STABILITY OF DRY- STACK MASONRY

by

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A thesis submitted to the Faculty of Engineering, University of the Witwatersrand, in the fulfilment of the requirements for the degree of Doctor of Philosophy in Engineering.

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DECLARATION

I declare that this thesis is my own, unaided work. It is being submitted in the Faculty of Engineering at the University of the Witwatersrand, for the degree of Doctor of Philosophy in Engineering. It has not been submitted before for any degree or examination in any other University

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ABSTRACT

This thesis presents the findings on empirical study of dry-stack masonry. Dry-stack masonry refers to a method of building masonry walls, where most of the masonry units are laid without mortar in the joints. Of late (since mid eighties) in modern construction, dry-stacking or mortarless technology is increasingly becoming popular because of its advantages. The construction industry is acknowledging the need to accelerate the masonry construction process, as the traditional method is labour intensive and hence slower due to the presence of a large number of mortar joints. Early attempts were made to increase the size of masonry units (block instead of brick), thereby reducing the number of mortar joints, wherein the use of bedding mortar imposed constraints on the number of courses to be constructed in a day. Elimination of bedding mortar accelerates construction; thereby reducing cost, variation due to workmanship and generally small pool of skilled labour is required in dry stacking. Dry-stack masonry is a relatively new technology not yet regulated in the code of practice and therefore very limited information on the structural behaviour of the masonry is available. This project is based on the investigation of the HYDRAFORM dry-stack system, which utilises compressed soil-cement interlocking, blocks. The system is now widely used in Africa, Asia and South America. The main objective of the project was to establish through physical testing the capacity of the system to resist lateral load (e.g. wind load), vertical load and dynamic load such as earthquake loading.

In the first phase of the project investigations were conducted under static loading where series of full-scale wall panels were constructed in the laboratory and tested under lateral loading, and others were tested under vertical loading to establish the mode of failure and load capacity of the system. Series of control tests were also conducted by testing series of wallettes to establish failure mechanism of the units and to establish the flexural strength of the system. Finally the test results were used for modelling, where load prediction models for the system under vertical loading and under lateral loading were developed. The theoretical load prediction models were tested against the test results and show good agreement. After the

load capacity was established the next step in the study was to further improve the system for increased capacity particularly under dynamic loading. The normal Hydraform system was modified by introducing a conduit, which allows introduction of reinforcements. Series of dry-stack seismic systems were constructed and initially tested under static lateral loading to establish the lateral load capacity.

The second Phase of the project was to investigate the structural behaviour and performance of the Hydraform system under seismic loading. A shaking table of 20 tonnes payload, (4m x 4m) in plan was designed and fabricated. A full-scale plain dry-stack masonry house was constructed on the shaking table and subjected to seismic base motions. The shaking table test was performed using sine wave signals excitations starting from low to very severe intensity. A conventional masonry test structure of similar parameters was also constructed on the table and tested in a similar manner for comparison. The tests were conducted using a frequency range of 1Hz to 12Hz and the specimens were monitored for peak accelerations and displacements. For both specimens the initial base motion was 0.05g.

The study established the mode of failure of the system; the structural weak points of unreinforced dry-stack masonry, the general structural response of the system under seismic condition and the failure load. The plain dry-stack masonry failed at 0.3g and the conventional masonry failed at 0.6g**.** Finally recommendations for further strengthening of system to improve its lateral capacity were proposed.

STATEMENT OF ACHIEVEMENT

I believe that the work reported in this thesis has made a contribution to the field of dry-stack masonry. The following technical papers were derived from this investigation:

1. Uzoegbo, H; Ngowi J.V;(2004) "Lateral Strength of Dry-stack Wall System", International Journal of British Masonry Society Vol.17,No.3 Dec. 2004, pp 122-128.

2. Uzoegbo, H; Ngowi J.V;(2005) "Empirical Studies of Flexural Strength for Interlocking Masonry", Botswana Journal of Technology (in press).

3. Uzoegbo H; Ngowi J.V; "Structural Behaviour of Dry-stack Interlocking block Walling Systems subjected to In-Plane Loading" Journal of the Concrete Society of the Southern Africa. Issue No 103, May 2003 pp. 8-13.

4. Uzoegbo H; Ngowi J.V; "Structural Behaviour of Dry-stack Interlocking block walling systems". Proceedings of the Sixth International Masonry Conference, British Masonry Society, London, 4th –6th Nov. 2002. pp. 498-502,

5. Uzoegbo H; Ngowi J.V; "Load prediction Model for Laterally Loaded Dry-stack Masonry", International Conference on Structural and Road Transportation (START), 3rd –5th Jan. 2005 INDIA

6. Uzoegbo H; Ngowi J.V; Senthivel R.;(2004) "Load Capacity of Dry-stack Masonry walls" The Masonry Society Journal –USA (*under review*)

DEDICATION

For my family, my wife Magdalena and my two sons

Nelson and Imani Ngowi

"By the way the African pyramids are dry-stacked"

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LIST OF SYMBOLS

f_{panel} = average compressive strength of the dry-stack wall panel

f_{cu} = masonry unit cube strength

f_{xdry} = flexural strength of the dry-stack masonry

$f_{kxparal-dry}$ = flexural strength of dry-stack masonry parallel to bed joint

$f_{kxperp-dry}$ = flexural strength of dry-stack masonry perpendicular to bed joint

h, = height of the wall panel

L = length of the wall panel

M_{cv} = vertical bending moment capacity

M = the bending moment

P = failing lateral pressure

μ_{dry} = orthogonal ratio fully dry stack masonry

μ_{pdry} = orthogonal ratio partially dry-stack masonry

$k_{dry-stack}$ = factor varies with the block characteristics and the geometry of the interlocking mechanism

Z = gross-sectional modulus

ϕ_m = safety factor on material