

# **THE BEHAVIOUR OF BRICK MASONRY UNDER CYCLIC COMPRESSIVE LOADINGS**

*A THESIS SUBMITTED  
IN FULFILMENT OF THE REQUIREMENTS  
FOR THE AWARD OF THE DEGREE OF  
DOCTOR OF PHILOSOPHY*

by  
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## CERTIFICATE

This is to certify that the thesis entitled "The Behaviour of Brick Masonry under Cyclic Compressive Loadings" being submitted by Mr.K.S.Naraine to the Indian Institute of Technology, Delhi for the award of the degree of Doctor of Philosophy in Civil Engineering, is a record of bonafide research work carried out by him. Mr.K.S.Naraine has worked under my guidance and supervision and has fulfilled the requirements for the submission of this thesis, which to my knowledge, has reached the requisite standard.

The matter embodied in this thesis has not been submitted, in part or in full, to any other University or Institute for the award of any degree or diploma.

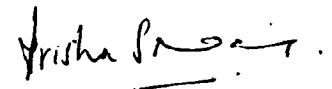


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(Krishna S. Naraine)

## PREFACE

The research work presented in this thesis was conducted over a period of four years. During this period the following ten papers have been accepted or communicated for publication.

- (1) Naraine, K. and Sinha, S.N. (1989). "Behaviour of Brick Masonry under Cyclic Compressive Loading," Journal of Struct. Engineering, ASCE, (to appear in June issue).
- (2) Naraine, K. and Sinha, S.N. (1988). "Test of Brick Masonry Models under Cyclic Compressive Loading," Proc. 8th Int. Brick Mas. Conf., Dublin, Ireland, 395-405.
- (3) Naraine, K. and Sinha, S.N. (1989). "Loading and Unloading Stress-Strain Curves for Brick Masonry," Journal of Struct. Engineering, ASCE, (to appear in Oct. issue).
- (4) Naraine, K. and Sinha, S.N. (1989). "Cyclic Stress-Strain Curves for Brick Masonry," Proc. 2nd. East Asia-Pacific Conf. on Struct. Engin. and Construct., Thailand, 55-62.
- (5) Naraine, K. and Sinha, S.N. (1989). "Geometrical Model for Brick Masonry under Cyclic Compressive Loading," paper accepted for presentation at the Second Int. Mas. Conf., London.

- (6) Naraine, K. and Sinha, S.N. (1989). "Energy Dissipation in Brick Masonry under Cyclic Compressive Loading," paper to be presented at the Second Int. Mas. Conf., London.
- (7) Naraine, K. and Sinha, S.N. (1989). "Fatigue Behaviour of Brick Masonry," paper accepted for presentation at STRUCENG-89, Numerical and Experimental Analysis of Structures, Los Angeles, California.
- (8) Naraine, K. and Sinha, S.N. (1989). "Model for Cyclic Compressive Behaviour of Brick Masonry," revised manuscript submitted to the Journal of Struct. Engin., ASCE.
- (9) Naraine, K. and Sinha, S.N. (1989). "Behaviour of Brick Masonry under Cyclic Biaxial Compressive Loading," paper communicated to the Journal of Materials in Civil Engineering, ASCE.
- (10) Naraine, K. and Sinha, S.N. (1989). "Stress-Strain Curves for Brick Masonry in Biaxial Compression - A Generalized Approach," paper to be communicated to the Journal of Struct. Engin., ASCE.

## ABSTRACT

This thesis presents a study of the behaviour of brick masonry under cyclic compressive loadings. The study commences by investigating the stress-strain characteristics of brick masonry under uniaxial cyclic compressive loading. The study is then extended to the investigation of brick masonry under low-cycle fatigue compressive loading. Finally, the behaviour of brick masonry under cyclic biaxial compressive loading is presented. A brief review of the study is now outlined.

An experimental program was conducted on prototype specimens and half scale models to investigate the behaviour of brick masonry under uniaxial cyclic compressive loading. Tests were conducted for two cases of loading, perpendicular and parallel to the bed joint, and three types of test were conducted for each case of loading: (i) Monotonic tests; (ii) Tests under cyclic loading in which the peak stress in each cycle of loading coincided approximately with the envelope stress-strain curve obtained under the monotonic tests. The cyclic stress-strain history so obtained possessed a locus of common points. (iii) Tests under cyclic loading in which the cyclic load was applied as in the case of the second test type except that in each cycle loading and unloading were repeated several times; each time unloading was done when the reloading curve intersected with the initial unloading curve. This point of intersection

gradually descended and stabilized at a lower bound and further cycling led to the formation of a closed hysteresis loop. Such lower bound points are termed stability points.

One general equation is proposed for the determination of the envelope stress-strain curve, the locus of common points and the locus of stability points. A mathematical model is presented to obtain the reloading and unloading stress-strain curves at different values of plastic (residual) strain. A geometrical model for the uniaxial cyclic compressive behaviour of brick masonry is also presented. The model utilizes several focal points in the uniaxial stress-strain plane that are derived based on geometrical properties of the cyclic stress-strain curves. The model facilitates the reproduction of the locus of common points, the locus of stability points, the reloading/unloading stress-strain curves and the plastic strain curves.

An experimental investigation consisting of tests on prototype brick masonry specimens was done to study the behaviour of brick masonry under repeated uniaxial compressive loading between maximum and minimum stress levels. Load cycles were applied between fixed stress levels until the strains accumulated to produce failure. The scope of this study was limited to low-cycle fatigue tests in the range of approximately up to 2000 cycles.

Cyclic compressive biaxial tests were conducted on half scale brick masonry models for a range of 5 principal stress ratios; the principal stresses were applied normal and parallel to the bed joint. For each stress ratio, the envelope stress-strain curve, the locus of common points and the locus of stability points were determined. The plastic deformation curves were also determined for each stress ratio.

An analytical expression, similar to the expression used in the uniaxial study, is proposed for the envelope curve, the common point curve and the stability point curve. A failure interaction curve in the compression-compression stress state region is proposed. A generalized approach is outlined to obtain the envelope curve, the common point curve and the stability point curve.

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