THE IN-PLANE FAILURE OF BRICKWORK

BY

W. SAMARASINGHE

(B.Sc. Eng)

DOCTOR OF PHILOSOPHY

UNIVERSITY OF EDINBURGH

1980

PREFACE

This thesis is the result of a three-year research work for the degree of doctor of philosophy in the Department of Civil Engineering and Building Science, University of Edinburgh since October 1977.

During this period three papers have been accepted for publication. The titles are as follows:

1. "The In-plane Failure of Masonry - An Overview" Co-authors A.W. Page and A.W. Hendry, A paper to be presented for the "Seventh International Symposium on Load Bearing Brickwork", November 1980.

2. "Strength of Brickwork under Biaxial Stresses" Co-author A.W. Hendry, A paper to be presented for the "Seventh International Symposium on Load Bearing Brickwork", November 1980.

3. "On the Failure of Masonry Shear Walls" Co-authors A.W. Page and A.W. Hendry, International Journal of Masonry Construction, June 1980, Vol. 1, No. 2.

It is declared that the thesis has been composed by the author himself, and all the work and results in the thesis have been carried out and achieved solely by him under the supervision of Professor A.W. Hendry, unless otherwise stated.

Edinburgh, September 1980

W. Samarasinghe

W. Samarasinghe

ABSTRACT

This thesis presents the results of an experimental investigation into the strength of brickwork under biaxial tension-compression. Since there is insufficient experimental evidence available on the strength of brickwork under biaxial stress to explain the behaviour of brick masonry walls under in-plane loads, experiments were carried out on one-sixth scale model brickwork panels under uniform stress conditions. An idealized failure surface is suggested based on experimental results, and the effect of shear bond strength and tensile bond strength on the results is discussed.

An iterative plane stress finite element computer programme incorporating the above information is used to simulate the in-plane behaviour of brickwork. Brickwork is treated as an elastic, isotropic material with limited capacity when stressed in a state of biaxial tension-compression. The model reproduces the non-linear behaviour of masonry produced by progressive cracking. Shear wall tests have been used to test the validity of the analytical model. Sensitivity analysis of the elastic constants used in the model are performed to illustrate their influence on the calculated stresses.

The influence of the stress distribution on shear wall behaviour, and the derivation of a failure criterion for local failure in masonry shear walls, are described. This criterion, in terms of the vertical stress and shear stress at a point, has been derived for particular values of horizontal stress from the three dimensional surface mentioned above. The effect of the shape of the specimen, testing technique, and boundary conditions on the shear strength of masonry panels is discussed.

ACKNOWLEDGEMENT

The author is gratefully indebted to a number of persons and parties who have helped, criticised, financed, encouraged and typed during the three years of this project.

In particular, the author is grateful to the British Council (Technical Coorporation Training Department) and members of his family for their financial support and encouragement during the period of this research. Thanks are also due to the authorities in the University of Moratuwa, Sri-Lanka, for granting leave to continue this study. Special thanks are due to Professor D.S. Wijeyesekara, Dean of the Faculty of Engineering and Architecture, University of Moratuwa, Sri-Lanka, for his warm encouragement and understanding throughout the whole period of work.

To Professor A.W. Hendry, Head of the Department of Civil Engineering and Building Science, University of Edinburgh, the author owes very special thanks for his kindness, generosity, encouragement and invaluable advice on every occasion.

Dr. S.R. Davies (University of Edinburgh) and Dr. A.W. Page (University of Newcastle, Australia) are gratefully acknowledged for their constructive advice, suggestions and interest during the period of developing the computer model.

Within the Department of Civil Engineering and Building Science at the University of Edinburgh the author wishes to thank the technical staff for their help with the experiments and photography. Thanks are also due to Dr. B.P. Sinha and Dr. R. Royles and the past and present fellow post-graduate students for their help on several occasions.

The British Ceramic Research Association is thanked for providing model bricks for the experimental programme.

Mrs. E. Wagner and Mr. and Mrs. W.H.R. Laird are deeply appreciated for reading the typed manuscript, and for their generosity, hospitality, kindness and encouragement during the author's stay in Edinburgh.

Finally the author is thankful to Miss Gillian Erskine and Mrs. Liz Paterson who turned tangled notes into a tidy typescript in a short time.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOTATIONS

Each symbol used in the text is explained where it first appears. However, a summary of frequently used symbols is also presented below for convenience.

Note: (1) The following general terminology has been adopted:

{ } denotes a column vector

[ ] denotes a row vector, or rectangular or square matrix

$[\ ]^T$ denotes the transpose of a matrix or a column vector.

(2) The notation adopted in the computer programme is listed in Appendix C.

σ_1	Major principal stress
σ_2	Minor principal stress
σ_t	Principal tensile stress at failure
σ_n	Average compressive stress at the brick-mortar interface
σ_N	Stress normal to the brick-mortar interface
σ_{NB}	Normal stress at the bed joints
σ_{NP}	Normal stress at the perpend joints
σ_x, σ_y	Local stresses parallel to x and y directions (parallel to bed joints and perpendicular to bed joints respectively)
τ_o	Initial shear bond strength at the brick-mortar interface
τ	Local shear stress
τ_{av}	Average shear stress at the brick-mortar interface
t_o	Tensile bond strength at the brick-mortar interface
θ	Direction of σ_1 relative to the bed joint direction
f_c	Principal compressive stress
f_t	Principal tensile stress
f_m	Compressive strength of masonry
f_{td}	Diagonal tensile strength of brickwork
f_{bt}	Flexural tensile strength of brick unit

μ	Coefficient of friction
$\bar{X}$	mean
S.D.	Standard deviation
C. of V.	Coefficient of variation
u, v,	Displacements in x and y directions
2a,2b	Rectangular element length and height respectively
{c}	Displacement function coefficients
{t}	Element displacements
[Z]	Transformation relating displacement function coefficients to element displacements
$[Z_n]$	Transformation relating nodal displacement function coefficients
{n}	Nodal displacements for an element
[P]	Transformation relating nodal and element displacements
$\{\varepsilon\}$	Element strains
$\varepsilon_x, \varepsilon_y, \varepsilon_{xy}$	Strain in x and y directions and shear strain
[s]	Transformation relating element strains to element displacements
[B]	Transformation relating strains and nodal displacements
[D]	Constitute strain-stress matrix
E	Elastic Modulus
ν	Poisson's Ratio
$\{\sigma\}$	Element stress
{f}	Nodal forces
[K]	Element stiffness matrix
[k]	Structure stiffness matrix
W	Load applied normal to the bed joints for shear walls
P	Shearing load applied for shear walls
α	$\tan^{-1}(W/P)$