bare frame. Then, they evaluated the effects of including various arrangements of infill walls in the two-story frames. The parameters under study were stiffness, load-carrying capacity, deformation profile, cracking, ductility and failure mode of the frame. Asteris et al. [9] proposed stiffness reduction factors for reinforced concrete frames with perforated infill walls in terms of the ratio of the effective width of the diagonal strut of an infill with openings over that of the solid infill. The validity of their proposed equations was verified against the results of the previously-performed experimental studies. They employed their modeling approach in nonlinear dynamic analyses of several multi-story infilled frames.

As stated, a new strut model is needed to consider more details in terms of behavioral characteristics of infilled frames. For this purpose, understanding the details of struts in different drift levels as well as distribution of internal forces in the frame members is necessary. Liauw and Kwan [10] stated that the moment distribution and magnitudes in columns experience considerable change in different drift ratios while the distribution and also the magnitude of shear forces in beams remains almost constant. Considerable change in moment and axial force distribution in columns of infilled frames was reported by Buonopane and White [11] in different excitation levels. Similar to the studies performed by Fardis and Panagiotakos [12], the distribution of internal forces in the frame members also depends on the position of column members of multi-story, multi-bay frames; the members located at the outward of the frame experience less alternation in the moment distribution alongside their length [2]. In agreement with these results, Asteris [13] found that the presence of the infill wall lead to a reduction in the columns' shear forces; however, this is not the case for the buildings with soft ground story. He performed