

36th Conference on

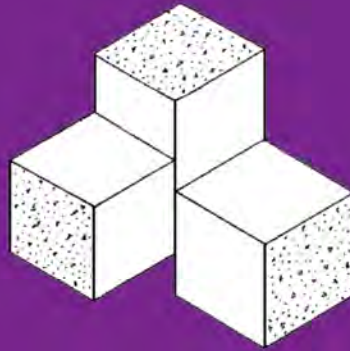
OUR WORLD IN CONCRETE & STRUCTURES

14 – 16 August 2011, Singapore

Conference Theme:

“Recent Advances in the Technology of Fresh Concrete”

Conference Documentation
Volume XXX



Conference Co-sponsors:

- BASF South East Asia Pte Ltd (*gold*)
- WAK Technologies Pte Ltd (*gold*)
- Unibeton Ready Mix, UAE
- Novaars International Pte Ltd
- Ready-Mixed Concrete Assn of Singapore
- Cement and Concrete Assn of Singapore
- Japan Concrete Institute

Organisers:

- CI-Premier Conference Organisation, Singapore

36th Conference on Our World in Concrete & Structures

OWICS 2011 Conference Advisors

- Mr David Ball, UK
- Dr O Wallevik, Iceland
- Prof V Ramakrishnan, USA
- Dr C C Chang, USA
- Prof M C Tandon, India
- Mr R Sundaram, India
- Prof K Carter, USA
- Prof Issam Harik, USA
- Prof H Wallbaum, Switzerland
- Prof Mario Collepardi, Italy
- Mr Michael Khrapko, New Zealand
- Mr Chung-Ming Ho, Taiwan

OWICS 2011 Conference Committee

Conference Chairpersons:	A/Prof K C Gary Ong, NUS, Singapore A/Prof Min-Hong Zhang, NUS, Singapore
Co-ordinator:	Mr Yogesh Chhabra, Novaars International Pte Ltd
Conference Director:	Er John S Y Tan, CI-Premier Conference Organisation
Secretary:	Ms Peggy L P Teo, CONLOG
IT Manager:	Ms Amanda Quek, Singapore

The OWICS Steering Council

OWICS Honorary Emeritus Chairmen

- Em Prof S L Lee, Singapore
- Dr C T Tam, Singapore

OWICS Honorary Chairmen

- Prof Franco Mola, Italy
- Prof G M Sabnis, USA
- Prof Shoji Ikeda, Japan
- Mr C R Alimchandani, India
- Mr Chris Stanley, UAE
- Prof N Otsuki, Japan

OWICS Advisors

- Yukio Aoyagi, Japan
- Ken Day, Australia
- Willie Kay, Singapore
- Robert G Lee, USA
- Hoe-Peng Lim, Singapore
- Steven Loh, Singapore
- Kiat-Huat Seow, Singapore
- Teng-Hooi Tan, Singapore
- Petr Prochazka, Czech Republic
- JiaBiao Jiang, Singapore
- Desmond King, UK
- Ryoji Sakurada, Japan
- Gary K C Ong, Singapore

OWICS Corporate Advisors

- W R Grace Singapore Pte Ltd
- BASF South East Asia Pte Ltd

OWICS Organisation Advisors

- Ready-Mixed Concrete Association of Singapore
- American Concrete Institute-Singapore Chapter
- Singapore Concrete Institute
- Prestressed & Precast Concrete Society
- Cement and Concrete Association of Singapore
- Japan Concrete Institute
- Indian Concrete Institute

Proceedings of the 36th Conference on
OUR WORLD IN CONCRETE & STRUCTURES
14- 16 August 2011, Singapore

Theme: "Recent Advances in the Technology of Fresh Concrete"

VOLUME XXX (2011): ISBN: 978-981-08-9528-0

Editors

Dr C T Tam (OWICS)
Prof. K C G Ong (NUS)
Dr S Teng (NTU)
Prof. M H Zhang (NUS)

Conference Co-sponsors:

- BASF South East Asia Pte Ltd (*gold*)
- WAK Technologies Pte Ltd (*gold*)
- Unibeton Ready Mix, UAE
- Novaars International Pte Ltd
- Ready-Mixed Concrete Assn of Singapore
- Cement and Concrete Assn of Singapore
- Japan Concrete Institute

Organisers:

- CI-Premier Conference Organisation, Singapore

Conference Secretariat

CI-PREMIER PTE LTD

150 Orchard Road #07-14, Orchard Plaza
Singapore 238841

Tel: +65 67332922 Fax: +65 62353530

E-mail: ci-p@cipremier.com

Web: <http://www.cipremier.com>

Copyright

Not to be reprinted without written authority

The Organising Committee is not responsible for the statements made or for the opinions expressed in this Proceedings. Papers included in this proceedings are peer reviewed.

FOREWORD

The 36th Conference on Our World in Concrete and Structures (OWICS11) is themed “Recent Advances in the Technology of Fresh Concrete”. This has always been a major area of focus in this series of conference. Over the years many papers have been presented in this area of concrete research. The intention this year is to bring together all those who share a common interest in this subject area to promote the sharing of new ideas and to sharpen the focus on the significant development and innovation that has taken place in recent years.

OWICS11 is also very special as we are dedicating it to Professor Olafur H Wallervick of the Innovation Centre Iceland for his support of this conference series and for his acknowledged contributions to concrete technology. He will deliver the OWICS11 Conference lecture.

The number of eminent and world renown speakers we have this year have exceeded all our expectations and I would like to thank all speakers, authors and participants for their contributions. Thanks are also due to the OWICS Honorary Chairmen, the OWICS Advisors, our Sponsors and the Organizing Committee.

Khim Chye Gary ONG
&
Min-Hong ZHANG
Conference Chairpersons

**36th Conference on
Our World in Concrete & Structures
14 – 16 August 2011, Singapore**

Volume XXX (2011): ISBN: 978-981-08-9528-0

Table of Contents

Foreword	iii
OWICS 2011 Dedication to Prof O H Wallevik	v
Conference Co-sponsors	xv
OWICS – Brief Milestone	xix
OWICS – Conference Awards 2010	xxix
Table of Contents	xxxiii
<i>Conference (Dedication) Lecture 2011</i>	
Rheology – My Way of Life	1
<i>Special Papers Session in honour of Prof. O H Wallevik</i>	
Theme: Chemical and mineral admixture for more sustainable structure	
High performance concrete (HPC) (revisited in 2011) P.-C. Aitcin	13
Water on the molecular scale: solvation and the hydrated torsions method [abstract only] K.F. Alexandersson and D.C. Clary	27
The structural behaviour of SCC at rest P.H. Billberg	29
Enhancing durability and sustainability of concrete structures Yogesh Chhabra	37
Effect of limestone filler as mineral addition in self-compacting concrete G. De Schutter	49
Ecological concrete and workability: a marriage with future? S.A.A.M. Fennis and J.C. Walraven	55
Longterm creep of concrete made with porous basaltic aggregate [abstract only] J.G. Gudmundsson, G. Jónsson, O.H. Wallevik, H. Jónsson and K. Khayat	65
Eco-crete with flaky aggregates [abstract only] Hreinn Jonsson, Richard Morton and O.H. Wallevik	69
Calcined marl and clay as mineral addition for more sustainable concrete structures H. Justnes, T. Østnor, K. De Weerdts and H. Vikan	73
The development of microstructure of portland cement mortars – from the fresh to the hardened state Knut O. Kjellsen and Sidney Diamond	83

Special Papers Session in honour of Prof. O H Wallevik

Chloride penetration and rheological measurements of high performance concrete [abstract only] T. I. Kristjánsson and O.H. Wallevik	91
On assessment of the influence of mineral additions on early age cracking of concrete [abstract only] T.A Martius-Hammer	95
Particle packing by gyratory intensive compaction as tool to optimize the aggregate gradation of low binder scc, eco-scc [abstract only] Florian V. Mueller and Olafur H. Wallevik	97
Application of nanotechnology in concrete [abstract only] Surendra P. Shah	101
The particle flow interaction theory – thixotropic behavior and structural breakdown J. E. Wallevik	103
Alkali activated volcanic ash: steps towards a alkali activated self compacting concrete [abstract only] S.O. Wallevik, K.F. Alexandersson, J.G. Guðmundsson, T.I. Kristjánsson and O.H. Wallevik	109
Concrete incorporating supplementary cementing materials: effect of curing on compressive strength and resistance to chloride-ion penetration [abstract only] Min-Hong Zhang, Alain Bilodeau, V. Mohan Malhotra, Kwang-Soo Kim, and Jin Choon Kim	111

OWICS Steering Council Keynote Papers

Eugène Freyssinet - his incredible journey to invent and revolutionize prestressed concrete construction Authors: Pierre Xercavins, Daniel Demarthe and Ken Shushkewich, <i>presented by C.R. Alimchandani</i>	113
The disaster due to the March Eleven 2011 East Japan earthquake and tsunami [abstract only] Shoji Ikeda, Akira Hosoda and Kazuhiko Hayashi	129
Possibility of sea water as mixing water in concrete Nobuaki Otsuki, Daisuke Furuya, Tsuyoshi Saito and Yutaka Tadokoro	131
The use and abuse of the slump test for measuring the workability of concrete Christopher Stanley	139
Shape optimization of fibers in fiber reinforced concrete Petr Prochazka and Martin Valek	149

OW11 Keynote Papers

Present and future potentials in concrete engineering G. L. Balázs	165
Highly sustainable, high durability concrete for the 21st century David M J Ball	179
Damaged concrete structures by East Japan natural disaster K. Maruyama	185

Technical Papers

Study on compressive strength of concrete using low quality recycled coarse aggregate Y. Akiyoshi, Y. Sato, T. Otani, K Ueda, N. Ito and H. Okada	187
Effects of solution concentration and spray amount on the results of silver nitrate solution spray method Yusuke Aoki, Keiji Shimano and Kazuya Satoh	197
Formwork – a concrete quality tool Chirag K. Baxi	205
Self-compacting alkali activated concrete for production of concrete elements Vlastimil Bilek	215
Analytical study on high strength concrete shear walls Jimmy Chandra, Yu Liu#, and Susanto Teng	221
Survey on the mechanical properties of SCC: 20 years of research P. Desnerck, P. Van Itterbeeck , V. Boel , B. Craeye and G. De Schutter	231
Strengthening of reinforced concrete beams under torsion using CFRP sheets El Mostafa Higazy and Mahmoud El-Kateb	241
Preliminary design of high-rise shear wall with outriggers and basement fin walls on non-rigid foundation J.C.D. Hoenderkamp	249
Evaluation of shrinkage cracking resistance for concrete containing mineral admixture by embeded reinforcing bar test H.Y. Jiang, T. Otani , Y. Sato , K. Ueda , T. Mishima and A. Oshiro	259
Synthesis and properties of high calcium fly ash based geopolymer for concrete applications P. Kamhangrittirong, P. Suwanvitaya , P. Suwanvitaya and P. Chindapasirt	269
Assessment of strength, permeability and hydraulic diffusivity of concrete through mercury intrusion porosimetry B. Kondraivendhan, B. Sabet Divsholi and Susanto Teng	277
Chloride penetration profiles in existing harbor structures constructed with blast furnace cement concrete M. Kubota, T. Saito , N. Otsuki and M. Miura	287
Effect of ultra fine slag replacement on durability and mechanical properties of high strength concrete Darren T.Y. Lim; Da Xu; B. Sabet Divsholi; B. Kondraivendhan and Susanto Teng	293
Evaluation of high performance concrete using electrical resistivity technique Darren T.Y. Lim, B. Sabet Divsholi, Da Xu and Susanto Teng	303
Shear analysis of reinforced concrete slabs with effective moment of inertia Yu Liu, Jimmy Chandra and Susanto Teng	313
Performance of rehabilitated rc beam-column sub-assembly under cyclic loading C. Marthong, S.K. Deb and A. Dutta	323

Technical Papers

Development of monitoring system for corrosion protect effect after patch repair Kenyu Muratani, Suguru Takeuchi, Shinichi Miyazato, Kosuke Yokozeki and Toshinori Oyamoto	333
Impact of high temperature on different combinations of fiber reinforced concrete S. Peskova and P.P. Prochazka	339
Behaviour of high strength metakaolin concrete at elevated temperatures N.V. Ramana Rao, Z. Abdul Rahim, P. Srinivasa Rao and T. Seshadri Sekhar	349
Durability of reinforced fly ash-based geopolymer concrete in the marine environment D.V. Reddy, J-B Edouard, K. Sobhan and S.S. Rajpathak	355
Effect of doping position of Sr Atom on crystal stability of beta-form belite R. Sakurada, A. K. Singh and Y. Kawazoe	365
Development on specific evaluation technique for the prediction of neutralization of concrete S. Sato, Y. Masuma , Y. Hasegawa , I. Natsuka , S. Aoyama and K. Yokoi	373
Influence of excessive bleeding on frost susceptibility of concrete incorporating ferronickel slag as aggregates Takayasu Sato, Kohei Watanabe, Akihiro Ota, Minoru Aba and Yuki Sako	381
The Asian experience in low fines self consolidating concrete (scc) in everyday applications Seow Kiat Huat, Nilotpol Kar, Dr Feng Qiuling	389
Creep deformations on high strength concrete made of montmorillonite mineral nano particles A.Sprince, L. Pakrastinsh and A. Korjakins	397
Some studies on flexural behaviour of glass fibre reinforced concrete members P. Sravana, P.Srinivasa Rao, K. Chandramouli, T. Seshadri Sekhar and P. Sarika	407
Studies on thermal cycles of glass fibre concrete mixes P. Srinivasa Rao, Mouli Chandra, T. Seshadri Sekhar, N. Pannirselvam P.Sravana and P. Sarika	413
Influence of fine-grained fraction amount in recycled fine aggregate on properties of mortar Shingo Tabata, Shinichi Miyazato, Takashi Habuchi, Takahiko Amino and Hidechika Tanaka	419
Sulfuric acid resistance of autoclaved cementitious materials containing γ -CaO·SiO and quartz Yuriko Tsuburaya, Nobuaki Otsuki, Tsuyoshi Saito and Saphouvong Khamhou	425
Performance evaluation of mortar mixed with fly ash - blast furnance slag and estimate of its enviromental impact Masayuki Watanabe and Shinichi Miyazato	433
Mechanical properties and durability of high performance concrete incorporating ultra fine slag and undensified silica fume Da Xu, B. Sabet Divsholi, Darren T.Y. Lim and Susanto Teng	441

A Chapter on The Conceptual Approach to Structural Design

Keynote Papers

Recent developments in the conceptual design of r.c. and p.c. structures F. Mola, E. Mola and L.M. Pellegrini	451
Seismic sustainability of a contemporary architectural expression M. Mezzi, F. Comodini and F. Marinacci	467
Innovative retrofit for upgrading reinforced concrete decks on non-composite steel girder bridges A.Peiris and I. Harik	477
Tall building design inspired by nature Mark Sarkisian	485

Technical Papers

Assessment and statically loading of haraz r.c frame type arch bridge M.H.A. Beygi, R. Moradi, A. R. Azizian, N. Ranjbar and H. R. H. A. Beygi	495
Ultra high performance and high early strength concrete Mehdi Sadeghi e Habashi	503
Study of fracture energy properties of portland blast furnace cement type-b concrete with partial replacement of aggregate with porous ceramic course aggregate M.M. Macharia, R. Sato, A. Shigematsu and H. Onishi	509
Architecture towards seismic engineering M. Mezzi and A. Parducci	517
Study of the hybrid structures changed from the steel bridges for railroad which considered construction Nozomu Taniguchi, Masanori Hansaka, Norio Koide, Kazuo Ohgaki, Fujikazu Okubo and Toshiyuki Saeki	525
Index of Authors	xxxix

INDEX OF AUTHORS

Author	Pg No.	Author	Pg No.
Aba, Minoru	381	Habuchi, Takashi	419
Abdul Rahim, Z.	349	Hansaka, Masanori	525
Aïtcin, P.-C.	13	Harik, I.	477
Akiyoshi, Y.	187	Hasegawa, Y.	373
Alexandersson, K.F.	27, 109	Hayashi, Kazuhiko	129
Alimchandani, C.R.	113	Higazy, El Mostafa	241
Amino, Takahiko	419	Hoenderkamp, J.C.D.	249
Aoki, Yusuke	197	Hosoda, Akira	129
Aoyama, S.	373	Ikeda, Shoji	129
Azizian, A.R.	495	Ito, N.	187
Balázs, G.L.	165	Jiang, H.Y.	259
Ball, David M.J.	179	Jónsson, G	65
Baxi, Chirag K.	205	Jónsson, H.	65, 69
Beygi, H. R. H. A.	495	Justnes, H.	73
Beygi, M.H.A.	495	Kamhangritirong, P.	269
Bilek, Vlastimil	215	Kar, Nilotpol	389
Billberg, P.H.	29	Kawazoe, Y.	365
Bilodeau, Alain	111	Khamhou, Saphouvong	425
Boel, V.	231	Khayat, K.	65
Chandra, Jimmy	221, 313	Kim, Jin Choon	111
Chandramouli, K.	407, 413	Kim, Kwang-Soo	111
Chhabra, Yogesh	37	Kjellsen, Knut O.	83
Chindapasirt, P.	269	Koide, Norio	525
Clary, D.C.	27	Kondraivendhan, B.	277, 293
Comodini, F.	467	Korjamins, A.	397
Craeye, B.	231	Kristjansson, T. I.	91, 109
De Schutter, G.	49, 231	Kubota, K.	287
De Weerd, K.	73	Lim, Darren T.Y.	293, 303, 441
Deb, S.K.	323	Liu, Yu	221, 313
Demarthe, Daniel	113	Macharia, M.M.	509
Desnerck, P.	231	Malhotra, V. Mohan	111
Diamond, Sidney	83	Marinacci, F.	467
Dutta, A.	323	Marthong, C.	323
Edouard, J-B	355	Mishima, T.	259
El-Kateb, Mahmoud	241	Martius-Hammer, T.A.	95
Feng Qiuling	389	Maruyama, K.	185
Fennis, S.A.A.M.	55	Masuma, Y.	373
Furuya, Daisuke	131	Mezzi, M.	467, 517
Gudmundsson, J.G.	65, 109	Miura, M.	287
Habashi, Mehdi Sadeghi e	503	Miyazato, Shinichi	333, 419, 433

INDEX OF AUTHORS

Author	Pg No.	Author	Pg No.
Mola , E.	451	Sato. S.	373
Mola, F.	451	Satoh, Kazuya	197
Moradi, R.	495	Seow Kiat Huat	389
Morton, Richard	69	Seshadri Sekhar, T.	349, 407, 413
Mueller, Florian V.	97	Shah, S.P.	101
Muratani, Kenyu	333	Shigematsu. A.	509
N.V. Ramana Rao, N.V.	349	Shimano, Keiji	197
Natsuka, I.	373	Shushkewich, Ken	113
Ohgaki, Kazuo	525	Singh, A.K.	365
Okada, H.	187	Sobhan, K.	355
Okubo, Fujikazu	525	Sprince, A.	397
Onishi, H.	509	Sravana, P.	407, 413
Oshiro, A.	259	Srinivasa Rao, P.	349, 407, 413
Østnor, T.	73	Stanley, Christopher	139
Ota, Akihiro	381	Suwanvitaya, P.	269
Otani, T	187, 259	Tabata, Shingo	419
Otsuki, Nobuaki	131, 287, 425	Tadokoro, Yutaka	131
Oyamoto, Toshinori	333	Takeuchi, Suguru	333
Pakrastinsh, L.	397	Tanaka, Hidechika	419
Pannirselvam, N.	413	Taniguchi, Nozomu	525
Parducci, A.	517	Teng, Susanto	221, 277, 293 303, 313, 441
Peiris, A.	477	Tsuburaya, Yuriko	425
Pellegrini, L.M.	451	Ueda, K.	187, 259
Peskova, S.	339	Valek, Martin	149
Prochazka, Petr	149, 339	Van Itterbeeck, P.	231
Rajpathak, S.S.	355	Vikan, H.	73
Ranjbar, N.	495	Wallevik, J.E.	103
Reddy, D.V.	355	Wallevik, O.H.	1, 65, 69, 91 97, 109
Sabet Divsholi, B.	277, 293, 303, 441	Wallevik, S.O.	109
Saeki, Toshiyuki	525	Walraven, J.C.	55
Saito, Tsuyoshi	131, 287, 425	Watanabe, Kohei	381
Sakoi, Yuki	381	Watanabe, Masayuki	433
Sakurada, R.	365	Xercavins, Pierre	113
Sarika, P.	407, 413	Xu, Da	293, 303, 441
Sarkisian, Mark	485	Yokoi, K.	373
Sato, R.	509	Yokozeeki, Kosuke	333
Sato, Takayasu	381	Zhang, Min-Hong	111
Sato, Y.	187, 259		

For Link, please click on page numberrrs

ISBN: 978-981-08-9528-0

ANALYTICAL STUDY ON HIGH STRENGTH CONCRETE SHEAR WALLS

Jimmy Chandra^{*}, Yu Liu[#], and Susanto Teng[#]

^{*}School of Civil and Environmental Engineering
Nanyang Technological University
50 Nanyang Avenue, Singapore 639798
e-mail: <jchandra1@e.ntu.edu.sg> webpage: <http://www.cee.ntu.edu.sg/>

Keywords: high strength concrete shear walls, nominal wall strengths, building code formulas

Abstract. *This paper presents an analytical study on the behavior of high strength concrete (HSC) shear walls. Several experiments on HSC shear walls with concrete strength above 60 MPa have been selected to be studied. Data from various experiments were collected and nominal wall strengths have been calculated using several building code formulas, such as those of the ACI (American), AIJ (Japanese), and EC (Eurocode). Subsequently, nominal wall strengths from the building code formulas were compared with actual wall strengths from experiments. Moreover, normalized actual wall strengths over nominal wall strengths and the average shear stresses were also plotted against some significant factors such as shear span ratio, axial load ratio, ratio of longitudinal and transverse reinforcements, etc., in order to observe the behavior of HSC shear walls as influenced by various parameters. The analysis results show that most of the building code formulas underestimate HSC wall strengths for low shear-span ratio (below 2.0) but they predict more accurately for high shear-span ratio (above 2.0). Furthermore, from the results, it seems that axial load up to 0.15 ($f'_c A_g$) does not contribute much to the wall strengths. In addition, the comparative study shows that the contribution of longitudinal reinforcement to wall strengths is more significant than that of the transverse reinforcement. This phenomenon is not accounted for in most building code formulas. Thus, there is a need to develop an expression that can take into account this phenomenon and that can yield better predictions of the strength of HSC walls.*

1 INTRODUCTION

Nowadays, the use of high strength concrete as a structural material has become more common in engineering practice. Compared to normal strength concrete, high strength concrete has many advantages including higher stiffness, higher durability, lower permeability, lower porosity, etc. These advantages make high strength concrete able to cope with modern architectural and structural needs. One of the benefits of high strength concrete is the reduction in the size of structural members such as columns, walls, etc. which can provide more space for other purposes. Furthermore, high strength concrete with low permeability and low porosity can provide better protection for steel reinforcement when corrosion is a major issue. This is a very important aspect when durability of the structure is a concern.

[#]Nanyang Technological University, Singapore

Shear walls have been used widely in many structures since they provide good resistance to lateral loadings. Moreover, not only for resisting lateral loadings, many structural walls are optimized to resist gravity loading as well. This study presents a review on the behavior of high strength concrete shear walls (HSC walls). Experiments on HSC walls reported by researchers from different countries¹⁻⁶ were collected and studied. Data from those experiments were used to calculate nominal wall strengths using building code formulas, such as those formulas recommended by the American Concrete Institute (ACI 318)⁷, Architectural Institute of Japan (AIJ)⁸, and Eurocode (EC 8)⁹. Subsequently, the nominal wall strengths calculated using the building code formulas were compared with actual wall strengths obtained from experiments. The predicted failure modes were also compared with the actual failure modes. In addition, to investigate further the behavior of HSC walls with various parameters, normalized actual wall strengths and normalized average shear stresses were plotted against shear span ratio, drift ratio, axial load ratio, longitudinal and transverse reinforcement ratios, and concrete strength. Finally, general conclusions based on this analytical study were made regarding the behavior of HSC walls which might be used as a basis for further experimental studies about HSC walls in the future.

2 HSC WALLS EXPERIMENTS

As mentioned before, several experiments about HSC walls reported by researchers from different countries¹⁻⁶ were collected and studied. These experiments were reported by Kabeyasawa and Hiraishi¹, Gupta and Rangan², Yun et al.³, Farvashany et al.⁴, Yan et al.⁵, and Deng et al.⁶. Data from these experiments were collected in terms of concrete strength (f'_c), shear span ratio (H/L ; where H is the wall height and L is the wall length), axial load ratio ($P/(f'_c A_g)$; where P is the axial load in wall, and A_g is the gross cross sectional area of wall), longitudinal and transverse reinforcement contributions ($\rho_l f_{yl}$ and $\rho_t f_{yt}$; where ρ_l and ρ_t are longitudinal and transverse reinforcement ratios of wall, f_{yl} and f_{yt} are the yield strengths of longitudinal and transverse reinforcements), maximum wall strength (lateral load) obtained from experiment, and drift ratio (%). These data are presented in Table 1.

3 ANALYTICAL STUDY

The nominal wall strengths were then calculated according to the methods of the ACI 318⁷, AIJ⁸, and EC 8⁹. The flexural strength of the walls was calculated based on flexural theory for members subjected to bending and axial loads whereas the shear strength was calculated using formulas given in the codes. The smaller value of the flexural strength and the shear strength was then taken as the nominal strength of the walls as well as the respective predicted failure mode. Shear strength formulas according to various building codes⁷⁻⁹ are given as follows.

3.1 ACI 318 (Chapter 21)

$$V_n = A_{cv} \left(\alpha_c \lambda \sqrt{f'_c} + \rho_t f_{yt} \right) \quad (1)$$

where:

V_n = nominal wall shear strength (N)

A_{cv} = gross area of concrete section bounded by web thickness and length of section in the direction of shear force considered (mm^2)

α_c = coefficient defining the relative contribution of concrete strength to nominal wall shear strength, which may be taken as 0.25 for $H/L \leq 1.5$, 0.17 for $H/L \geq 2.0$, and varies linearly between 0.25 and 0.17 for H/L between 1.5 and 2.0

λ = modification factor reflecting the reduced mechanical properties of lightweight concrete, all relative to normal weight concrete of the same compressive strength

No.	Ref No [No]	Specimen ID	Concrete Strength (f'_c) (MPa)	Shear Span Ratio (H/L)	Axial Load Ratio [$P/(f'_c A_g)$]	Longitudinal Reinforcement Ratio ($\rho_l f_y$) (MPa)	Transverse Reinforcement Ratio ($\rho_t f_y$) (MPa)	V_{max} (kN)	Drift (%)
1	[1]	NW-1	87.6	2.00	0.11	5.34	5.34	1062	1.970
2	[1]	NW-2	93.6	1.33	0.10	5.34	5.34	1468	1.490
3	[1]	NW-3	55.5	2.00	0.13	2.01	2.01	717	0.990
4	[1]	NW-4	54.6	2.00	0.16	2.01	2.01	784	0.930
5	[1]	NW-5	60.3	2.00	0.12	4.02	4.02	900	1.520
6	[1]	NW-6	65.2	2.00	0.13	4.02	4.02	1056	1.340
7	[1]	W-08	103.3	0.67	0.09	5.75	5.75	1670	0.729
8	[1]	W-12	137.5	0.67	0.09	5.75	5.75	1719	0.776
9	[1]	No. 1	65.1	1.33	0.13	1.58	1.58	1101	0.710
10	[1]	No. 2	70.8	1.33	0.12	2.75	2.75	1255	0.700
11	[1]	No. 3	71.8	1.33	0.12	4.22	4.22	1379	0.760
12	[1]	No. 4	103.4	1.33	0.14	4.22	4.22	1697	0.720
13	[1]	No. 5	76.7	2.00	0.11	4.22	4.22	1159	1.000
14	[1]	No. 6	74.1	1.33	0.12	9.31	9.31	1412	0.720
15	[1]	No. 7	71.5	1.33	0.12	7.92	7.92	1499	0.740
16	[1]	No. 8	76.1	1.33	0.11	11.52	11.52	1639	0.760
17	[1]	M35X	62.6	2.00	0.15	6.48	6.48	1049	1.490
18	[1]	M35H	68.6	2.00	0.15	6.48	6.48	1055	1.500
19	[1]	P35H	66.5	2.00	0.15	6.48	6.48	959	1.500
20	[1]	M30H	61.4	2.00	0.13	6.48	6.48	1020	1.450
21	[1]	MW35H	59.7	2.00	0.15	6.48	6.48	1012	1.500
22	[1]	MAE03	58.3	0.60	0.03	3.83	3.83	1460	0.623
23	[1]	MAE07	58.1	0.60	0.03	6.42	6.42	1676	0.592
24	[1]	W48M6	82.3	0.80	0.02	4.44	4.44	1516	0.601
25	[1]	W48M4	82.3	0.80	0.02	4.12	4.12	1479	1.005
26	[1]	W72M8	82.3	0.80	0.02	7.24	7.24	2066	1.014
27	[1]	W72M6	82.3	0.80	0.02	6.65	6.65	2015	1.023
28	[1]	W72M8	101.8	0.80	0.02	7.24	7.24	2128	1.005
29	[1]	W96M8	101.8	0.80	0.02	9.41	9.41	2483	1.022
30	[1]	SMZ01	83.6	0.65	0.00	2.10	2.10	1154	0.865
31	[1]	SMZ03	83.3	0.65	0.00	2.10	2.10	2081	0.809
32	[1]	W8N18	72.7	2.00	0.15	11.31	11.31	882	1.500
33	[1]	W8N13	79.0	2.00	0.10	11.31	11.31	762	1.500
34	[1]	W8N8H	79.4	2.00	0.06	11.31	11.31	689	1.500
35	[1]	TAK01	62.3	1.80	0.11	4.78	4.78	971	1.500
36	[1]	TAK02	62.3	1.80	0.11	6.91	6.91	987	1.500
37	[1]	TAK03	62.3	1.20	0.11	4.78	4.78	1288	1.000
38	[2]	S-1	79.3	1.00	0.00	5.45	2.89	428	1.607
39	[2]	S-2	65.1	1.00	0.07	5.45	2.89	720	1.114
40	[2]	S-3	69.0	1.00	0.13	5.45	2.89	851	0.559
41	[2]	S-4	75.2	1.00	0.00	8.00	2.89	600	1.213
42	[2]	S-5	73.1	1.00	0.06	8.00	2.89	790	0.784
43	[2]	S-6	70.5	1.00	0.13	8.00	2.89	970	0.735
44	[2]	S-7	71.2	1.00	0.06	5.45	5.45	800	0.935
45	[2]	S-F	60.5	1.00	0.04	5.45	2.89	487	2.060
46	[3]	HW1	69.0	1.80	0.06	3.50	3.50	442	2.386
47	[3]	HW2	69.0	1.80	0.03	3.50	3.50	375	2.441
48	[3]	HW3	69.0	1.80	0.00	3.50	3.50	234	2.063
49	[3]	HW4	69.0	1.80	0.03	3.50	7.00	363	2.225
50	[3]	HW5	69.0	1.80	0.03	3.50	1.78	372	2.908
51	[4]	HSCW1	104.0	1.25	0.04	6.74	2.51	735	0.968
52	[4]	HSCW2	93.0	1.25	0.09	6.74	2.51	845	1.125
53	[4]	HSCW3	86.0	1.25	0.09	4.01	2.51	625	0.928
54	[4]	HSCW4	91.0	1.25	0.22	4.01	2.51	866	0.763
55	[4]	HSCW5	84.0	1.25	0.09	6.74	4.01	801	1.318
56	[4]	HSCW6	90.0	1.25	0.05	6.74	4.01	745	1.342
57	[4]	HSCW7	102.0	1.25	0.08	4.01	4.01	800	1.265
58	[5]	SW-1	90.0	2.36	0.15	1.66	1.66	260	1.594
59	[5]	SW-2	90.0	2.36	0.15	6.97	6.97	367	2.836
60	[5]	SW-3	60.0	2.36	0.15	1.66	1.66	200	3.642
61	[5]	SW-4	90.0	2.36	0.25	1.66	1.66	255	2.061
62	[5]	SW-5	90.0	1.50	0.15	1.66	1.66	350	1.714
63	[6]	HPCW-01	61.4	2.10	0.16	2.10	3.36	326	2.019
64	[6]	HPCW-02	73.6	2.10	0.14	2.10	3.36	333	2.480
65	[6]	HPCW-03	75.3	2.10	0.13	2.10	5.09	379	2.448
66	[6]	HPCW-04	86.0	2.10	0.12	2.10	5.09	370	2.677

Table 1: Details of HSC walls reported by researchers¹⁻⁶

3.2 AIJ

$$V_n = tL\rho_t f_{yt} \cot\phi + 0.5 \tan\theta (1 - \beta) tLv f'c \quad (2)$$

where:

V_n = nominal wall shear strength (N)

t = thickness of wall panel (mm)

$\cot\phi = 1.0$

$\tan\theta = \sqrt{(H/L)^2 + 1} - H/L$

$\beta = (1 + \cot^2\phi)\rho_t f_{yt} (v f'c)^{-1}$

$v = 0.7 - (f'c/2000)$

3.3 EC8

For diagonal compression failure of the web due to shear:

$$V_n = \alpha_{cw} t z v_1 f'c (\cot\theta + \tan\theta)^{-1} \quad (3)$$

where:

V_n = nominal wall shear strength (N), which for the critical region, it may be taken as 40% of the calculated value

α_{cw} = coefficient taking account of the state of the stress in the compression chord, which may be taken as 1.0 for non-prestressed structures; $[1 + P/(f'cA_g)]$ for $0 < P/(f'cA_g) \leq 0.25$; 1.25 for $0.25 < P/(f'cA_g) \leq 0.5$; or $2.5 [1 - P/(f'cA_g)]$ for $0.5 < P/(f'cA_g) < 1.0$

t = thickness of wall panel (mm)

z = inner lever arm, for a member with constant depth, corresponding to the bending moment in the element under consideration, which may be taken equal to $0.8L$

v_1 = strength reduction factor for concrete cracked in shear, which is $0.6 (1.0 - f'c/250)$

$\cot\theta = \tan\theta = 1.0$

For diagonal tension failure of the web due to shear:

$$\text{If } M/(VL) \geq 2.0: V_n = td [C_{Rd,c} k (100\rho_l f'c)^{1/3} + k_1 \sigma_{cp}] + z t \rho_t f_{yt} \cot\theta \quad (4)$$

$$\text{If } M/(VL) < 2.0: V_n = td [C_{Rd,c} k (100\rho_l f'c)^{1/3} + k_1 \sigma_{cp}] + 0.75 t \rho_t f_{yt} M/V \quad (5)$$

where:

V_n = nominal wall shear strength (N)

t = thickness of wall panel (mm)

d = effective depth of a cross section (mm)

$C_{Rd,c} = 0.18/\gamma_c$, which γ_c is taken as 1.0 for nominal strength without reduction factor for material

$k = 1 + \sqrt{(200/d)} \leq 2.0$

$k_1 = 0.15$

$\sigma_{cp} = P/A_g < 0.2 f'c$ (MPa)

$z = 0.8L$

$\cot\theta = \tan\theta = 1.0$

M = applied bending moment in wall

V = applied shear force in wall

The minimum value of V_n from diagonal compression failure and diagonal tension failure is taken as the nominal shear strength of walls according to EC8⁹.

4 ANALYSIS RESULTS

Results are presented in terms of actual wall strengths obtained from experiments normalized by nominal wall strengths, actual mode of failures versus predicted mode of failures, and average shear stresses (shear force divided by wall web area, A_c) normalized by square root of concrete strength. These values are then plotted against various parameters such as shear span ratio, drift ratio, axial load ratio, longitudinal and transverse reinforcement ratios, and concrete strength to investigate further the relationship between these values and those parameters. The analysis results are presented in Tables 2 and 3 as well as Figures 1 to 6.

No.	Specimen ID	Actual Mode of Failure	Vexp / Vcal						Vexp / (Ac√fc)
			ACI 318	Predicted Mode	AIJ	Predicted Mode	EC 8	Predicted Mode	
1	NW-1	FLEXURE	1.16	FLEXURE	1.16	FLEXURE	1.17	SHEAR	0.83
2	NW-2	FLEXURE	1.39	SHEAR	1.07	FLEXURE	1.58	SHEAR	1.12
3	NW-3	FLEXURE	1.48	SHEAR	0.95	FLEXURE	1.23	SHEAR	0.71
4	NW-4	FLEXURE	1.63	SHEAR	0.91	SHEAR	1.30	SHEAR	0.78
5	NW-5	FLEXURE	1.18	SHEAR	0.97	FLEXURE	1.22	SHEAR	0.85
6	NW-6	FLEXURE	1.36	SHEAR	0.97	FLEXURE	1.35	SHEAR	0.96
7	W-08	SHEAR	1.48	SHEAR	0.61	FLEXURE	2.58	SHEAR	1.21
8	W-12	SHEAR	1.46	SHEAR	0.54	FLEXURE	2.40	SHEAR	1.08
9	No. 1	SHEAR	2.25	SHEAR	0.90	SHEAR	2.58	SHEAR	1.00
10	No. 2	SHEAR	1.90	SHEAR	0.89	SHEAR	2.15	SHEAR	1.10
11	No. 3	SHEAR	1.60	SHEAR	0.89	SHEAR	1.78	SHEAR	1.20
12	No. 4	SHEAR	1.84	SHEAR	0.83	SHEAR	1.89	SHEAR	1.23
13	No. 5	SHEAR	1.41	SHEAR	0.87	SHEAR	1.36	SHEAR	0.97
14	No. 6	SHEAR	1.45	SHEAR	0.70	SHEAR	1.69	SHEAR	1.21
15	No. 7	SHEAR	1.57	SHEAR	0.80	SHEAR	1.82	SHEAR	1.30
16	No. 8	SHEAR	1.66	SHEAR	0.73	SHEAR	1.93	SHEAR	1.38
17	M35X	FLEXURE	1.17	SHEAR	1.08	FLEXURE	1.35	SHEAR	0.97
18	M35H	FLEXURE	1.13	SHEAR	1.04	FLEXURE	1.28	SHEAR	0.94
19	P35H	FLEXURE	1.04	SHEAR	0.96	FLEXURE	1.18	SHEAR	0.86
20	M30H	FLEXURE	1.15	SHEAR	1.13	FLEXURE	1.35	SHEAR	0.96
21	MW35H	FLEXURE	1.16	SHEAR	1.07	FLEXURE	1.34	SHEAR	0.96
22	MAE03	SHEAR	1.46	SHEAR	0.64	SHEAR	3.00	SHEAR	1.10
23	MAE07	SHEAR	1.52	SHEAR	0.68	SHEAR	2.38	SHEAR	1.26
24	W48M6	SHEAR	1.10	SHEAR	0.98	FLEXURE	1.98	SHEAR	0.81
25	W48M4	SHEAR	1.12	SHEAR	1.05	FLEXURE	1.96	SHEAR	0.79
26	W72M8	SHEAR	1.33	SHEAR	0.98	FLEXURE	1.88	SHEAR	1.10
27	W72M6	SHEAR	1.30	SHEAR	1.01	FLEXURE	1.92	SHEAR	1.08
28	W72M8	SHEAR	1.23	SHEAR	1.01	FLEXURE	1.91	SHEAR	1.02
29	W96M8	SHEAR	1.44	SHEAR	0.95	FLEXURE	1.80	SHEAR	1.19
30	SMZ01	FLEXURE	1.30	SHEAR	1.00	FLEXURE	3.31	SHEAR	0.62
31	SMZ03	FLEXURE	2.35	SHEAR	0.90	FLEXURE	5.96	SHEAR	1.13
32	W8N18	FLEXURE	1.11	SHEAR	1.06	FLEXURE	1.29	SHEAR	0.92
33	W8N13	FLEXURE	1.07	FLEXURE	1.07	FLEXURE	1.11	SHEAR	0.77
34	W8N8H	FLEXURE	1.03	FLEXURE	1.03	FLEXURE	1.04	SHEAR	0.69
35	TAK01	FLEXURE	1.11	FLEXURE	1.11	FLEXURE	1.11	FLEXURE	0.76
36	TAK02	FLEXURE	1.04	FLEXURE	1.04	FLEXURE	1.10	SHEAR	0.77
37	TAK03	FLEXURE	1.22	SHEAR	0.99	FLEXURE	1.43	SHEAR	1.01
38	S-1	SHEAR	1.11	SHEAR	0.89	FLEXURE	1.22	SHEAR	0.64
39	S-2	SHEAR	1.96	SHEAR	0.90	SHEAR	1.25	SHEAR	1.19
40	S-3	SHEAR	2.28	SHEAR	1.01	SHEAR	0.98	SHEAR	1.37
41	S-4	SHEAR	1.58	SHEAR	0.84	FLEXURE	1.21	SHEAR	0.92
42	S-5	SHEAR	2.10	SHEAR	0.90	SHEAR	1.24	SHEAR	1.23
43	S-6	SHEAR	2.59	SHEAR	1.13	SHEAR	1.76	SHEAR	1.54
44	S-7	SHEAR	1.52	SHEAR	0.91	FLEXURE	2.52	SHEAR	1.26
45	S-F	FLEXURE	1.34	SHEAR	1.20	FLEXURE	2.53	SHEAR	0.83
46	HW1	FLEXURE	1.22	FLEXURE	1.22	FLEXURE	2.37	FLEXURE	0.52
47	HW2	FLEXURE	1.25	FLEXURE	1.25	FLEXURE	2.63	FLEXURE	0.44
48	HW3	FLEXURE	0.98	FLEXURE	0.98	FLEXURE	2.78	FLEXURE	0.28
49	HW4	FLEXURE	1.21	FLEXURE	1.21	FLEXURE	1.85	FLEXURE	0.43
50	HW5	FLEXURE	1.24	FLEXURE	1.24	FLEXURE	1.87	FLEXURE	0.44
51	HSCW1	SHEAR	2.20	SHEAR	0.83	SHEAR	2.60	SHEAR	1.09
52	HSCW2	SHEAR	2.60	SHEAR	1.04	SHEAR	2.70	SHEAR	1.33
53	HSCW3	SHEAR	1.96	SHEAR	0.82	SHEAR	2.10	SHEAR	1.02
54	HSCW4	SHEAR	2.68	SHEAR	1.09	SHEAR	2.19	SHEAR	1.38
55	HSCW5	SHEAR	1.93	SHEAR	0.99	SHEAR	1.99	SHEAR	1.32
56	HSCW6	SHEAR	1.77	SHEAR	0.87	SHEAR	2.00	SHEAR	1.19
57	HSCW7	SHEAR	1.85	SHEAR	0.85	SHEAR	2.03	SHEAR	1.20
58	SW-1	FLEXURE	1.13	SHEAR	1.10	FLEXURE	0.98	FLEXURE	0.39
59	SW-2	FLEXURE	0.95	FLEXURE	0.95	FLEXURE	1.00	FLEXURE	0.55
60	SW-3	FLEXURE	1.10	FLEXURE	1.10	FLEXURE	0.99	FLEXURE	0.37
61	SW-4	FLEXURE	1.11	SHEAR	0.73	FLEXURE	1.03	SHEAR	0.38
62	SW-5	SHEAR	1.24	SHEAR	0.94	FLEXURE	1.10	SHEAR	0.53
63	HPCW-01	FLEXURE	0.98	FLEXURE	0.98	FLEXURE	0.95	FLEXURE	0.42
64	HPCW-02	FLEXURE	1.00	FLEXURE	1.00	FLEXURE	1.10	FLEXURE	0.39
65	HPCW-03	FLEXURE	0.99	FLEXURE	0.99	FLEXURE	0.74	FLEXURE	0.44
66	HPCW-04	FLEXURE	1.03	FLEXURE	1.03	FLEXURE	1.09	FLEXURE	0.40

Table 2: Values of normalized actual wall strengths and normalized average shear stresses; actual mode of failure and predicted mode of failure

Statistical Parameters	V _{exp} / V _{cal}			V _{exp} / (A _c f _c)
	ACI 318	AIJ	EC 8	
Minimum Value	0.95	0.54	0.74	0.28
Maximum Value	2.68	1.25	5.96	1.54
Average (Mean Value)	1.46	0.96	1.77	0.91
Standard Deviation	0.44	0.15	0.80	0.32
Covariance	0.30	0.16	0.45	0.35

Table 3: Statistical parameters of normalized actual wall strengths and normalized average shear stresses

As observed, in general, the ACI and EC8 methods underestimate the actual wall strengths. It is understood that most of building codes tend to give lower predictions on strengths such that the design formulas are safe enough to be used for practical design. The AIJ method seems to be the most accurate, with the lowest coefficient of variation compared to the other methods. However, the AIJ method may overestimate wall strengths in some cases.

Comparing the actual mode of failure versus predicted mode of failure, the AIJ method gives the least false predictions of modes of failure among the three codes. The AIJ method fails to predict modes of failure of 13 specimens out of 66 specimens whereas the ACI-318 method fails in 17 specimens and the EC8 method fails in 20 specimens. Further investigation on the failure modes shows that most of the time, the AIJ method gives nominal wall shear strengths higher than the actual ones, which results in the tendency of predicting flexural failures instead of shear failures. On the other hand, the ACI-318 and the EC8 methods tend to give lower nominal wall shear strengths compared to the actual ones, and hence resulting in the tendency of predicting shear failures instead of flexural failures.

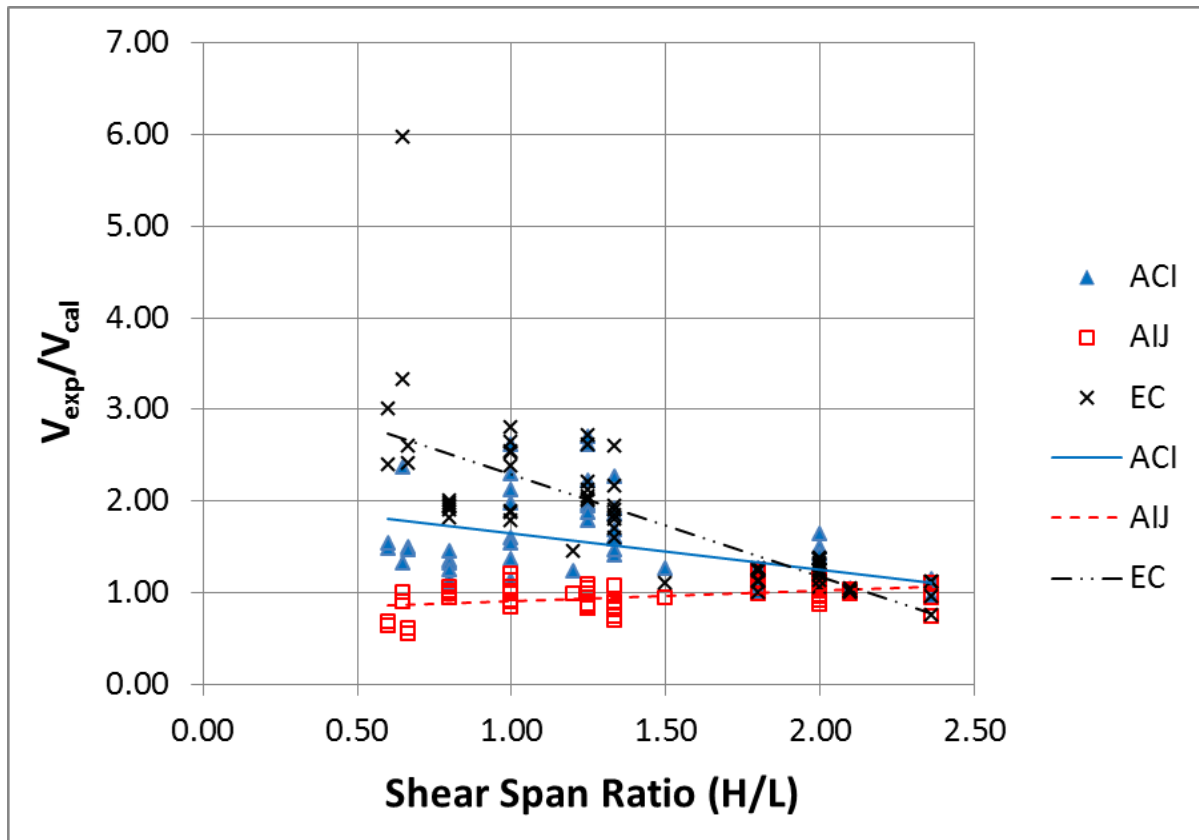


Figure 1: Normalized actual wall strengths plotted against shear span ratio

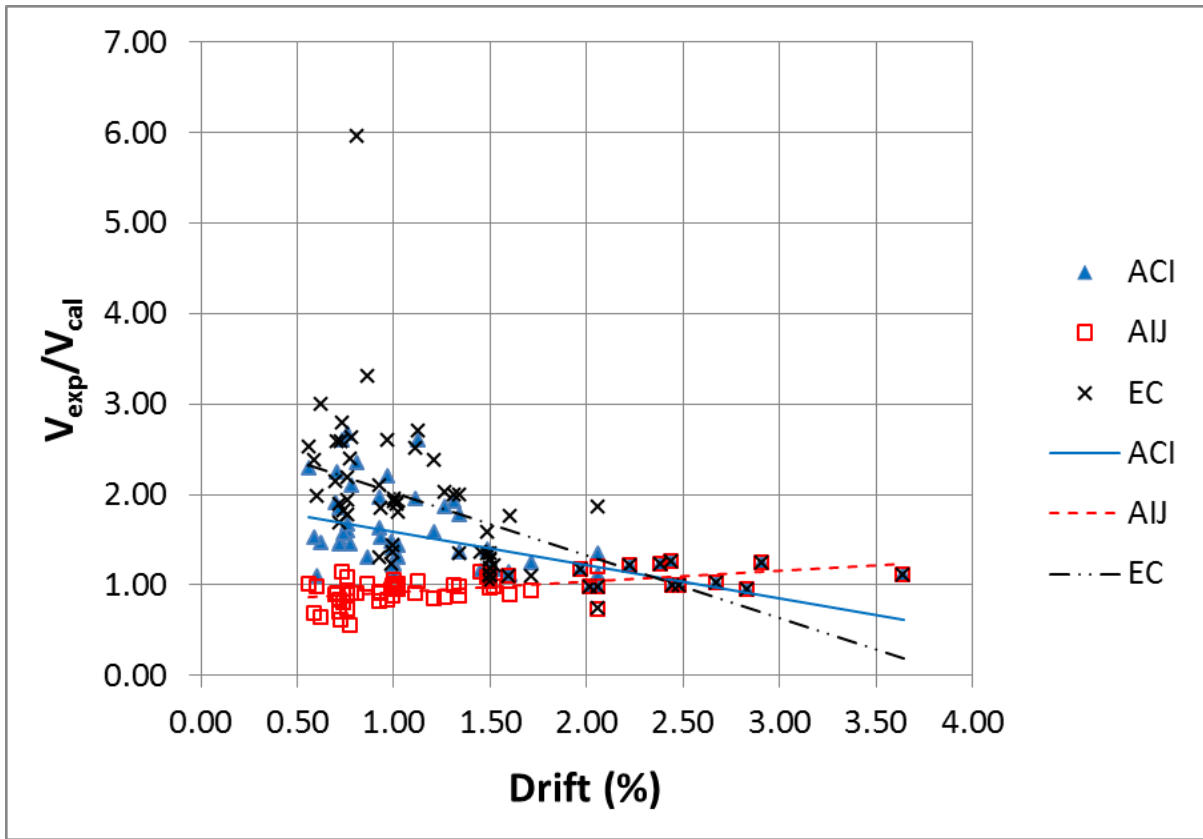


Figure 2: Normalized actual wall strengths plotted against drift ratio

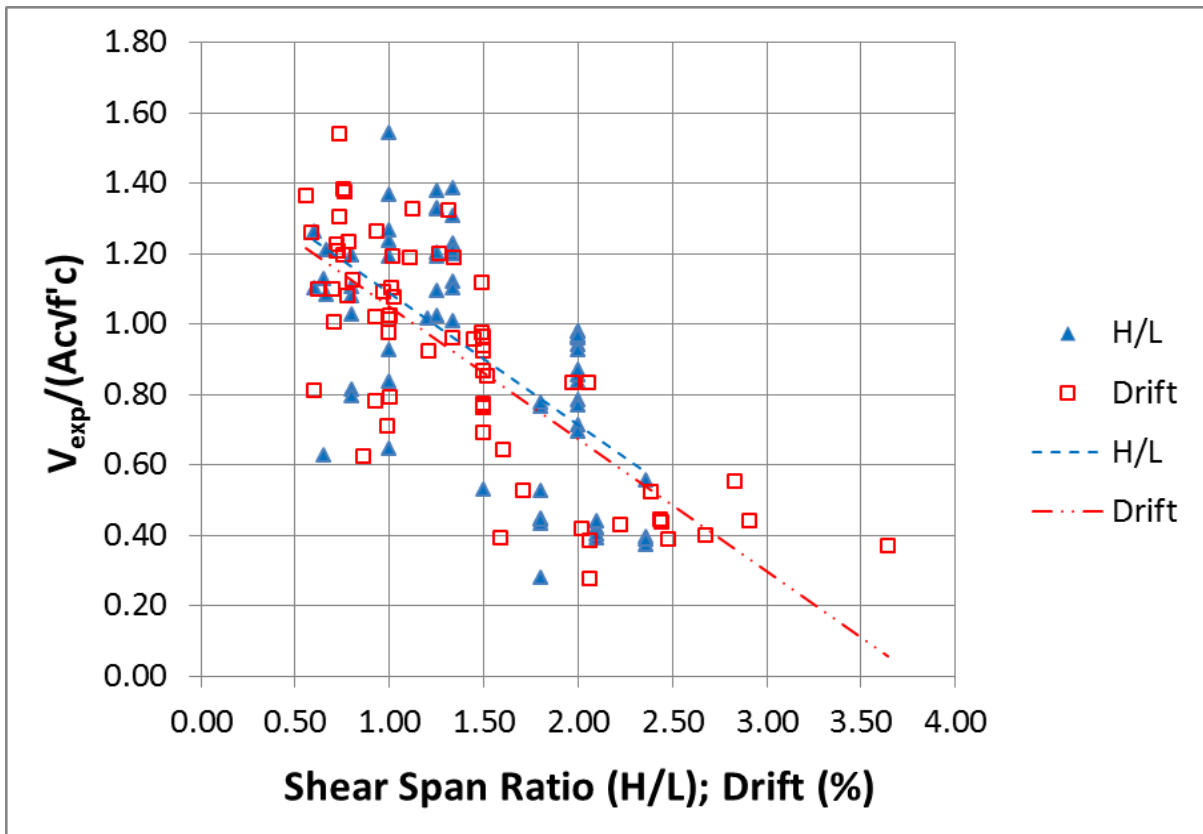


Figure 3: Normalized average shear stresses plotted against shear span ratio and drift ratio

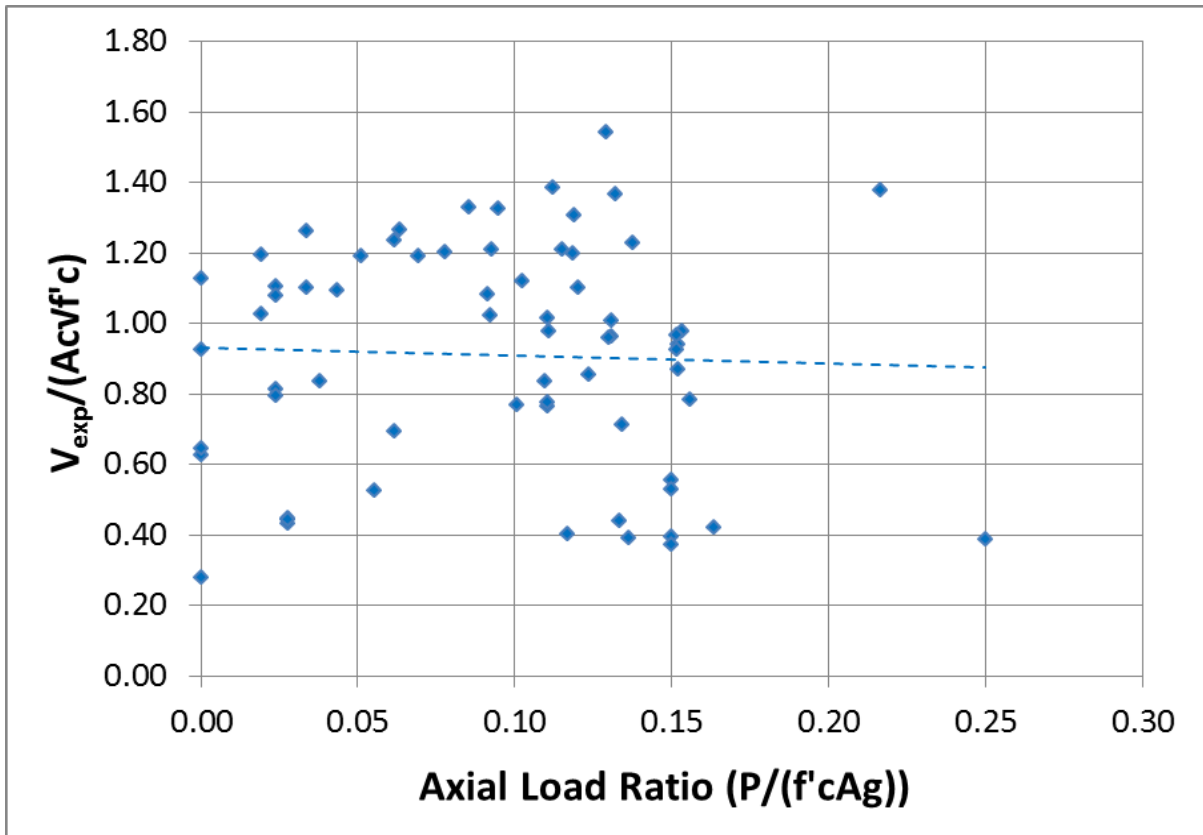


Figure 4: Normalized average shear stresses plotted against axial load ratio

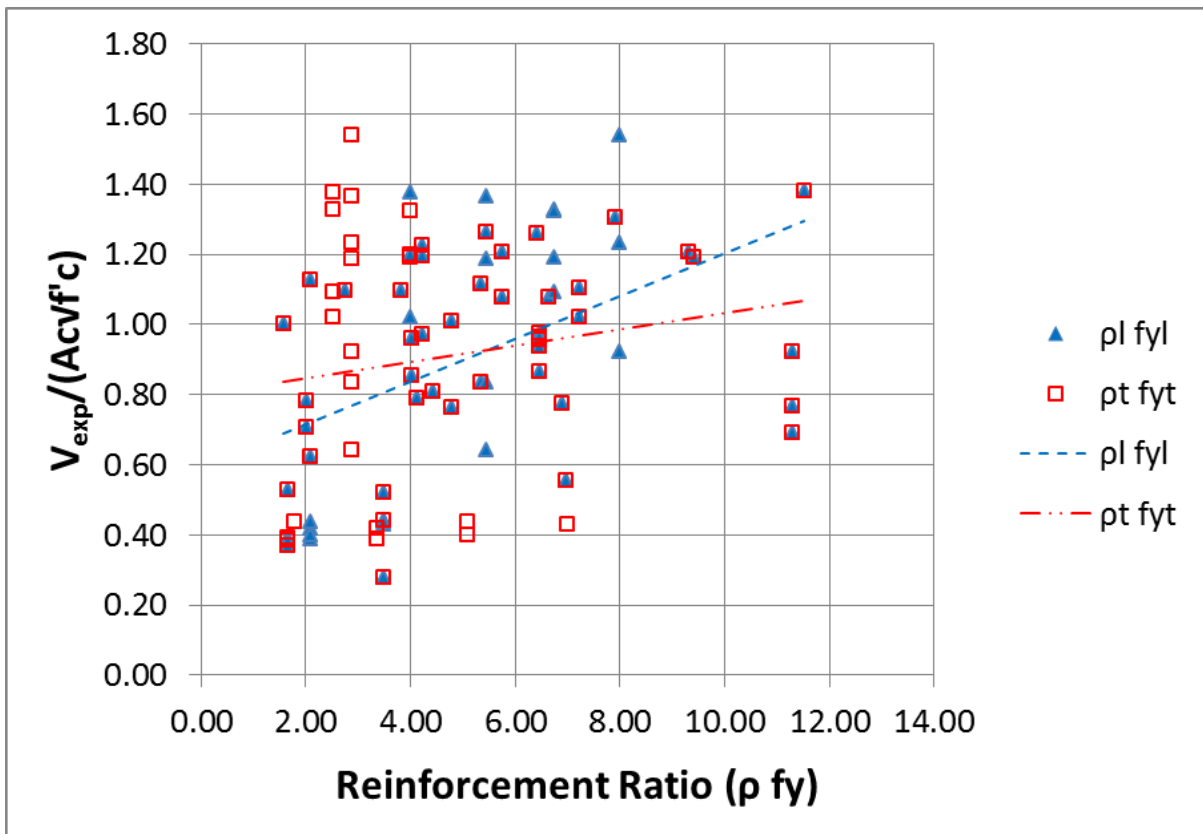


Figure 5: Normalized average shear stresses plotted against reinforcement ratio

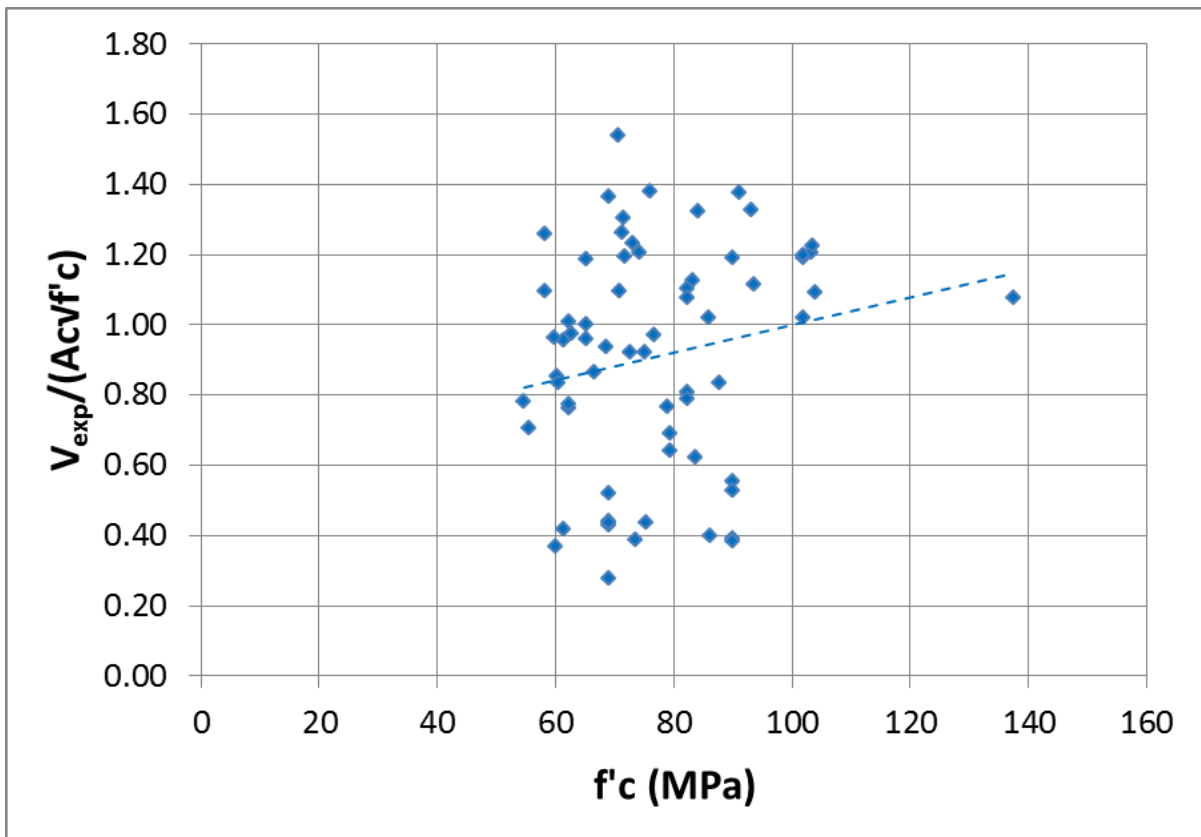


Figure 6: Normalized average shear stresses plotted against concrete strength

From Figure 1, it can be concluded that both the ACI and EC8 formulas underestimate the wall strengths in low shear span ratios (i.e., shear behavior dominates) whereas in high shear span ratios (i.e., flexural behavior dominates), they predict relatively close to the actual wall strengths. Similar phenomenon can also be observed (Figure 2) from the drift ratio, which shows that both the ACI and EC8 formulas underestimate the strength of walls failing in low drift ratio (i.e., shear failure) whereas they predict more accurately the strength of walls failing in high drift ratio (i.e., flexural failure). This means that for the flexural strength, the flexural theories given in those building codes are quite reasonable for predicting the actual flexural strength of HSC walls. For the shear strength, those building code formulas, which are mostly empirical, do not give accurate prediction of the actual shear strength of HSC walls. Moreover, from Figure 3, another conclusion that can be drawn is that as the shear span ratio and the drift ratio increase, the normalized average shear stresses tend to reduce. This means that the flexural behavior is more dominant in high shear span ratio and high drift ratio. Furthermore, according to Figure 4, it seems that an axial load of up to 0.15 ($f'_c A_g$) does not affect much the wall strengths. The trend line of normalized average shear stresses is nearly flat regardless of the changes in the axial load ratio.

Figure 5 shows that the longitudinal reinforcement affects wall strengths more than the transverse reinforcement. The normalized average shear stresses (i.e., wall strengths) increase more when the longitudinal reinforcement ratio increases, as compared to the increment due to the increase in the transverse reinforcement ratio. This phenomenon, however, is not taken into account in most building code formulas for calculating wall shear strengths. Most of building code formulas only take into account the contribution of the transverse reinforcement while neglecting the contribution of the longitudinal reinforcement. Thus, there is a need to develop a general expression to take into account the contribution of the longitudinal reinforcement when calculating wall shear strengths in order to obtain better predictions. Furthermore, from further investigation of the data, in some cases the ACI-318 and EC8 methods underestimate wall shear strengths because of the upper limit that is imposed on the maximum wall shear strength. For example, in ACI-318, there is a limitation on the value of the maximum shear stress in walls, which is set at $0.83\sqrt{f'_c}$. From the analysis results, it is shown that the average shear stresses in HSC walls is about $0.91\sqrt{f'_c}$ which exceeds the maximum limit provided by ACI-318. Hence, the ACI-318 method can underestimate wall shear strengths because of the upper

bound values of the nominal wall shear strength.

The effect of concrete strength is shown in Figure 6. It can be seen that the normalized average shear stresses seems to increase with an increase in concrete strength. Note, however, that the shear strength of walls also depends on factors, such as reinforcement ratios, shear span ratio, etc.

5 CONCLUSIONS

An analytical study on the behavior of HSC walls (above 60 MPa) based on various available experimental results is presented in this paper. Several general conclusions can be drawn. These conclusions are as follows.

Most of building code formulas underestimate the strength of HSC walls failing in shear while they can predict relatively accurately for the ones failing in flexure. The underestimation of the shear strength of HSC walls can be caused by a few inaccuracies in the shear strength formulas, but two factors are especially important. One is the neglected contribution of longitudinal reinforcement to wall shear strengths, and another one is the limitation on the maximum shear strength values, which seems to be quite conservative for HSC walls.

This paper discusses 66 HSC wall specimens that the authors can find in the literature. More experimental studies on the behavior of HSC walls (above 60 MPa), especially those failing in shear, are needed to provide more data which can be used to develop a general expression for predicting the strength of HSC walls. That kind of research is currently being done by the authors.

ACKNOWLEDGEMENTS

The authors appreciate very much the research funding provided by the National Research Foundation of Singapore (NRF) under the CRP funded Project "Underwater Infrastructure and Underwater City of the Future". The funding enables the authors to make real progress in this research work.

REFERENCES

- [1] T. Kabeyasawa and H. Hiraishi, "Tests and Analyses of High-Strength Reinforced Concrete Shear Walls in Japan," *ACI Special Publication*, vol. 176, pp. 281-310, 1998.
- [2] A. Gupta and B.V. Rangan, "High-Strength Concrete (HSC) structural walls," *ACI Structural Journal*, vol. 95, (no. 2), pp. 194-204, 1998.
- [3] H.-D. Yun, C.-S. Choi, and L.-H. Lee, "Behaviour of high-strength concrete flexural walls," *Structures and Buildings*, vol. 157, (no. SB2), pp. 137-148, 2004.
- [4] F.E. Farvashany, S.J. Foster, and B.V. Rangan, "Strength and deformation of high-strength concrete shearwalls," *ACI Structural Journal*, vol. 105, (no. 1), pp. 21-29, 2008.
- [5] S. Yan, L.F. Zhang, and Y.G. Zhang, "Seismic performances of high-strength concrete shear walls reinforced with high-strength Rebars," in Book *Seismic performances of high-strength concrete shear walls reinforced with high-strength Rebars*, vol. 323, *Series Seismic performances of high-strength concrete shear walls reinforced with high-strength Rebars*, Editor ed.^eds., City: ASCE, 2008.
- [6] M. Deng, X. Liang, and K. Yang, "Experimental Study on Seismic Behavior of High Performance Concrete Shear Wall with New Strategy of Transverse Confining Stirrups," in Proc. The 14th World Conference on Earthquake Engineering, 2008, pp. Pages.
- [7] ACI Committee 318., American Concrete Institute., and International Organization for Standardization., *Building code requirements for structural concrete (ACI 318-08) and commentary*, Farmington Hills, Mich.: American Concrete Institute, 2008.
- [8] Architectural Institute of Japan., *AIJ Structural Design Guidelines for Reinforced Concrete Buildings based on Ultimate Strength Concept (in English)*, Tokyo: Architectural Institute of Japan (AIJ), 1994.
- [9] Comite Europeen de Normalisation., *Eurocode 8: Design of Structures for Earthquake Resistance Part 1: General Rules, Seismic Actions and Rules for Buildings (EN 1998-1)*, Brussels: Comite Europeen de Normalisation (CEN), 2004.

- Word Count: 779

Plagiarism Percentage

0%

sources:

There are no matching sources for this report.

paper text:

Statistical Parameters ACI 318 $V_{e,n} / V_{cal}$ EC B AIJ $V_{exp} / (A_{vi})$ Minimum Value 0.95 0.54 0.74 0.28
 Maximum Value 2.68 1.25 5.96 1.54 Average Mean Value 1.46 0.96 1.77 0.91 Standard Deviation 0.44
 0.15 0.80 0.32 Covariance 0.30 0.16 0.45 0.35 Table 3: Statistical parameters of normalized actual wall
 strengths and normalized average shear stresses As observed, in general, the ACI and EC8 methods
 underestimate the actual wall strengths. It is understood that most of building codes tend to give lower
 predictions on strengths such that the design formulas are safe enough to be used for practical design. The
 AIJ method seems to be the most accurate, with the lowest coefficient of variation compared to the other
 methods. However, the AIJ method may overestimate wall strengths in some cases. Comparing the actual
 mode of failure versus predicted mode of failure, the AIJ method gives the least false predictions of modes
 of failure among the three codes. The AIJ method fails to predict modes of failure of 13 specimens out of 66
 specimens whereas the ACI-318 method fails in 17 specimens and the EC8 method fails in 20 specimens.
 Further investigation on the failure modes shows that most of the time, the AIJ method gives nominal wall
 shear strengths higher than the actual ones, which results in the tendency of predicting flexural failures
 instead of shear failures. On the other hand, the ACI-318 and the EC8 methods tend to give lower nominal
 wall shear strengths compared to the actual ones, and hence resulting in the tendency of predicting shear
 failures instead of flexural failures. 7.00 6.00 x 5.00 ;"; 4.00 "a. x x ACI AIJ EC >" 3.00 2.00 1.00 !!! -
 AIJ -EC 0.00 0.00 0.50 1.00 1.50 2.00 2.50 Shear Span Ratio (H/L) Figure 1: Normalized actual wall
 strengths plotted against shear span ratio 7.00 6.00 5.00 i.:<"x>.'. 43..0000 ACI AIJ)(> x EC 2.00 AIJ LOO
 0.00 0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00 Drift (%) Figure 2: Normalized actual wall strengths
 plotted against drift ratio 1.80 1.60 1.40 - v 1.20 -9C>ui;(<">' 00L.O.86000 H/L Drift H/L 0.40 Drift 0.20 0.00
 0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00 Shear Span Ratio (H/L); Drift (%) Figure 3: Normalized
 average shear stresses plotted against shear span ratio and drift ratio 1.80 1.60 1.40 \bar{u} 1.20: 0.80 <(x
 1.00 • c.. >" 0.60 0.20 0.00 0.00 0.05 0.10 0.15 0.20 0.25 0.30 Axial Load Ratio ($P/(f_c A_g)$) Figure 4:
 Normalized average shear stresses plotted against axial load ratio 1.80 1.60 1.40 pl fyl pt f yt pl fyl 0.40 pt
 fyl III 0.20 0.00 0.00 2.00 4.00 6.00 8.00 10.00 12.00 14.00 Reinforcement Ratio (ρ_{fy}) Figure 5: Normalized
 average shear stresses plotted against reinforcement ratio 1.80 1.60 - 1.40 u 1.20 -"S<>au&;";":_"
 001...860000 0.40 • • 0.20 0.00 0 20 40 60 80 100 120 140 160 f_c (MPa) Figure 6: Normalized average
 shear stresses plotted against concrete strength From Figure 1, it can be concluded that both the ACI and
 ECB formulas underestimate the wall strengths in low shear span ratios (i.e., shear behavior dominates)
 whereas in high shear span ratios (i.e., flexural behavior dominates), they predict relatively close to the
 actual wall strengths. Similar phenomenon can also be observed (Figure 2) from the drift ratio, which shows
 that both the ACI and ECB formulas underestimate the strength of walls failing in low drift ratio (i.e., shear
 failure) whereas they predict more accurately the strength of walls failing in high drift ratio (i.e., flexural
 failure). This means that for the flexural strength, the flexural theories given in those building codes are

quite reasonable for predicting the actual flexural strength of HSC walls. For the shear strength, those building code formulas, which are mostly empirical, do not give accurate prediction of the actual shear strength of HSC walls. Moreover, from Figure 3, another conclusion that can be drawn is that as the shear span ratio and the drift ratio increase, the normalized average shear stresses tend to reduce. This means that the flexural behavior is more dominant in high shear span ratio and high drift ratio. Furthermore, according to Figure 4, it seems that an axial load of up to 0.15 ($f_c A_g$) does not affect much the wall strengths. The trend line of normalized average shear stresses is nearly flat regardless of the changes in the axial load ratio. Figure 5 shows that the longitudinal reinforcement affects wall strengths more than the transverse reinforcement. The normalized average shear stresses (i.e., wall strengths) increase more when the longitudinal reinforcement ratio increases, as compared to the increment due to the increase in the transverse reinforcement ratio. This phenomenon, however, is not taken into account in most building code formulas for calculating wall shear strengths. Most of building code formulas only take into account the contribution of the transverse reinforcement while neglecting the contribution of the longitudinal reinforcement. Thus, there is a need to develop a general expression to take into account the contribution of the longitudinal reinforcement when calculating wall shear strengths in order to obtain better predictions. Furthermore, from further investigation of the data, in some cases the ACI-318 and ECB methods underestimate wall shear strengths because of the upper limit that is imposed on the maximum wall shear strength. For example, in ACI-318, there is a limitation on the value of the maximum shear stress in walls, which is set at $0.83 \sqrt{f_c}$. From the analysis results, it is shown that the average shear stresses in HSC walls is about $0.91 \sqrt{f_c}$ which exceeds the maximum limit provided by ACI-318. Hence, the ACI-318 method can underestimate wall shear strengths because of the upper bound values of the nominal wall shear strength.

Jimmy Chandra, Yu Liu and Susanto Teng Jimmy Chandra, Yu Liu and Susanto Teng Jimmy Chandra, Yu Liu and Susanto Teng Jimmy Chandra, Yu Liu and Susanto Teng 221 22 2 22 3 22 4 22 5 22 6 22 7 22 8 22 9 230