UNIVERSITI PUTRA MALAYSIA

STRUCTURAL BEHAVIOR OF INTERLOCKING LOAD BEARING HOLLOW BLOCK WALL PANELS WITH STIFFENERS UNDER IN-PLANE VERTICAL AND LATERAL LOADS

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By

NISREEN N. ALI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science

September 2009

To:

All those who have contributed to my journey up the ladder of knowledge

my father's soul

And all the people whom I like and they like me

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Chairman: Professor Ir. Abang Abdullah Abang Ali

Faculty: Engineering

An experimental study was conducted at the Universiti Putra Malaysia to investigate the effect of stiffeners on the structural behavior of Putra interlocking load bearing hollow block wall panels under vertical and lateral loadings. Putra block building system, developed by the Housing Research Centre of Universiti Putra Malaysia, consists of three types of blocks namely stretcher, corner and half blocks. Six wall panels each with 0.9 m width, 1.0 m height and 0.15 m thickness were tested. These wall panels were divided into two sets, each containing three specimens, one with no stiffener and the other two were stiffened with 2 and 3 steel bars and cement grout respectively. The steel bars were placed along the perimeter of the wall panels. All test specimens were subjected to in-plane loading. For vertical load test, uniformly distributed vertical load was applied from zero until failure. In lateral load test, a constant vertical load was applied on the top of the wall, while in-plane lateral load was applied from zero until failure. The effect of stiffeners was investigated by comparing important parameters such as; vertical deflection as well as in-plane and out of plane lateral deflections, failure loads and failure patterns between the stiffened and un-stiffened wall panels. To evaluate the resistances of the wall panels with different stiffeners, strength, cracks pattern and deformation were recorded and analyzed. The results show a significant increase in strength capacity associated with reduction in both lateral and vertical deflections for the stiffened wall panels. In addition, there was reduction in the in-plane lateral deflection for wall panels under the effect of lateral load. A significant change in crack pattern and failure mechanism was also observed. Compressive strength and shear strength for wall panels under the effect of vertical and lateral load which stiffened with 2 and 3 reinforcement steel bars were increased as compared with un-stiffened wall panel. The compressive strength was increased by 21% and 33% for wall panels stiffened with 2 and 3 reinforcement bars respectively as compared with un-stiffened wall panel. And, the shear strength was increased by 50% and 68.7% for wall panels stiffened with 2 and 3 reinforcement bars respectively as compared with un-stiffened wall panel.

Abstrak thesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai mematuhi keperluan untuk ijazah Master Sains

SIFAT STRUKTUR PANEL DINDING BLOK BERONGGA BEBAN TANGGUNGAN SALINGKUNCI DENGAN PENGUKUH DI BAWAH BEBANAN SESATAH MENEGAK DAN MENGUFUK

Oleh

NISREEN N. ALI

September 2009

Pengerusi: **Profesor, Ir. Abang Abdullah Abang Ali**

Fakulti: **Kejuruteraan**

Satu kajian eksperimen telah dijalankan di Universiti Putra Malaysia untuk menyiasat kesan pengukuh ke atas sifat struktur panel dinding blok berongga beban tanggungan saling kunci Putra di bawah bebanan menegak dan mengufuk. Sistem bangunan blok Putra yang dimajukan oleh pusat kajian perumahan, Universiti Putra Malaysia, terdiri daripada tiga jenis blok iaitu peregang, penjuru dan separah. Enam panel dinding dengan lebar 0.9 m, ketinggian 1.0 m dan ketebalan 0.15 m telah diuji. Panel-panel dinding ini telah dibahagi kepada dua set yang mengandungi tiga spesimen masing-masing, satu tanpa pengukuh manakala baki dua dikukuhkan dengan 2 dan 3 bar keluli dengan turapan simen masing-masing. Bar-bar keluli diletak di sepanjang perimeter panel dinding. Kesemua spesimen ujian telah tertakluk kepada bebanan sesatah, untuk ujian beban menegak, taburan seragam beban menegak telah dikenakan dari sifar sehingga gagal. Di dalam ujian beban mengufuk, bebanan menegak yang malar telah dikenakan ke bahagian atas dinding manakala bebanan mengufuk sesatah telah dikenakan dari sifar sehingga gagal. Kesan pengukuh telah disiasat dengan membandingkan parameter-parameter

penting seperti pesongan menegak dan juga pesongan mengufuk sesatah dan di luar satah, beban gagal dan pola kegagalan antara panel dinding yang dikukuhkan dengan tanpa dikukuhkan untuk menilai ketahanan panel dinding dengan pengukuh yang berbeza, kekuatan, pola retakan dan kecacatan telah direkod dan dianalisa. Keputusan menunjukkan peningkatan signifikan dalam kapasiti kekuatan yang dikaitkan dengan pengurangan di dalam kedua-dua pesongan mengufuk dan menegak untuk panel dinding yang telah dikukuhkan. Tambahan pula, terdapat pengurangan pesongan mengufuk sesatah untuk panel dinding di bawah kesan bebanan mengufuk. Perubahan signifikan di dalam pola retakan dan mekanisma kegagalan juga telah diperhatikan. Kekuatan mampatan dan kekuatan ricih untuk panel-panel dinding di bawah kesan vertikal dan beban sisi yang dikuatan dengan 2 dan 3 palang-palang besi telah bertambah secara berperingkat berbanding dengan panel tanpa dinding tetulang. Kekuatan mampatan telah meningkat sebanyak 21% dan 33% untuk panel-panel dinding bertetulang dengan 2 dan 3 peneguhan batang masing-masing berbanding dengan dinding panel tanpa tetulang. Dan, kekuatan ricih telah meningkat sebanyak 50% bagi dinding panel dengan 2 tetulang dan 68.7% bagi dinding panel dengan 3 tetulang jika dibandingkan dengan dinding panel tanpa tetulang.

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I certify that a Thesis Examination Committee has met on **10th September 2009** to conduct the final examination of **NISREEN N. ALI** on her thesis entitled "**Structural Behaviour of Interlocking Load Bearing Hollow Block Wall Panels with Stiffeners Under In-Plane Vertical and Lateral Loads**" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U. (A) 106] 15 March 1998. The Committee recommends that the student be awarded the **Master of Science**.

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

NISREEN N. ALI

Date: February 2010

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LIST OF ABBREVIATIONS

W_s saturated weight of specimen, kg,

W_d oven-dry weight of specimen, kg,

W_l lab environment weight of specimen, kg,

V_{net} net volume of specimen, m^3

N_d vertical ultimate load

b width of the wall section

t thickness of wall section

d_c effective depth of masonry in compression

β capacity reduction factor due to slenderness and eccentricity for top of wall

f_k compressive strength of masonry

f_y yield stress for steel

f_s yield stress for steel, $f_s = f_y$ multiplied by a factor 0.83

γ_{mm} partial safety factor for masonry

γ_{ms} partial safety factor for steel

A_s area of steel under compression

P unit lateral load on wall

H height of wall

A cross sectional area of wall

I moment of inertia of wall in the direction of bending

E_v shear modules of masonry = 0.4

E_m modules elasticity of masonry= k. f_k

k 7500-1000, for concrete block (k) value equal 750 has been used as a better estimate.

Δ_P deflection at the free end due to a horizontal load P

Δ_v deflection in a cantilever at free end due to shear P

Δ the total deflection

CHAPTER 1

INTRODUCTION

1.1 General

Masonry has been widely used for building construction since 19th century because of its versatility, low cost, energy efficiency and fire and wind resistance. In addition, masonry is considered to be strong under imposed gravity loads. It is well accepted building material for the construction of many varieties of buildings due to its high durability and low maintenance. Currently masonry units are produced in many sizes and shapes with various external finishes, and a variety of colours and textures. With the escalating price of steel, labour and other construction materials all over the world, a mortarless load bearing hollow block building system may be a better choice for building construction in the future.

Putra interlocking load bearing hollow block building system was developed by the Housing Research Centre of Universiti Putra Malaysia to promote a cheaper and faster construction system. It includes an interlocking block modular system for mortarless wall assembly in which blocks are laid up in courses in a staggered manner. The use of such blocks speeds up the construction process because of the elimination of mortar layers. Besides, the self-aligning feature of the blocks enables the walls to be assembled at a much faster speed compared to the conventional mortared masonry construction (Abang Abdullah et al., 2002).

Compressive strength is the most important parameter in the design of masonry structures which primarily depends on the strength of the individual blocks. In traditional bonded masonry, strength characteristic of a wall is evaluated in terms of compressive strength of individual blocks and mortar layer as per design code requirements. In the case of mortarless interlocking hollow block wall, characteristic strength of the wall is evaluated either experimentally or analytically (Alwathaf, 2006).

Masonry buildings must have higher ductility and strength to resist the stresses caused in various parts of the structure due to lateral movements (wind and seismic forces). In addition, lateral and vertical deflections must also be limited to avoid damages to finishes. Load bearing masonry buildings usually have strength capacity to carry gravity loads to the foundation. These bearing walls also act as shear walls to resist lateral loads due to wind or seismic forces. The lateral load-carrying capacity of shear wall structures is mainly dependent on the in-plane resistance of the shear walls because the in-plane stiffness of a shear wall is far greater than its out-of-plane stiffness.

Usually, masonry structures are designed for vertical loads and since masonry has adequate compressive strength, the structures behave well as long as the loads are vertical (Jagadish et al., 2001). The walls and partitions supply in-plane lateral stiffness and stability to resist wind, earthquake and any other lateral loads (Taly, 2001).

Masonry wall undergo in-plane shear stress if the internal forces are in the plane of the wall. Shear failure in the form of diagonal cracks are observed due to the effect of this force. Lateral loads (seismic and wind loads) acting on the buildings in-plane and out-of-plane of the wall, disturb the structural stability and may cause collapse. Therefore, the buildings must have high ductility and flexibility to resist the stresses in various parts due to the lateral movement. Wind force is calculated from the wind velocity and some coefficients related to the geometry of the structures. Ground motion during earthquake results in base shear to the structure, this shear force can cause the structure to collapse. However, the base shear force induced by earthquake can be considered as equivalent static lateral load in the superstructure. Many design codes (Indonesian, Indian Japanese codes etc.) provide mathematical formulation to convert base shear into equivalent static lateral load.

Malaysia is situated at the southern edge of the Eurasian Plate. Sabah and Sarawak has experienced moderate earthquakes of local origin that appear to be related to several possible active faults (Majid et al., 2005). On 26th December 2004, several countries on the Indian Ocean were hit by a tsunami (Figure 1.1). This phenomenon was triggered by a massive earthquake with a recorded magnitude of 9.0 on the Richter scale, with the epicenter just off the west coast of North Sumatra, Indonesia. Malaysia was also affected by the tsunami besides Indonesia (Acheh), Sri Lanka, Thailand, India, Maldives, Myanmar, Bangladesh Somalia, Seychelles, Tanzania, Kenya and Yemen (Siwar et al., 2006). The affected states in Malaysia were Penang, Kedah, Perak and Selangor. The tsunami had claimed a number of lives in Malaysia. Commonly, most tsunami victims suffered damages of houses, boats, fishing equipments and aquaculture projects.