UNIVERSITI PUTRA MALAYSIA

STRUCTURAL BEHAVIOR OF INTERLOCKING MORTARLESS PUTRA BLOCK WALL SYSTEM

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By

NOR AZIZI BT SAFIEE

Thesis Submitted to the School of Graduates Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Doctor of Philosophy

March 2011

Dedication

To my husband, Zahid and my son, Alif Farhan
and
to all my family members

Abstract of thesis presented to the senate of Universiti Putra Malaysia
in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chairman : Professor Ir Mohd Saleh Jaafar, PhD

Faculty : Engineering

The masonry industry has undergone changes where designers now have a variety of choices from the types of block to types of construction. Traditional bonded masonry system can now be replaced with mortarless masonry systems. Interlocking block mortarless wall systems can be defined as walls made of assemblages of interlocking block unit without use of any mortar or adhesive material at interlayer between courses. However, the structural behavior of interlocking block mortarless wall has not yet been completely explained. The structural behavior and design parameters for this system are expected to be different than the conventional wall system. In order to understand the performance of the wall system, the behavior and important design parameters of walls under different loadings need to be determined and identified.

This study was primarily conducted through experimental investigation and finite element analysis. A total of 21 full scale specimens were used to observe the behavior and response of three different groups of interlocking mortarless wall systems namely walls without opening, walls with openings and walls with pilasters.

For walls without opening, the experimental investigation was carried out under in-plane and out-of-plane loading. Whereas for the other two groups, they were investigated under compressive loading only. A parametric study using finite element analysis was carried out to study the effect of different parameters on each interlocking wall group considered in addition to the existing data. The finite element program used was developed using the Fortran language while considering important features of the interlocking block mortarless interface. Four different models were developed to represent the different wall systems in this study. Results obtained from the simulation were validated with the corresponding experimental results to check its appropriateness and accuracy. The validation study revealed the finite element results based on the proposed models were in good agreement with the experimental results.

The wall specimens under in-plane and out-of-plane loads were tested under constant pre-compressive vertical load and increasing lateral load. The maximum lateral load carrying capacity, development of strain and failure characteristics were recorded. In the in-plane case, shear stress capacity of the wall became a major concern in this observation. Failure of the in-plane wall is controlled by diagonal shear failure and moderate toe crushing. The main outcome from this in-plane wall investigation was the relationship between average pre-compressive stress and shear stress at failure. For walls under out-of-plane load, the results indicated that pre-compressive vertical loads and reinforcement significantly affected the structural behavior of interlocking block mortarless walls. The failure of wall was dominated by opening between dry joint, cracking, flexure deflection and toe crushing. The design of walls under out-of-plane was controlled by dry joint opening mechanism at mid height of the wall.

Wall panels with opening were tested under vertical compressive loading taking into consideration different sizes of opening and slenderness ratio. The results revealed that the opening size would reduce the maximum load carrying capacity of the wall. The location of openings within the wall also affected the behavior of the wall with opening.

The test results of walls with pilaster revealed that the slenderness ratio had significant effect on the load carrying capacity. The pilasters may also increased the lateral resistance with respect to the out-of-plane displacement and load carrying capacity of the wall systems. By adding pilasters to the wall system failure may be delayed in comparison to that expected to occur in similar specimens of walls without pilaster.

The results indicate that pre-compressive load and slenderness ratio has a significant effect on walls under combined loading. While for other wall groups (wall with opening and wall with pilaster) which were primarily subjected to compressive vertical loads, the slenderness ratio and size opening were factors affecting the behavior of wall systems. The effect of the important parameters contributed to the behavior and prediction of strength for each groups of mortarless interlocking wall system considered. As a contribution, a few formulae, tables and curves were proposed to be used in predicting the ultimate strength of interlocking mortarless Putra block wall system according to their loading condition on each group of wall system. Finally, with a deeper understanding of the behavior of mortarless masonry wall systems, it may contribute to a better application of design and construction.

Abstrak tesis yang dikemukakan kepada senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

KELAKUAN STRUKTUR SISTEM DINDING PUTRA BLOK BERKUNCI TANPA MORTAR

Oleh

NOR AZIZI BT SAFIEE

Mac 2011

Pengerusi : Professor Ir Mohd Saleh Jaafar, PhD

Fakulti : Kejuruteraan

Industri masonri telah mengalami perubahan di mana sekarang perekabentuk mempunyai pelbagai pilihan dari jenis batu bata sehinggalah kepada jenis pembinaan. Sekarang sistem tradisi masonri terikat boleh diganti dengan sistem masonri tanpa mortar. Sistem dinding blok berkunci tanpa mortar boleh didefinasikan sebagai dinding diperbuat daripada penyatuan blok berkunci tanpa menggunakan sebarang mortar atau bahan pelekat diantara lapisan. Walaubagaimanapun, kelakuan struktur dinding blok berkunci tanpa mortar belum lagi difahami sepenuhnya. Kelakuan struktur dan parameter rekabentuk untuk sistem ini dijangka berlainan dengan sistem dinding konvensional. Bagi tujuan untuk memahami kelakuan sistem dinding, sifat dan parameter penting untuk rekabentuk dinding di bawah beban yang berlainan perlu ditentukan dan dikenal pasti.

Kajian ini dijalankan melalui penyelidikan bereksperimen dan analisis unsur terhingga. Sejumlah 21 spesimen berskala penuh telah digunakan untuk memerhati kelakuan dan tindakbalas tiga kumpulan berlainan bagi dinding blok berkunci tanpa mortar yang dinamakan sebagai dinding tanpa bukaan, dinding dengan bukaan dan

dinding dengan pilaster. Bagi dinding tanpa bukaan, penyelididikan bereksperimen telah dijalankan dibawah beban satah dan luar satah. Manakala bagi dua kumpulan dinding yang lain, ia diselidik dibawah beban mampatan sahaja. Satu kajian parametrik menggunakan analisis unsur terhingga telah dijalankan untuk mengkaji kesan parameter berlainan ke atas setiap kumpulan dinding blok berkunci yang dipertimbangkan dalam menambahkan data yang sedia ada. Program unsur terhingga yang digunakan telah dibangunkan menggunakan bahasa Fortran dengan mempertimbangkan elemen penting bagi lapisan antara muka blok berkunci. Empat model berlainan telah dibangunkan bagi mempertimbangkan kumpalan dinding yang berbeza dalam kajian ini. Keputusan yang diperolehi dari simulasi kemudiannya dibandingkan dengan keputusan eksperimen untuk memeriksa kecukupan dan ketepatannya. Kajian validasi menunjukkan keputusan unsur terhingga berdasarkan model yang dicadangkan dengan keputusan eksperimen adalah bagus.

Spesimen dinding di bawah beban satah dan luar satah telah diuji di bawah beban pra-mampatan tegak malar dan beban tepi ditingkatkan. Kapasiti beban tepi maksimum yang boleh ditanggung, perkembangan terikan dan ciri-ciri kegagalan telah direkodkan. Dalam kes di bawah beban satah, kapasiti tegasan ricih menjadi tumpuan penting dalam pemerhatian ini. Kegagalan dinding di bawah beban satah dikawal oleh kegagalan ricih pepenjuru dan kehancuran sederhana di kaki dinding. Hasil penting kajian dinding dibawah beban satah ialah hubungan antara tegasan pra-mampatan purata dan tegasan ricih pada kegagalan. Bagi dinding di bawah beban luar satah, keputusan menunjukkan bahawa beban pra-mampatan tegak dan tetulang pengukuh memberi kesan penting kepada kelakuan struktur dinding blok berkunci tanpa mortar. Kegagalan dinding adalah didominasi oleh bukaan antara join kering,

keretakan, anjakan lenturan dan kehancuran kaki dinding. Rekabentuk dinding di bawah beban luar satah dikawal oleh mekanisma bukaan join kering di tengah ketinggian dinding.

Panel dinding dengan bukaan telah diuji di bawah beban mampatan tegak dengan mengambil kira saiz bukaan berbeza dan nisbah kelangsingan. Keputusan menunjukkan bahawa saiz bukaan boleh mengurangkan kapasiti beban maksimum yang boleh ditanggung oleh dinding. Lokasi bukaan di dinding juga menyumbangkan kesan terhadap kelakuan dinding dengan bukaan.

Keputusan dinding dengan pilaster menunujukkan bahawa nisbah kelangsingan mempunyai kesan penting terhadap kapasiti beban yang boleh ditanggung oleh pilaster. Pilaster juga boleh meningkatkan rintangan tepi terhadap anjakan luar satah dan kapasiti beban yang boleh ditanggung oleh sistem dinding. Dengan menambah sendi/pilaster kepada sistem dinding, mod kegagalan mungkin boleh dilambatkan dalam kontak kegagalan yang dijangka berlaku dalam spesimen dinding yang sama tetapi tanpa pilaster.

Keputusan menunjukkan bahawa beban pra-mampatan dan nisbah kelangsingan mempunyai kesan penting terhadap dinding di bawah beban gabungan. Manakala bagi kumpulan dinding lain (dinding dengan bukaan dan dinding dengan pilaster) yang mana di bebani oleh beban mampatan tegak, nisbah kelangsingan dan saiz bukaan ialah faktor yang memberi kesan kepada kelakuan sistem dinding. Kesan parameter penting menyumbang kepada ramalan sifat dan kekuatan untuk setiap kumpulan yang dipertimbangkan bagi sistem dinding Putra blok berkunci tanpa

mortar. Sebagai sumbangan, beberapa formula, jadual dan lengkung telah dicadangkan untuk digunakan dalam meramal kekuatan maksimum bagi sistem dinding tanpa mortar mengikut keadaan beban bagi setiap kumpulan sistem dinding. Akhirnya, dengan kefahaman yang mendalam ke atas sifat sistem dinding masonri tanpa mortar ianya menyumbangkan kegunaan yang lebih baik di dalam rekabentuk dan pembinaan.

ACKNOWLEDGEMENT

Praises and thanks to Allah SWT for giving the opportunity to further my study at this level and able to complete it. I would like to express my deep thanks and gratitude to my Supervisor, Prof Ir Dr Mohd Saleh Jaafar, for his great supervision and valuable help and encouragement. Many thanks also go to Assoc Prof Dr Jamaloddin Norzaei and for his valuable advice and discussion especially on the numerical method. Thanks also to Dr Ahmed Hassan Al-Wathaf whose comment on my thesis during my writing process.

Thanks also go to structural laboratory technician, Mr Mohd Halim Othman and Mr Jaafar for their valuable assistance in helping me during my tiring day performing my lab work especially in helping fixing test setup and instrumentation.

Thanks you also to Ministry of Higher Learning of Malayisa and University Putra Malaysia for their sponsorship for this study.

I would also like to express my great appreciation and deep gratitude to my husband, Mohamad Zahid Abd Wahab and my son, Alif Farhan whose being understanding during this study period, to my father and mother also father and mother in-law for their encouragement and for all my family members.

I certify that a Thesis Examination Committee has met on 28 Mac 2011 to conduct the final examination of Nor Azizi binti Safiee on her thesis entitled " Structural Behavior of Interlocking Mortarless *Putra* Block Wall System" in accordance with the Universities and University College 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 Doctor of Philosophy.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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DECLARATION

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

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NOR AZIZI BT SAFIEE
Date: 28 March 2011

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