REINFORCED MASONRY SQUAT WALLS UNDER HORIZONTAL MONOTONIC AND CYCLIC LOADING

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SUMMARY

An approximate analytical model is used for the prediction of strength as well as of deformational behaviour of reinforced masonry walls under both monotonic and cyclic horizontal loading.

INTRODUCTION

Traditionally, seismic behaviour of masonry walls is assessed by means of rather simple models: In the case of plain masonry, cracking load under monotonic action is considered to be critical for reinforced masonry walls, oversimplified expressions are used taking into account only horizontal reinforcements at yield.

Therefore, intensive research in this field is needed; response degradation under cyclic loading should be thoroughly understood and pragmatically predicted. This paper was intended to contribute to this purpose.

INTERACTION DIAGRAMS UNDER MONOTONIC LOADING

A better understanding of failure mechanisms of unreinforced and of reinforced masonry walls under monotonic loading, is thought to be a prerequisite for any investigation regarding masonry walls behaviour under cyclic actions.

Plain masonry

Fig. 1 is an example of interaction diagrams for an isolated unreinforced masonry wall under monotonic compression and shear forces. Simple analytical expressions shown on the figure (taken from Ref. 1), describe the "critical domain" 0, I, II, III, IV, V, VI, VII, 0. This numerical example has been prepared on the basis of input data of a test made by Jolley (Ref. 2): $\alpha = 1$, $f_{wc} = 43.5$, $f_{bc} = 100.0$, $f_{bt} \simeq 3.0$, $c_{m_b} \simeq 0.7$, $f_{mt} \simeq 0.85$ N/mm^2. Local friction coefficients have been estimated by means of the empirical expression (Ref. 1) $\mu_{\sigma_o} \simeq 3(\sigma_o : f_{wc})^{-2/3}$

Experimental results found by Jolley (Ref. 2) are available only for $\sigma_o : f_{wc}$ values ranging between 0,02 and 0,20; the results seem to confirm the part II, III of the critical domain. Due to the high uncertainty of basic data values, as well as of the "vicinity" of several failure curves

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Reinforced masonry

Under the light of the last remark, the additional parameters (listed here below) regarding reinforced masonry walls render unpractical any general representation of interaction diagrams: In addition to the five failure modes of unreinforced walls, several steel percentages (as well as several ratios of horizontal to vertical steel percentage) will drastically influence the ultimate shear resistance of reinforced masonry walls. However, the combined model of "shear-truss" with simultaneous action of "diagonal strut", is expected to be a versatile model to describe this behaviour, as in the case of R.C. short columns (Ref. 3, 4) depicted in Fig. 2.

POST-CRACKING, POST-PLASTIC MODEL

In order to predict, roughly though, the full load-displacement diagram of reinforced masonry walls under both monotonic and cyclic horizontal loading, Tassios (Ref. 5) has proposed an analytical model ("stereostatic" model) which is briefly described in Fig. 3 and here below.

A large diagonal full crack is considered to be the prevailing failure mode, combined with yielding of reinforcements crossing this crack; local compressive failure of masonry near the other end of this diagonal crack is also considered. The two (triangular and or trapezoidal) parts of the wall after cracking, are supposed to be solid bodies. Therefore, the reactions of steel bars along the crack may be predicted by means of kinematic data such as the diagonal shear slip "s" (s. Fig. 3) and the horizontal displacement "u", which do mobilize corresponding dowel and pullout forces of steel bars embedded in masonry. Parallely, friction reactions along the compressed length of the diagonal crack should also be taken into account. Specific submodels are needed for these three categories of reaction forces, as functions of the relevant displacements (s. sketches in Fig. 3). Consequently, equilibrium equations (for step by step increased or decreased horizontal load V) may be written in terms of the previously mentioned kinematic data, leading finally to the global force-displacement (V, u) relationship sought. Its maximum V-value may also be retained as the ultimate shear strength of the wall.

MONOTONIC HORIZONTAL LOADING

The submodels for dowel, pullout and friction reactions mobilised along the main diagonal crack are temporarily derived from similar submodels available for reinforced concrete (Ref. 6), making approximative corrections to account for lower strength and softer behaviour of masonry.

Fig. 4 is an example of applications of the stereomatic model for monotonic horizontal loading of a reinforced masonry wall of equal length and height; input data are also shown in Fig. 4.

Several parametric studies made by means of the computerized stereostatic model, allow for some more general practical conclusions regarding design.

CYCLIC HORIZONTAL LOADING

The step by step procedure when applying the stereostatic model previously described, allows for unloading from any level of horizontal loading or displacement. In such a case, the submodels used for dowel, pullout and friction, should also contain descending and reversed branches. To this purpose, some formalistic models have indicatively been used, after appropriate modifications of the models regarding reinforced concrete, from Ref. 6. Fig. 5 shows such a numerical application on a reinforced masonry wall having input data as in a test made by Priestley-Bridgeman (Ref. 7).

Finally, cyclic fully reversed horizontal displacements may also be analytically applied; however, a modification of the stereostatic model is needed: Instead of two solid-body parts, four solid-bodies should be considered. Such a developed model is the subject of another publication.

INTRODUCTORY EXPERIMENTAL MODEL

An experimental research has been initiated, in order to check, modify or calibrate the models previously presented. An introductory test on a 1:4 scale model of reinforced brick masonry wall has been performed, under fully reversed lateral displacements (Fig. 6).

MAIN NOTATIONS

α = $h_w : l_w$, wall form ratio
α_s = $M : V.l_w$ shear ratio
a_y = pullout displacement at yield of steel
A_{sh}, A_{sv} = horizontal and vertical reinforcement cross-section
A_w = $l_w.b_w$ horizontal cross section of the wall
b_w = width of wall
B = pullout force
β = numerical factor for shear stress distribution
c_{mb}= cohesion (shear strength under zero normal stress) between mortar and block-unit
d = length of crack where steel bars have yielded
D = dowel force
f_{bc}= compressive strength of block-units
f_{bt}= tension-strength of block units
f_{mc}= compressive strength of mortar
f_{mt}= tension-strength of mortar
f_{wc}= compressive strength of masonry
f_{wt}= tension-strength of masonry
h_w = height of wall
l_w = length of wall base
$\mu_{\sigma o}$= friction coefficient, being a function of normal stress σ_o
P = vertical load (permanent)

ρ = percentage of reinforcement (ρ_v vertical, ρ_h horizontal)
ρ_w = equivalent steel percentage perpendicular to the diagonal crack
s = slip along diagonal crack
σ_o = vertical normal stress acting on top of the wall
σ_c = maximum compressive stress on masonry
σ_s = steel stress
$\bar{\tau}$ = average shear stress acting on top of the wall
$\bar{\tau}_u$ = ultimate value of $\bar{\tau}$
τ_f = local friction shear stress
T = friction force along the compressed area of the diagonal crack
u = horizontal displacement
V = horizontal load
x = compressed length of the diagonal crack

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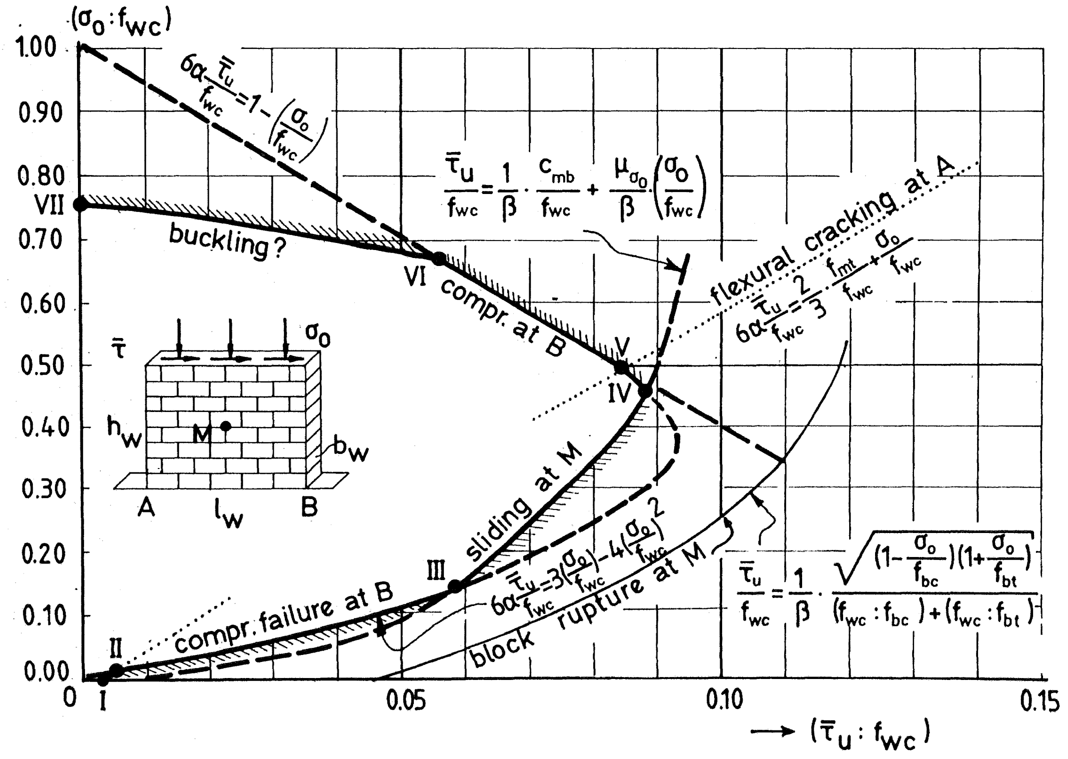

Fig. 1: Calculated interaction diagrams of a plain masonry wall tested by Jolley (Ref. 2)

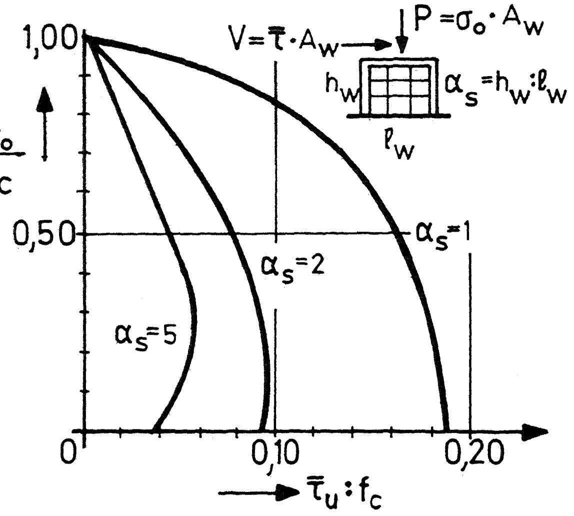

Fig. 2: Interaction diagrams of R.C. short columns (highly reinforced), predicted by the combined model "shear-truss" / "diagonal strut", (Ref. 4)

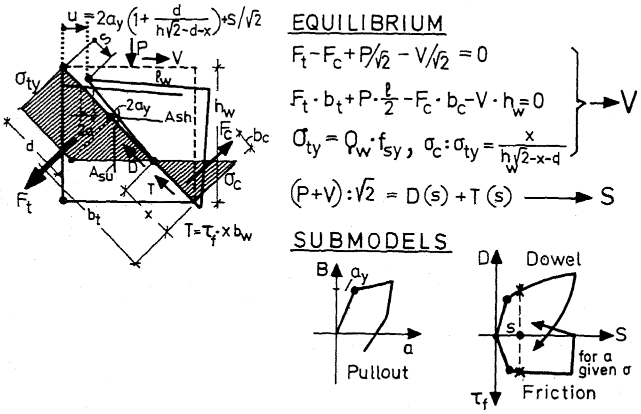

Fig. 3: Post-cracking, post-plastic ("stereostatic") model for an appropriate analytical prediction of horizontal force vs. horizontal displacements relationship of reinforced masonry walls

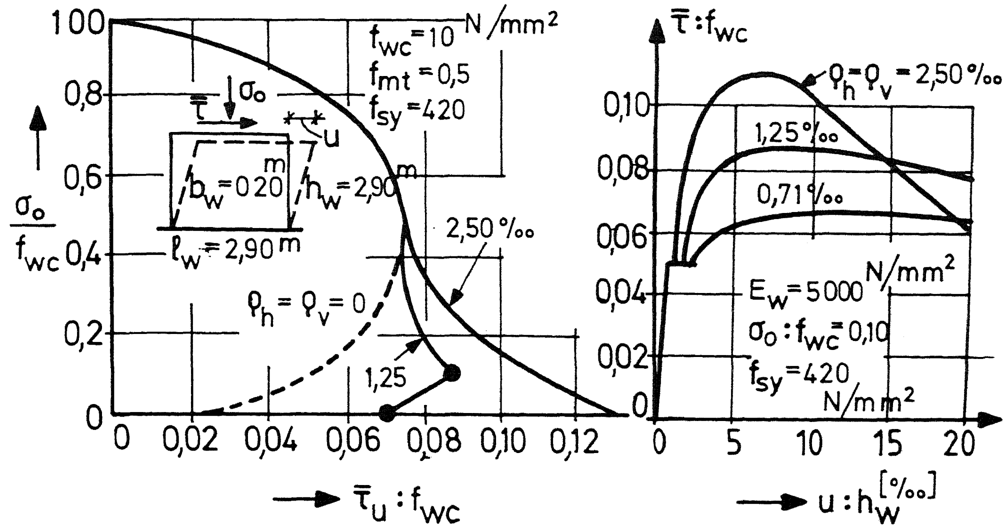

Fig. 4: Analytical predictions of strength and stress-angular deformation relationships of a reinforced masonry wall under monotonic loading. Post-cracking behaviour, together with several steel reinforcement reactions, is considered

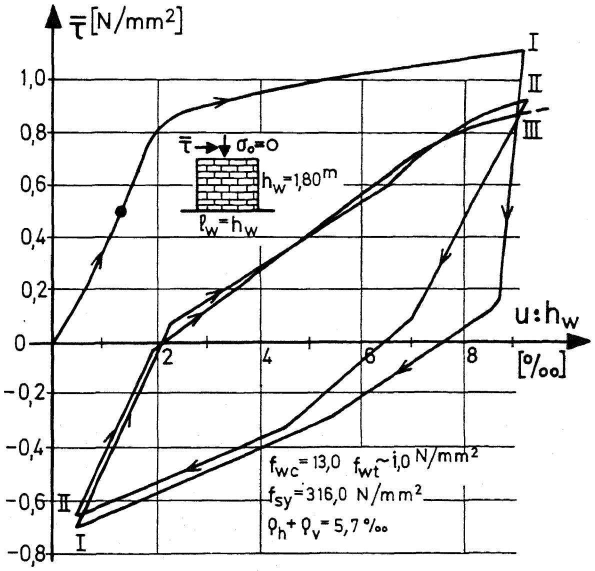

Fig. 5: Cyclic horizontal loading (+V, $-\frac{V}{2}$) of a masonry reinforced wall: Analytical predictions, by means of the stereostatic model

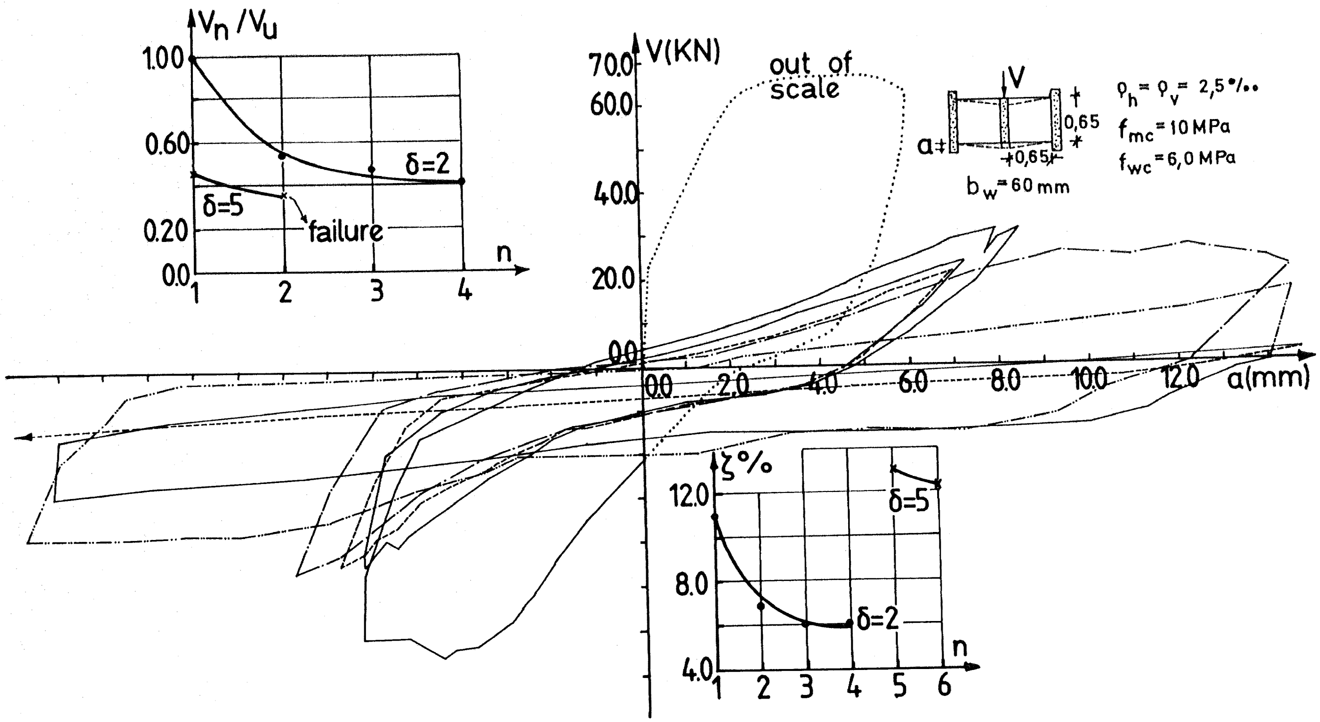

Fig. 6: Experimental results of cyclically reversed lateral displacements of a reinforced masonry model wall; post-yield response and damping characteristics are shown.