

15th IB²MaC Brazil

Developing
the future of masonry

Abstracts of the 15th International Brick And Block Masonry Conference

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Support



Edited by
Humberto Ramos Roman
Guilherme Aris Parsekian

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ABSTRACTS

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Conference Chairs

Humberto Ramos Roman

Guilherme Aris Parsekian

Edited by

Humberto Ramos Roman

Guilherme Aris Parsekian

Organizers



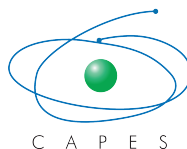
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Foreword

The two Brazilian Federal Universities, of São Carlos (UFSCar) and of Santa Catarina (UFSC), are here jointly organizing the 15th International Brick and Block Masonry Conference (15IB²MaC) in the city of Florianópolis at the South region of Brazil.

These two major Brazilian Universities together have more than 40,000 students currently enrolled in undergraduate, graduate and professional degree programs. The three UFSCar campuses are located in the São Paulo State, with its main campus, that includes the Civil Engineering Department, in the São Carlos City. The UFSC has campuses in the Santa Catarina State and the main campus in Florianópolis where is located the Civil Engineering Department.

Other universities and institutions as the University of Newcastle, the University of São Paulo, the University of Calgary, the University of Minho and the Federal University of Minas Gerais, the Brazilian Ceramic Association and the Brazilian Portland Cement Association are also members of the steering committee.

Previous conferences were held at:

| | | | |
|------|--------------------------|----------------|-----------------|
| 1967 | 1st IB ² MaC | Austin Texas | USA |
| 1970 | 2nd IB ² MaC | Stoke-on-Trent | England |
| 1973 | 3rd IB ² MaC | Essen | Germany |
| 1976 | 4th IB ² MaC | Bruges | Belgium |
| 1979 | 5th IB ² MaC | Washington | USA |
| 1982 | 6th IB ² MaC | Rome | Italy |
| 1985 | 7th IB ² MaC | Melbourne | Australia |
| 1988 | 8th IB ² MaC | Dublin | Ireland |
| 1991 | 9th IB ² MaC | Berlin | Germany |
| 1994 | 10th IB ² MaC | Calgary | Canada |
| 1997 | 11th IB ² MaC | Shanghai | China |
| 2000 | 12th IB ² MaC | Madrid | Spain |
| 2004 | 13th IB ² MaC | Amsterdam | The Netherlands |
| 2008 | 14th IB ² MaC | Sydney | Australia |

On Sunday, a special event named Construction and Building Industry Day will take place. In the morning, lectures on Structural Masonry Design and Construction, Tall Buildings Experience in Brazil, Materials Life-cycle, Job-site Details, Pre-fabricated structural masonry panels and other will be offered to the construction industry attendants. After lunch a very special session will be shared by some of the internationally most known masonry experts to discuss the Masonry Engineering - Past Development, Current Overview and Future Improvements at different world regions.

A total of 160 papers were approved to be presented during the conference session which extends from Monday to Wednesday, including three keynote papers: “Current perspectives on conservation of heritage masonry in Canada”, “Performance Of Earthquake Strengthened URM Buildings In The 2010/2011 Christchurch Earthquake Sequence”, “Sustainability: Masonry’s Corner Stone Or Stumbling Block?”

The mornings of Monday and Tuesday are scheduled for short-courses on Special Masonry Topics: Accidental Damage and Progressive Collapse Design, Slender Wall Design, Non-Linear Numerical Modeling of Masonry, Prestressed Masonry Design. The lectures are given by some of the best worldwide specialists on each topic.

Developing the future of Masonry

Masonry has proven to be a very efficient construction material for thousands of years. In recent years masonry construction has tended to decline in some regions, but is just starting and/or rapidly increasing in others. As an example millions of masonry residential units were built in Brazil during the last decade. Probably the same happens in other countries.

The recent development of new materials and techniques, particularly the use of FRP reinforcement, prestressed masonry and the industrialization of the construction process, has facilitated the use of masonry in situations where traditionally it would not have been efficient.

Sustainability has become a major concern. Topics as Building Energy Performance, Green Building, LEED, Recycled Materials and others need to be improved and developed among the masonry industry.

Important heritage masonry buildings must be protected, rehabilitated or retrofitted. Understanding the behavior of these outstanding buildings and to propose the best materials and techniques to retrofit them is also a goal of the masonry industry.

The principal aim of the conference is to explore new opportunities for masonry: *"where we should go and what we should develop"*.

Conference Co-Chairs

Humberto Ramos Roman, PhD
Federal University of Santa Catarina – UFSC

Guilherme Aris Parsekian, PhD
Federal University of São Carlos – UFSCar

Conference Message

The two Brazilian Federal Universities, of São Carlos (UFSCar) and of Santa Catarina (UFSC), are very honoured in organizing the 15th International Brick and Block Masonry Conference (15IB²MaC) in the city of Florianópolis Brazil.

We are excited to welcome you from 3rd to 6th of June of 2012.

On Sunday, a special event named Construction and Building Industry Day will take place. In the morning, lectures on Mortar Joint Reinforcement, Tall Buildings Experience in Brazil, Materials Life-cycle, Job-site Details and other will be given by the industry. After lunch a very special session will be shared by some of the internationally most known masonry experts to discuss the Masonry Engineering - Past Development, Current Overview and Future Improvements at different world regions.

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All of these high level technical events will be in this very special place, the several times awarded the best beach hotel in Brazil, Costão do Santinho Resort. Construction is booming in Brazil, where millions of residential unit were made with structural masonry the last 4 years, creating an exciting environment for those involved with masonry.

We carefully took care of the conference preparations aiming to give you all the best.

Hope you will enjoy it and our staff is ready to help in anything you need!

Best wishes,

Humberto Ramos Roman, PhD
Federal University of Santa Catarina – UFSC

Guilherme Aris Parsekian, PhD
Federal University of São Carlos – UFSCar

Important Information

The City

City to visit the whole year, Florianópolis, or Floripa as it is known by the more intimate is the fate of all. Today is considered the capital with better quality of life in Brazil. Each region has its own island sightseeing tour with postcards unforgettable. There are approximately 42 beaches, dunes, waterfalls, hot springs, lakes and beautiful mountains. The city has an excellent infrastructure to receive all kind of attractions for visitors and whole family. The nightlife happens in various parts of the island and varied cuisine pleases the most discerning palates.

Known as the Magic Island, the capital of Santa Catarina is beautiful, sophisticated and unique, it attracts Brazilian and foreign tourists from various parts of the world to admire the exuberance of its 42 beaches, and historical sights and monuments that form part of your beauty.

In the center is concentrated most of the infrastructure and non-natural sights of the city of Florianópolis. Hotels, bars, restaurants, old homes belonging the National Heritage, the great Public Market built in 1898, squares, museums and theaters that have the island's history. The Bridge Hercílio Luz built in 1926 to make the connection between the island and the mainland, is the postcard of the city; gigantic and wonderful; enchants its structure both day and night. In November XV Square, the large fig tree centennial year of 1871 is shade for their contemplators.

Florianópolis is a center of international tourism, which combines comfort and luxury with lots of nature and beautiful beaches. For all that the city has to offer, number of tourists visiting the capital of Santa Catarina, is growing every year, a good sign that here are worth.

Registration Area

Day 0: June 2nd – 02PM – 7PM

Day 1: June 3rd – 08AM – 6PM

Day 2: June 4th – 08AM – 7PM

Day 3: June 5th – 08AM – 7PM

Day 4: June 6th – 08AM – 2PM

Congress schedule

Day 1: June 3rd – 09AM – 6PM

Day 2: June 4th – 09AM – 8PM

Day 3: June 5th – 09AM – 8PM

Day 4: June 6th – 09AM – 2PM

Badge

Badges must be worn at all times during the event. Access to the convention center will be denied to anyone not wearing a badge. If a delegate loses a handling fee of R\$ 50,00 will be charged for every replacement.

Certificate

All regularly registered delegates can collect their certificate of attendance at the Registration desk.

Media Desk

Speakers should deliver and view/check their PowerPoint presentations at the Media Desk (located in Room Vip) at least 2 hours prior to the start of the respective session.

Travel Agency

The America do Sol (Travel Agency) will be available to delegates at the event. The agency will be providing services as accommodation, air tickets, car rentals, packed tours and other related services.

Simultaneous Translation

The simultaneous translation (Portuguese to English and English to Portuguese) will be available during plenary sessions on June 3rd.

Social activities

Welcome Reception - June 3rd – 6PM

Conference Barbecue – June 4th – 9PM

Conference Dinner – June 5th – 9PM

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- | | | | |
|--|---|--|--|
| 01 Administração Administrative Center | 12 Estacionamento Parking Lot | 23 SPA/Salão de Beleza Spa & Beauty Parlor | 34 Carijós Sound & Bar Camp's Sound & Bar |
| 02 Portaria Main Entrance | 13 Heliporto Helipoint | 24 Wine Bar Decanter Decanter's Wine Bar | 35 Boutique Gift Shop |
| 03 Recepção Front Desk | 14 Quadras de Tênis Tennis Courts | 25 Piscinas Ala Internacional Swimming Pools | 36 Bar Campari Campari's Bar |
| 04 Centro Comercial Shopping Area | 15 Estádio de Tênis Tennis Stadium | 26 Sala Tupi-Guarani Tupi-Guarani Hall | 37 Restaurante Costão Grill (sazonal) Costão Grill Restaurant (seasonal) |
| 05 Restaurante Açores Açores Restaurant | 16 Choupama Hut | 27 Costão Teen Costão Teen | 38 Restaurante Rancho do Pescador Rancho do Pescador Restaurant |
| 06 Cine Costão Movie Theater | 17 Campo de Futebol Soccer Field | 28 Costão Gym by LifeFitness Fitness Center | 39 Restaurante N. Sra. das Ondas N. Sra. das Ondas Restaurant |
| 07 Centro de Eventos Event Center | 18 Paredes de Escalada Climbing Wall | 29 Costão Kids Costão Kids | 40 Restaurante Trattoria di Mare (sazonal) Trattoria di Mare Restaurant (seasonal) |
| 08 Clínica Médica Medical Center | 19 Arvorismo Tree Trekking | 30 Costão Baby Costão Baby | 41 Costão Zen Costão Zen |
| 09 Quadra Poliesportiva Multi-Sports Court | 20 Caminho Ecológico Hiking Trail | 31 Piscinas Aquecidas e Saunas Heated Swimming Pools and Sauna | 42 Engenho de Farinha Flour Mill |
| 10 Salão Cascaes Cascaes Hall | 21 Costão Mágico Magical Costão | 32 Bar das Piscinas Swimming Pool Bar | 43 Engenho de Cana-de-Açúcar Cane Mill |
| 11 Espaço Tuguá Tugue Hall | 22 Restaurante N. Sra. da Vitória N. Sra. da Vitória Restaurant | 33 Piscinas Swimming Pools | 44 Costão Náutico (canto sul da Praia dos Ingleses) Marine (located at Ingleses Beach south end) |



Schedule of the 15th International Brick and Block Masonry Conference

June 3rd to 6th, 2012
Costão do Santinho Resort

Monday, June 4th

| 3:15pm to 4:30pm | Session 1 - Room | | | |
|------------------|-----------------------|--|---------------------|---|
| | Flores | Graciosa | Santa Maria | Ilha Terceira |
| Theme | Compression strength | Environmental Performance | Historical Masonry | FRP & rehabilitation |
| 3:15pm | 1A 1 | 1B 1 | 1C 1 | 1D 1 |
| 3:30pm | 1A 2 | 1B 2 | 1C 2 | 1D 2 |
| 3:45pm | 1A 3 | 1B 3 | 1C 3 | 1D 3 |
| 4:00pm | 1A 4 | 1B 4 | 1C 4 | 1D 4 |
| 4:15pm | 1A 5 | 1B 5 | | 1D 5 |
| 5:00pm to 6:15pm | Session 2 - Room | | | |
| | Flores | Graciosa | Santa Maria | Ilha Terceira |
| Theme | Composite Interaction | Materials Research & Properties | Infill | Seismic – existing building modeling & evaluation |
| 5:00pm | 2A 1 | 2B 1 | 2C 1 | 2D 1 |
| 5:15pm | 2A 2 | 2B 2 | 2C 2 | 2D 2 |
| 5:30pm | 2A 3 | 2B 3 | 2C 3 | 2D 3 |
| 5:45pm | 2A 4 | 2B 4 | 2C 4 | 2D 4 |
| 6:00pm | 2A 5 | 2B 5 | 2C 5 | 2D 5 |
| 6:45pm to 8:15pm | Session 3 - Room | | | |
| | Flores | Ilha Terceira | Graciosa | Santa Maria |
| Theme | Dry/thin joint | Seismic – numerical modeling & performance | Numerical Modelling | Shear |
| 6:45pm | 3A 1 | 3B 1 | 3C 1 | 3D 1 |
| 7:00pm | 3A 2 | 3B 2 | 3C 2 | 3D 2 |
| 7:15pm | 3A 3 | 3B 3 | 3C 3 | 3D 3 |
| 7:30pm | 3A 4 | 3B 4 | 3C 4 | 3D 4 |
| 7:45pm | 3A 5 | 3B 5 | 3C5 | 3D 5 |

Tuesday, June 5th

| 3:15pm to 4:30pm | Session 4 - Room | | | |
|-------------------------|----------------------------|--|---|--|
| | Ilha Terceira | Santa Maria | Graciosa | Flores |
| Theme | Shear & Flexure | Building envelope and modeling | Creep, elastic and long term deformation | Modern Masonry Development |
| 3:15pm | 4A 1 | 4B 1 | 4C 1 | 4D 1 |
| 3:30pm | 4A 2 | 4B 2 | 4C 2 | 4D 2 |
| 3:45pm | 4A 3 | 4B 3 | 4C 3 | 4D 3 |
| 4:00pm | 4A 4 | 4B 4 | 4C 4 | 4D 4 |
| 4:15pm | 4A 5 | 4B 5 | 4C 5 | 4D 5 |
| 5:00pm to 7:00pm | Session 5 - Room | | | |
| | Flores | Graciosa | Ilha Terceira | Santa Maria |
| Theme | Mortar | Construction process | Historical Masonry – evaluation & properties Masonry | Seismic – experimental tests |
| 5:00pm | 5A 1 | 5B 1 | 5C 1 | 5D 1 |
| 5:15pm | 5A 2 | 5B 2 | 5C 2 | 5D 2 |
| 5:30pm | 5A 3 | 5B 3 | 5C 3 | 5D 3 |
| 5:45pm | 5A 4 | 5B 4 | 5C 4 | 5D 4 |
| 6:00pm | 5A 5 | | 5C 5 | 5D 5 |
| 6:45pm to 8:15pm | Session 6 - Room | | | |
| | Flores | Graciosa | Santa Maria | Ilha Terceira |
| Theme | Flexure & Beam | Build masonry properties evaluation | Compression strength | Seismic – existing building modeling & evaluation |
| 6:45pm | 6A 1 | 6B 1 | 6C 1 | 6D 1 |
| 7:00pm | 6A 2 | 6B 2 | 6C 2 | 6D 2 |
| 7:15pm | 6A 3 | 6B 3 | 6C 3 | 6D 3 |
| 7:30pm | 6A 4 | 6B 4 | 6C 4 | 6D 4 |
| 7:45pm | 6A 5 | 6B 5 | 6C 5 | 6D 5 |

Wednesday, June 6th

| 10:30am to 12:00am | Session 7 – Room | | | |
|---------------------------|------------------------------|-----------------------------|----------------------------|--|
| | Ilha Terceira | Graciosa | Flores | Santa Maria |
| Theme | Shear and compression | Construction process | Masonry performance | Seismic performance and blast loading |
| 10:30am | 7A 1 | 7B 1 | 7C 1 | 7D 1 |
| 10:45am | 7A 2 | 7B 2 | 7C 2 | 7D 2 |
| 11:00am | 7A 3 | 7B 3 | 7C 3 | 7D 3 |
| 11:15am | 7A 4 | 7B 4 | 7C 4 | 7D 4 |
| 11:30am | 7A 5 | | 7C 5 | 7D 5 |

Program for the 15th International Brick and Block Masonry Conference

June 3rd to 6th, 2012
Costão do Santinho Resort

Day 1: Jun 3rd, 2012

Pre-conference Event (Optional): Construction and building industry Day & Welcome Reception

| | |
|----------------|--|
| 09:00am | Welcome and Opening |
| 09:30am | Structural Masonry By A Constructor Point Of View Eng. Renato Soffiatti Mesquita de Oliveira - Fortenge Construções |
| 10:00am | Site Implementation Of Structural Masonry Eng. Marcio Santos Faria - Arq.EST Consultoria & Projetos |
| 10:30am | High-Rise Structural Masonry Buildings in Brazil Arq. Carlos Alberto Tauil - Bloco Brasil Eng. Claudio Oliveira Silva - ABCP |
| 11:00am | Coffee Break |
| 11:30am | Masonry Pre-Fabrication Eng. João Alberto Kerber - Edifficaz Tecnologia em Construção |
| 12:00am | Life Cycle Assessment (LCA) Of Clay Masonry Dra. Cássia Ugaya - Anicer |
| 12:30am | Alvenarias Reforçadas com Trelças Galvanizadas Murfor Eng. Roberto de Araujo Coelho - Belgo Bekaert Arames |
| 13:00am | Lunch |
| 02:00pm | Special Session (Optional): Masonry Engineering - Past Development, Current Overview, Future Improvements |
| 02:00pm | In Brazil - Marcio Correa |
| 02:30pm | In the United Kingdom - Barry Haseltine |
| 03:00pm | in Canada - Robert Drysdale |
| 03:30pm | Coffee Break |
| 04:00pm | In the United States - Richard Klingner |

04:30pm In Australia - Adrian Page
05:00pm Discussion – Guilherme Parsekian (Moderator)

06:00pm Welcome Reception

Day 2: Jun 4th, 2012

Short Courses (optional), Keynote Speech, Technical Sessions

Room: FLORES

09:00 Ecological Hiking at Costão

09:00 / 10:45 **Short Course (Optional) - Special Masonry Topics: Accidental Damage and Progressive Collapse Design**
Barry Haseltime

11:00 / 12:45 **Short Course (Optional) - Special Masonry Topics: Slender Wall Design**
Robert Drysdale

12:30pm Lunch

02:00pm **Conference Opening and Welcome**
Keynote Speech: Current perspectives on conservation of heritage masonry in Canada
Nigel Shrive

03:15pm Technical Sessions

04:30pm Coffee break

05:00pm Technical Sessions

09:00pm Conference Barbecue

Day 3: Jun 5, 2012

Short Courses (Optional), Keynote Speech, Technical Sessions

Room: FLORES

09:00 Ecological Hiking at Costão

09:00 / 10:45 **Short Course (Optional) - Special Masonry Topics: Non-Linear Numerical Modelling of Masonry**
Paulo Lourenço

| | |
|---------------|---|
| 11:00 / 12:45 | Short Course (Optional) - Special Masonry Topics: Prestressed Masonry Design Nigel Shrive |
| 12:30pm | Lunch |
| 02:00pm | Conference Keynote Speech: Performance of earthquake strengthened buildings in the Christchurch earthquake Jason Ingham |
| 03:15pm | Technical Sessions |
| 04:30pm | Coffee break |
| 05:00pm | Technical Sessions |
| 09:00pm | Conference Dinner |

Day 4: Jun 6th, 2012

Keynote Speech, Technical Sessions, Closure

| | |
|---------|---|
| 09:30am | Conference Sustainability Aspects of Masonry Materials and Buildings Gregg Borchelt |
| 10:30am | Coffee break |
| 11:00am | Technical Session |
| 12:30am | Conference Close |

Detailed Program and Abstract Table of Contents for the 15th International Brick and Block Masonry Conference

June 3rd to 6th, 2012
Costão do Santinho Resort

Date: Monday, June 4th

Theme: Compression Strength – 1^a

Room: Flores

- | | | |
|--------|------|--|
| 3:15pm | 1A 1 | Composite load bearing behaviour of unreinforced and reinforced wall constructions made of clay units filled with standard concrete Markus Graubohm |
| 3:30pm | 1A 2 | Clay block prisms under compressive loads: testing and modeling Marcio Antonio Ramalho, Alberto Taliercio Marcio Antonio Ramalho, Alberto Taliercio |
| 3:45pm | 1A 3 | Contribution of mortar covering on compressive behavior of non-loadbearing clay brick small walls Carlos Wellington de Azevedo Pires Sobrinho, Sama Tavares Andrade, Romilde Almeida Oliveira, Fernando Artur Nogueira |
| 4:00pm | 1A 4 | Examination of the prescribed concrete block masonry compressive strengths in the canadian masonry design standard, csa s304.1-04 Yasser Korany |
| 4:15pm | 1A 5 | Permissible stress level of brick masonry under compressive cyclic loading Milad Alshebani |

Date: Monday, June 4th

Theme: Environmental Performance – 1B

Room: Graciosa

- | | | |
|--------|------|--|
| 3:15pm | 1B 1 | A study of wall surface temperature variations for housing in moderate climates Dariusz Alterman, Adrian William Page, Stuart Hands, Caimao Luo, Behdad Moghtaderi |
| 3:30pm | 1B 2 | Development of ceramic blocks for masonry constructions with thermal insulation filling on the basis of easily renewable raw materials and by-products Jiri Zach, Jiri Brozovsky |

- 3:45pm 1B 3 **Evaluation of damage evolution in masonry due to environmental parameters and salt capillary rise**
Elena Gabrielli, Friedrich Gruener, Camilla Colla
- 4:00pm 1B 4 **Improvement of the thermal resistance of load-bearing perforated fired-clay brickwork**
Zoubeir Lafhaj, Christophe Chapiseau, Fayçal El Fgaier, Ibrahim Lemniei
- 4:15pm 1B 5 **Theoretical analysis of thermal performance of clay and concrete masonry structural under various conditions**
Regina Candeloro Grabarz, Lea Cristina Souza, Guilherme Aris Parsekian

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|--|
| <p>Date: Monday, June 4th Theme: Historical Masonry – 1C Room: Santa Maria</p> |
|--|

- 3:15pm 1C 1 **Behavior of masonry vaults in millstone strengthened by composite materials**
Maamoun Saade, Stephan Kesteloot, Chafika Dantec, Lotfi Hamitouche, Idriss Benslimane
- 3:30pm 1C 2 **Construction process numerical simulation and seismic assessment of Mallorca Cathedral**
Pere Roca, Luca Pelà, Miguel Cervera
- 3:45pm 1C 3 **Discrete and finite element modeling of the walls of the prince of wales fort**
Andrea Cathleen Isfeld, Nigel Graham Shrive
- 4:00pm 1C 4 **Structural aspects of traditional Cretan masonry**
Kevin Glowacki, John Morgan Nichols, Nancy Lee Holland

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| <p>Date: Monday, June 4th Theme: FRP & rehabilitation – 1D Room: Ilha Terceira</p> |
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- 3:15pm 1D 1 **Cyclic in-plane shear behavior of unreinforced masonry wall panels strengthened with NSM FRP strips**
Chaminda Konthesingha, Mark John Masia, Robert Bruce Petersen, Adrian William Page
- 3:30pm 1D 2 **In-situ testing of brick masonry walls strengthened with CFRP fabric**
Samo Gostic, Vlatko Zvonimir Bosiljkov, Mojca Jarc Simoncic

- 3:45pm 1D 3 **Reliability of unreinforced masonry bracing walls**
Eric Brehm, Shelley Lissel
- 4:00pm 1D 4 **Structural design of supplementary injection anchors inside masonry**
Birger Gigla
- 4:15pm 1D 5 **The new italian guide lives for FRP strengthening of masonry and timber structures**
Andrea Benedetti, Elio Sacco

| |
|---|
| <p>Date: Monday, June 4th Theme: Composite Action – 2A Room: Flores</p> |
|---|

- 5:00pm 2A 1 **Analysis of influencing factors on composite action for reinforced grouted concrete block wall-beam**
Ximei Zhai, Yanfeng Guo, Song Gao
- 5:15pm 2A 2 **Development of reliability assessment software for existing masonry buildings supported by reinforced concrete frames**
Xianglin Gu, Dongjie Sun, Kai Sun, Bin Peng
- 5:30pm 2A 3 **Macro modeling of the arch effect: a parametric study**
Rafael Santos de Moraes, Jorge Augusto Serafim, Guilherme Aris Parsekian
- 5:45pm 2A 4 **The effect of the position of the supports on the behaviour of composite masonry walls**
Dirk Martens, A.T. Vermeltfoort
- 6:00pm 2A 5 **Practical aspects of testing composite masonry walls**
A T Vermeltfoort

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| <p>Date: Monday, June 4th Theme: Materials Research & Properties – 2B Room: Graciosa</p> |
|--|

- 5:00pm 2B 1 **A mix design methodology for concrete block units**
Artêmio Frasson Jr, Juliana Machado Casali, Alexandre Lima Oliveira, Luiz Roberto Prudêncio Jr
- 5:15pm 2B 2 **Experiences and analysis on masonry materials subjected to high-temperatures**
Marco Andreini, Anna De Falco, Mauro Sassu

- 5:30pm 2B 3 **Hygrothermal characteristics of pumice aggregate concrete used for masonry wall blocks**
Hülya Kus
- 5:45pm 2B 4 **Use of natural sisal fiber in concrete blocks for structural masonry**
Indara Soto Izquierdo, Marcio Antonio Ramalho, Orieta Soto Izquierdo
- 6:00pm 2B 5 **Replacement of portland cement with supplemental cementitious materials in masonry grout**
Fernando S Fonseca, Kurt Siggard

Date: Monday, June 4th

Theme: Infill – 2C

Room: Santa Maria

- 5:00pm 2C 1 **Analysis of the contribution of masonry infill in the overall stiffness of concrete frames**
Jean Marie Désir, Thiago Pedreschi Busi, Lucas Ramires
- 5:15pm 2C 2 **Frictional energy dissipation and damping capacity of framed semi-interlocking masonry infill panel**
Yuri Zarevich Totoev, Kun Lin
- 5:30pm 2C 3 **Interpretation of in-plane response and definition of damage levels for masonry infilled RC frames**
Sanja Hak, Paolo Morandi, Guido Magenes
- 5:45pm 2C 4 **Masonry infilled steel frames under combined in-plane lateral and axial loading**
Yi Liu, Pouria Manesh
- 6:00pm 2C 5 **Solutions for infilled masonry buildings: shaking table tests**
João Miguel Carvalho Leite, Paulo Brandão Barbosa Lourenço

Date: Monday, June 4th

Theme: Existing building modeling & evaluation – 2D

Room: Ilha Terceira

- 5:00pm 2D 1 **Proposed experimental study to compare the seismic performance of reinforced concrete and reinforced masonry structural walls**
Omar El-Azizy, Wael El-Dakhakhni, Robert Drysdale
- 5:15pm 2D 2 **New seismic construction categories for reinforced concrete block structural walls: analysis**
Marwan Shedid, Wael El-Dakhakhni, Robert Drysdale

- 5:30pm 2D 3 **New seismic construction categories for reinforced concrete block structural walls: experiments**
Marwan Shedid, Wael El-Dakhakhni, Robert Drysdale
- 5:45pm 2D 4 **Seismic behavior comparison of confined masonry walls of clay and concrete bricks**
Angel Francisco San Bartolomé, Paola Angles, Daniel Roberto Quiun
- 6:00pm 2D 5 **Seismic retrofit of partially grouted concrete masonry walls with polymer-cement mortar**
Kenji Kikuchi, Masayuki Kuroki, Hideko Nonaka, Tomohiro Eguchi

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| Date: Monday, June 4th Theme: Dry/thin joint – 3A Room: Flores |
|--|

- 6:45pm 3A 1 **Axial capacity of dry stacked masonry wall**
Fernando S Fonseca, Eric B Murray
- 7:00pm 3A 2 **Characterization of flexural bond strength in thin bed concrete masonry**
Julian Ajith Thamboo, Manicka Dhanasekar, Cheng Yan
- 7:15pm 3A 3 **Compressive strength of thin layer mortar bed joints masonry made of polish calcium silicate units**
Lukasz Drobiec, Radoslaw Jasinski, Adam Piekarczyk
- 7:30pm 3A 4 **Sustainable dry interlocking block masonry construction**
Bansal Deepak
- 7:45pm 3A 5 **Study of the influence of compressive strength and thickness of mortar on compressive strength of prisms of structural clay blocks**
Flavio Barbosa Lima, Alexandre Nascimento Lima, Wayne Santos Assis

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| Date: Monday, June 4th Theme: Seismic – Numerical modelling and performance – 3B Room: Ilha Terceira |
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- 6:45pm 3B 1 **Shake table testing and analytical modeling of fully-grouted reinforced concrete block masonry shear walls**
Saeid Mojiri, Michael Tait, Wael El-Dakhakhni

- 7:00pm 3B 2 **Nonlinear seismic analysis of a modern aggregate of masonry buildings through macro-element modeling**
Rui Filipe Pedreira Marques, Graça Fátima Moreira Vasconcelos,
Paulo José Brandão Barbosa Lourenço
- 7:15pm 3B 3 **Seismic behavior of reduced-scale two-storey reinforced concrete masonry shear walls**
Mustafa Siyam, Wael El-Dakhakhni, Robert Drysdale
- 7:30pm 3B 4 **Identification of performance-based damage indicators of reinforced concrete block structural walls with end confinement**
Bennet Banting, Wael El-Dakhakhni
- 7:45pm 3B 5 **Hybrid masonry seismic systems**
Daniel Abrams, David Biggs

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|---|
| <p>Date: Monday, June 4th Theme: Numerical models – 3C Room: Graciosa</p> |
|---|

- 6:45pm 3C 1 **3D interaction domains for unreinforced masonry panels subjected to eccentric compression and shear**
Fulvio Parisi, Nicola Augenti
- 7:00pm 3C 2 **Development of a fiber model for load bearing masonry members**
Francesca da Porto, Giovanni Guidi
- 7:15pm 3C 3 **Numerical analysis of unreinforced flanged walls subjected to biaxial bending**

Vladimir Guilherme Haach, Marcio Antonio Ramalho, Márcio Roberto Silva Corrêa
- 7:30pm 3C 4 **Definition of equivalent damping for masonry structures in support of displacement based design**
Francesca da Porto, Luca Nicolini
- 7:45pm 3C 5 **Numerical simulation of urm walls subjected to out-of-plane solicitations using a "unit and interaction" micro-modeling approach**
Elodie Bultot, Laurent Van Parys

| |
|---|
| <p>Date: Monday, June 4th Theme: Shear – 3D Room: Santa Maria</p> |
|---|

- 6:45pm 3D 1 **A shear response surface for the characterization of unit-mortar interfaces**
Fulvio Parisi, Nicola Augenti

- 7:00pm 3D 2 **Comparison of in-plane shear strength of reinforced concrete masonry walls**
Nusrat Hoque, Shelley L. Lissel
- 7:15pm 3D 3 **Effect of construction method on shear resistance of masonry walls**
Ahmed Faisal Oan, Nigel Shrive
- 7:30pm 3D 4 **Experimental assessment of the shear response of autoclaved aerated concrete (AAC) masonry with flat truss bed-joint reinforcement**
Martina Mandirola, Andrea Penna, Maria Rota, Guido Magenes
- 7:45pm 3D 5 **Experimental study on shear properties of insulating perforated concrete brick masonry materials**
Li Xiang, Gao Zhi Nan, Gu Xiang Lin, Song Xiao Bin, Li Yi Hong

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|---|
| <p>Date: Tuesday, June 5th Theme: Shear & Flexure – 4^a Room: Ilha Terceira</p> |
|---|

- 3:15pm 4A 1 **Assessment of the AS3700 relationship between shear bond strength and flexural tensile bond strength in unreinforced masonry**
Mark John Masia, Goran Simundic, Adrian William Page
- 3:30pm 4A 2 **Modeling the flexural tensile strength of masonry**
Ulf Schmidt, Joachim Hannawald, Matthias Koster, Markus Graubohm, Wolfgang Brameshuber
- 3:45pm 4A 3 **In-plane sheared unreinforced masonry wallettes – proposition of failure criterion**
Jan Emil Kubica
- 4:00pm 4A 4 **Influence of distinct reinforcing schemes on the shear resistance of masonry**
Graça Vasconcelos, Pedro Alves, Paulo B Lourenço
- 4:15pm 4A 5 **Limestone prisms - shear strength study**
Nancy Lee Holland, John Morgan Nichols

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| <p>Date: Tuesday, June 5th Theme: Building envelope and modeling – 4B Room: Santa Maria</p> |
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- 3:15pm 4B 1 **Comparative analyses through simplified method, plane frames and space frames of design of structural masonry buildings**
Francisco Quim, Adriano de Oliveira Lima, Nilson Oliveira da Silva

- 3:30pm 4B 2 **Economic methods for confining borders of reinforced masonry walls**
Daniel Roberto Quiun, Angel Francisco San Bartolomé, Abel Higinio Moscol
- 3:45pm 4B 3 **Experimental analysis of shear walls submitted to vertical and horizontal loads**
Joel Araújo Nascimento Neto, Márcio Roberto Silva Corrêa, Marcio Antonio Ramalho
- 4:00pm 4B 4 **The influence of architecture flexibility in masonry structure designing**
Fabiana Cristina Mamede, Augusto Guimarães Pedreira Freitas
- 4:15pm 4B 5 **Shear transfer capacity of alternative materials for horizontal slip joints in masonry**
Yuri Zarevich Totoev, Goran Simundic

Date: Tuesday, June 5th

Theme: Creep, elastic and long term deformation – 4C

Room: Graciosa

- 3:15pm 4C 1 **Creep test in the prism of dry and saturated ceramic blocks**
Jenner Miranda Carvalho, Luís Ferreira Ramos, Paulo Barbosa Lourenço, Humberto Ramos Roman
- 3:30pm 4C 2 **Deformation capacity of structural masonry: a review of experimental research**
Amir Hosein Salmanpour, Nebojša Mojsilović, Joseph Schwartz
- 3:45pm 4C 3 **Prestress loss of wall-floor connections in post-tensioned shear walls of CASIEL-TLM masonry**
Lex van der Meer, Dirk Martens, Ad Vermeltfoort
- 4:00pm 4C 4 **The failure mode, deformability and strength of masonry walls**
Gihad - Mohamad, Paulo Brandão Lourenço, Eduardo - Rizzatti, Humberto Ramos Roman, Elizabete Yukiko Nakanishi
- 4:15pm 4C 5 **Stress-strain behavior of concrete block masonry prisms under compression**
Gihad Mohamad, Paulo Brandão Lourenço, Humberto Ramos Roman, Claudius de Souza Barbosa, Eduardo Rizzatti

Date: Tuesday, June 5th
Theme: Modern Masonry Development – 4D
Room: Flores

- 3:15pm 4D 1 **Development and use of a new type of concrete masonry unit**
Leonardo Tolaine Massetto, Carlos Alberto Tauil, Mario Sergio Guimaraes
- 3:30pm 4D 2 **Development of masonry modular production system**
Leonardo Tolaine Massetto, Fernando Henrique Sabbatini, Carlos Alberto Tauil, Mario Sergio Guimarães
- 3:45pm 4D 3 **Digitally augmented masonry: applications of digital technologies to the design and construction of unconventional masonry structures**
Tristan Al-Haddad, T. Russell Gentry, Andres Cavieres, Trang Thai
- 4:00pm 4D 4 **The Glasser Case: 40 years leading Brazilian CMU market**
Leonardo Tolaine Massetto, Carlos Alberto Tauil, Mario Sergio Guimarães, Luciano Salvador Lima
- 4:15am 4D 5 **Experimental investigation on the seismic behaviour of new concrete block masonry buildings**
Leonardo Avila, Graça Vasconcelos, Paulo B Lourenço, Pedro Alves, Nuno Mendes

Date: Tuesday, June 5th
Theme: Mortar – 5^a
Room: Flores

- 5:00pm 5A 1 **Effects of dewatering on long term movement characteristics of lime mortars**
Stella Muthoni Kioy, Pete Walker, Richard Ball, Enrico Fodde
- 5:15pm 5A 2 **Experimental characterization of mortar by testing on small specimens**
Luca Pelà, Andrea Benedetti
- 5:30pm 5A 3 **Use of pozzolana in reinforcement mortar for nonstructural masonry**
Romilde Almeida de Oliveira, João Manoel Freitas Mota
- 5:45pm 5A 4 **Poisson behavior of bedding mortar under multi-axial stress conditions**
Gihad - Mohamad, Paulo Brandão Lourenço, Humberto Ramos Roman, Eduardo - Rizzatti

- 6:00pm 5A 5 **Sustainable masonry: the importance of the mortar quality for the masonry behaviour**
Frederik Konstantijn Verhelst, Erik H Kjaer, Wolfram Jäger, Bernard Middendorf, Koenraad Vanbalen, Pete Walker

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| Date: Tuesday, June 5th Theme: Construction process – 5B Room: Graciosa |
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- 5:00pm 5B 1 **Construction technology of the internal vertical sealing with gypsum blocks**
Alberto Casado Lordsleem Junior, Maria Luiza Rodrigues Neves
- 5:15pm 5B 2 **Contribution to the adoption of ready wooden doors in the design of structural masonry buildings**
Regina Candeloro Grabarz, Guilherme Aris Parsekian
- 5:30pm 5B 3 **Design and service processes for producing vertical non-loadbearing masonry: scope analysis**
Alberto Casado Lordsleem Junior, Silvio Burrattino Melhado
- 5:45pm 5B 4 **Seismic behavior of confined masonry walls reinforced with welded steel and ductile steel**
Angel Francisco San Bartolomé, Daniel Roberto Quiun

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| Date: Tuesday, June 5th Theme: Historical Masonry - evaluation & properties masonry – 5C Room: Ilha Terceira |
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- 5:00pm 5C 1 **Experimental evaluation of the coefficient of restitution value of rocking stone masonry façades**
Alexandre Anibal Costa, Antonio Arede, Andrea Penna, Anibal Costa
- 5:15pm 5C 2 **Energy dissipation and stiffness identification of unreinforced masonry**
Thomas Zimmermann, Alfred Strauss, Konrad Bergmeister
- 5:30pm 5C 3 **Improved neutron-based system for nde of salt contamination and moisture in historic masonry**
Amde M Amde, Richard A Livingston
- 5:45pm 5C 4 **Inspection and lifetime assessment for arch bridges**
Alexander Krawtschuk, Alfred Strauss, Oliver Zeman, Roman Wendner

- 6:00pm 5C 5 **Uncertainties in the assessment of the seismic vulnerability of stone masonry buildings**
Vlatko Zvonimir Bosiljkov, Patricia CotiĂ, Mojmir Uranjek, Meta KrĂan

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| Date: Tuesday, June 5th Theme: Seismic - experimental tests – 5D Room: Santa Maria |
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- 5:00pm 5D 1 **Out-of-plane in-situ cyclic testing of unreinforced stone masonry walls with distributed loads**
Aníbal Costa, Alexandre A. Costa, Antônio Arêde
- 5:15pm 5D 2 **Pushover seismic analysis of quasi-static tested confined masonry buildings through simplified models**
Rui Filipe Pedreira Marques, Paulo José Brandão Barbosa Lourenço
- 5:30pm 5D 3 **Shake-table testing of a 3-story, full-scale, reinforced masonry wall system**
Andreas Stavridis, Marios Mavros, Farhad Ahmadi, P Benson Shing, Richard Evans Klingner, David I McLean
- 5:45pm 5D 4 **Shaking table study on unreinforced masonry buildings**
Li Xiang, Li Qiang, Gu Xiang Lin, Zhang Wei Ping, Lu Jin Biao
- 6:00pm 5D 5 **Shaking table test to assess the out-of-plane behaviour of a stone of masonry building**
Alexandre Aníbal Costa, António Arêde, Alfredo Campos Costa, Andrea Penna, Aníbal Costa

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| Date: Tuesday, June 5th Theme: Flexure & Beam – 6A Room: Flores |
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- 6:45pm 6A 1 **Empirical flexural behaviour approach of adobe masonry**
Daniel Torrealva, Mario Solis, Patricia Santillán, Gonzalo Montoya
- 7:00pm 6A 2 **Bending capacity of dry stacked lightweight concrete block masonry**
Miklós Molnár, Johan Jönsson
- 7:15pm 6A 3 **Msjc provisions for the design of masonry deep beams**
Fernando S Fonseca, Sunup Mathew
- 7:30pm 6A 4 **The development of masonry reinforced by bond beams and bond columns to resist lateral load**
Geoff John Edgell, Andrew Best

- 7:45pm 6A 5 **Out-of-plane seismic performance of unreinforced masonry walls retrofitted using post-tensioning**
Najif Ismai, Arturo E. Schultz, Jason M. Ingham

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| <p>Date: Tuesday, June 5th Theme: Built masonry properties evaluation – 6B Room: Graciosa</p> |
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- 6:45pm 6B 1 **Evaluation of technical condition of masonry structures**
Jiri Brozovsky, Jiri Zach
- 7:00pm 6B 1 **Evaluation of the effectiveness of masonry consolidation treatments based on scratching tomography**
Fabrice Dagrain, Jean-Christophe Scaillet, Sevasti Modestou, Ioannis Ioannou
- 7:15pm 6B 3 **Radiation from masonry products - measurement and assessment**
Dieter Rosen
- 7:30pm 6B 4 **Mechanical properties of masonry samples for theoretical modeling**
Arsash Sayari
- 7:45pm 6B 5 **Quantifying the impact of soil defects on plain masonry buildings through a global indicator based on a control-profile approach**
Laurent Van Parys, Olivier Kaufmann, Elodie Bultot

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| <p>Date: Tuesday, June 5th Theme: Compression strength – 6C Room: Santa Maria</p> |
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- 6:45pm 6C 1 **Influence of mortar type in the compressive strength of structural masonry of concrete blocks**
Orieta Soto Izquierdo, Márcio Roberto Silva Corrêa, Indara Soto Izquierdo
- 7:00pm 6C 2 **Investigation on using of mortar as infilling material on clay blockwork**
Marcio Rogerio Nascimento, Francisco Claudio Morato Leite, Humberto Ramos Roman, Roberto Hemckmeier, Marcelo Vieira Santos, Viviany Melchior Albuquerque
- 7:15pm 6C 3 **Numerical simulation of concrete block masonry under compression**
Gihad Mohamad, Paulo Brandão Lourenço, Humberto Ramos Roman, Eduardo – Rizzatti

- 7:30pm 6C 4 **Numerical simulations of masonry laboratory tests: a sensitivity analysis of the compressive behaviour**
Rui Sousa, Hipólito Sousa
- 7:45pm 6C 5 **Strength of masonry prisms with high amounts of supplemental cementitious materials**
Scott M Watterson, Fernando S Fonseca

Date: Tuesday, June 5th

Theme: Seismic - Existing building modeling & evaluation – 6D

Room: Ilha Terceira

- 6:45pm 6D 1 **Finite element analyse for damage of typical masonry school building and anti-seismic strengthening method**
Cui Wei, Qu Wenjun
- 7:00pm 6D 2 **Masonry assessment for the seismic risk evaluation of historic structures**
Camilla Colla, Elena Gabrielli, Giovanni Pascale
- 7:15pm 6D 3 **Observed performance of residential masonry veneer construction in the 2010/2011 canterbury earthquake sequence**
Dmytro Dizhur, Lisa Margaret Moon, Jason M Ingham
- 7:30pm 6D 4 **Proposed technique for seismic vulnerability evaluation of single storey unreinforced masonry residential buildings in developing countries**
Miqdad Khalfan, Michael Tait, Wael El-Dakhakhni
- 7:45pm 6D 5 **Seismic safety assessment of the Church of Monastery of Jerónimos, Portugal**
Paulo B Lourenco, Joao Roque, Daniel V Oliveira

Date: Wednesday, June 6th

Theme: Shear and compression – 7^a

Room: Ilha Terceira

- 10:30am 7A 1 **Reinforced masonry in Europe - state of the art: masonry under compression and shear**
Jan Emil Kubica, Nebojsa Mojsilović
- 10:45am 7A 2 **Shear strength variation due to mortar strength variation and the use of triplets**
A.T. Vermeltfoort
- 11:00am 7A 3 **Shear tests on masonry elements with damp-proof course membrane**
Nebojsa Mojsilovic, Matthias Krucker

- 11:15am 7A 4 **Experimental and numerical analysis of masonry load-bearing walls**
Fabiana Martins de Rezende, Eduardo - Rizzatti, Gihad - Mohamad, Humberto Ramos Roman, Marcos Scherer Bastos
- 11:30am 7A 5 **The effect of mortar bedding type and hollow concrete block geometry on the mechanical behavior of high-strength structural masonry**
Juliana Machado Casali, Alexandre Lima Oliveira, Cintya Sakamoto, Rudiele Schankoski, Luiz Roberto Prudêncio Jr

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| <p>Date: Wednesday, June 6th Theme: Construction process – 7B Room: Graciosa</p> |
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- 10:30am 7B 1 **Masonry walls with bed joint reinforcement - a trial of description of the problem with first preposition of design method**
Jan Emil Kubica
- 10:45am 7B 2 **Development of a resilient polyurethane reinforced masonry wall system**
Carly Forsythe and Wael El-Dakhakhni
- 11:00am 7B 3 **Rationalized masonry sealing with concrete blocks: Professional qualification through of the Construction Community/ABCP**
Alberto Casado Lordsleem Junior, Emanuelle Pontes Falcão
- 11:15am 7B 4 **Pre-sealing concrete blocks & pavers using silicone nanotechnology**
Kebao Ren, Douglas Kagi

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| <p>Date: Wednesday, June 6th Theme: Masonry performance – 7C Room: Flores</p> |
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- 10:30am 7C 1 **Water penetration test on concrete block masonry**
Rolando Ramirez Vilató
- 10:45am 7C 2 **Thermophoresis on external facades: evaluation and origins**
Aécio de Miranda Breitbach, Glêdes Cabral de Albuquerque Viotti
- 11:00am 7C 3 **Quantitative analysis of the waste generated by the execution of ceramic brick masonry in residential buildings in the city of São Carlos**
Felipe Fumachi, Marilu Pereira Serafim Parsekian
- 11:15am 7C 4 **The strength of masonry walls when subject to flood loading**
Daniel Herbet

- 11:30am 7C 5 **The structural evaluation of a novel solution for sustainable masonry construction**
Ian David Molesworth, Peter Walker, Enrico Fodde

Date: Wednesday, June 6th

Theme: Seismic performance and blast loading – 7D

Room: Santa Maria

- 10:30am 7D 1 **Modified compression field theory (MCFT) for shear strength predictions of reinforced masonry shear walls**
Bennet Banting, Wael El-Dakhakhni
- 10:45am 7D 2 **Masonry design for blast loading**
Mostafa ElSayed, Wael El-Dakhakhni
- 11:00am 7D 3 **The effect of one-way arching on enhancing the performance of concrete block walls subjected to blast loading**
Badr Abou-Zeid, Wael El-Dakhakhni, Ghani Razaqpur, Simon Foo
- 11:15am 7D 4 **System-level seismic performance assessment of reinforced concrete block wall buildings, phase I: coupling prevented, torsion allowed**
Paul Heerema, Wael El-Dakhakhni
- 11:30am 7D 5 **UngROUTED cell inspection tool for masonry walls**
Amr Nassr, Marwan Shedid, Wael EL-Dakhakhni

Pôsters

- 1 - ***Structural performance of masonry walls made of ceramic blocks produced from the mixture of red mud with clay***
Diogo Henrique Pereira Costa, Sandro Roberto Santos Trindade, Alcebiades Negrão Macêdo, Ronaldson José França Mendes Carneiro, Dênio Ramam Carvalho Oliveira
- 2 - ***Analysis of the resistance of prisms and ceramic structural masonry small walls for different types of mortars***
Mauro Friederich Santos, Marcus Friederich Santos, Eduardo – Rizzatti
- 3 - ***Mat foundations for buildings up to five pavements in structural masonry***
Melina Baruki Haack, Augusto Guimarães Pedreira Freitas
- 4 - ***Limit plastic analysis of a structural concrete block wall***
Márcio Augusto Roma Buzar, Marcos Henrique Ritter de Gregorio

Keynotes

MASONRY ENGINEERING IN BRAZIL

PAST DEVELOPMENT, CURRENT OVERVIEW, FUTURE IMPROVEMENTS

Corrêa, Márcio R. S.

PhD, A. Professor, University of São Paulo, São Carlos Engineering School, Structural Engineering Department, mcorrea@sc.usp.br

This paper presents an overview of the use of masonry in Brazil. Some historical remarks are presented showing how masonry was introduced and has been developed in the country. A brief on the Brazilian Universities is also reviewed, showing the extensive efforts made to improve the educational system and to insert Brazil into the international masonry research environment. Current materials are shown, focusing on the use of structural and non-structural masonry. The paper points out the development of Codes, considering the most important regulated characteristics of masonry in order to be used in Brazilian constructions. The building situation is addressed, stressing the large housing demands and how the masonry industry can help to partly solve the problem. Finally, present and future challenges are discussed, showing Brazil's constructions needs, as an emerging country.

Keywords: *masonry, Brazil, past, current, future.*

MASONRY ENGINEERING IN THE UK

PAST DEVELOPMENT, CURRENT OVERVIEW AND FUTURE

Barry Haseltine¹

¹MBE FREng Consulting engineer, Jenkins and Potter London

The paper gives a brief history of the use of masonry, mainly clay brickwork and stonework, for historic buildings in the UK. The development of a modern Code of Practice is described, leading to BS 5628: Parts 1 (1978), 2 (1985) and 3 (1985). The development and use of reinforced masonry is covered, as is the need for sensible rules to ensure that correct materials and workmanship are used. The development of new materials and methods is mentioned. The result of the European Union succeeding in changing National European Codes of Practice into Eurocodes has made a profound difference for designers and the Eurocodes are described. Finally the future use of masonry in the UK is discussed.

Keywords: *Clay brickwork, concrete blockwork, stonework, Codes of Practice, Eurocodes.*

MASONRY ENGINEERING IN CANADA

PAST, CURRENT, AND FUTURE DEVELOPMENTS

Robert G. Drysdale , Ph.D., P.Eng., FCAE

Professor Emeritus, Department of Civil Engineering, McMaster University, Hamilton, Ontario,
drysdale@mcmaster.ca

This paper provides an opportunity to formulate a statement of the current status of masonry engineering in Canada with some perspective from the past and some insight into potential for the future. Notwithstanding the fact that this represents the view of the author only, an attempt is made to provide a balanced and comprehensive overview. When we talk about masonry in Canada, by far the largest part of clay brick production and most of the concrete block used are employed in buildings based on the very simple to apply provisions of Part 9 of the National Building Code that applies to small buildings and is not “engineered” through any proper analysis and does not require the participation of a licensed structural engineer. However, growth potential is greatest in the area of engineered masonry.

This paper provides information on education, research, development of codes and standards, and the general state of masonry engineering in Canada. Problems facing masonry in terms of maintaining or expanding market share of construction, areas requiring most attention, and opportunities for enhancement of masonry are discussed.

Keywords: *Canada, codes, construction, design, masonry, materials, standards.*

MASONRY ENGINEERING IN THE UNITED STATES OF AMERICA

PAST DEVELOPMENT, CURRENT OVERVIEW, FUTURE IMPROVEMENTS

Klingner, Richard E.

PhD, Professor, University of Texas, Austin, Texas, USA, klingner@mail.utexas.edu

In this paper, the process used to develop building codes in the United States of America (USA) is summarized, with emphasis on masonry. Masonry materials used in the USA are discussed. Types of masonry construction in the USA are reviewed, addressing historical as well as modern masonry. Current non-structural and structural applications of masonry in the USA are reviewed. Historical development of masonry codes in the USA is summarized, with emphasis on the current Masonry Standards Joint Committee (MSJC) *Code and Specification*. Future trends in that document are predicted. The paper closes with a list of challenges to the masonry industry, and a list of focused research topics intended to meet those challenges.

Keywords: *masonry, United States of America, USA, past, current, future.*

MASONRY ENGINEERING IN AUSTRALIA

PAST DEVELOPMENT, CURRENT OVERVIEW, FUTURE IMPROVEMENTS

Page, Adrian

Emeritus Professor, School of Engineering, The University of Newcastle, Australia,
adrian.page@newcastle.edu.

Masonry is a construction material which is widely used in Australia in a number of forms (fired clay, concrete, calcium silicate, natural stone, autoclaved aerated concrete) and in a wide range of both loadbearing and non-loadbearing applications. As such, it serves as the primary structural element in structures such as 3-4 story “walk up” apartment buildings or low rise commercial structures, or as a veneer or infill in housing or high rise framed construction. Despite its current widespread use, for masonry to remain a viable construction material in the future, design and construction practices need to be flexible, able to adapt to change and be receptive to innovation. This applies not only to advances in materials technology and the development of new products and building systems, but also an effective response to changes in the regulatory framework which have an increasing emphasis on thermal and acoustic performance, seismic resistance and sustainable practices. In this context, an overview of the Australian past, present and possible future masonry scene is given.

Keywords: *masonry, Australia, past, current, future.*

CURRENT PERSPECTIVES ON CONSERVATION OF HERITAGE MASONRY IN CANADA

Shrive, Nigel

D.Phil, Professor, University of Calgary, Civil Engineering Department, ngshrive@ucalgary.ca

Canada is a young country with respect to its built heritage. The need to conserve examples of its structures as a record of the history of settlement and growth has been recognized for some time by the somewhat small conservation community. The heritage conservation sector is growing compared to new construction. Unfortunately, there is a distinct lack of professional expertise (architects and engineers) familiar with the older traditional construction methods and even less knowledge with respect to understanding how modern interventions will affect the construction supposedly being conserved. The need for education in conservation principles and methodology is discussed. Two new programs are described, one at the undergraduate level at Carleton University, and the other at the graduate level at the University of Calgary, both of these programs are being developed with advice from the Heritage Conservation Directorate of Public Works and Government Services Canada. The potentially negative consequences of the current lack of expertise for heritage structures are compounded by the current system for deciding whether or not a structure has heritage value. The system is inconsistent across the country, depending on how the guidelines interpreted and enforced. The federal and provincial and some municipal governments have collaborated in establishing guidelines for their areas of responsibility, however there is no overarching regulation for the protection of heritage across the country.

Keywords: *Heritage, Conservation.*

PERFORMANCE OF EARTHQUAKE STRENGTHENED URM BUILDINGS IN THE 2010/2011 CHRISTCHURCH EARTHQUAKE SEQUENCE

Ingham, Jason M¹; Dizhur, Dmytro²; Moon, Lisa M³; Griffith, Michael C⁴

¹ PhD, Associate Professor, University of Auckland, Department of Civil and Environmental Engineering,
j.ingham@auckland.ac.nz

² PhD Candidate, University of Auckland, Department of Civil and Environmental Engineering,
ddiz001@aucklanduni.ac.nz

³ PhD Candidate, University of Adelaide, Civil, Environmental and Mining Engineering Department,
lmoon@civeng.adelaide.edu.au

⁴ PhD, Professor, University of Adelaide, Civil, Environmental and Mining Engineering Department,
mcgrif@civeng.adelaide.edu.au

Following the 22 February 2011 Christchurch earthquake a comprehensive damage survey of the unreinforced masonry (URM) building stock of Christchurch city, New Zealand was undertaken. Because of the large number of aftershocks associated with both the 2011 Christchurch earthquake and the earlier 4 September 2010 Darfield earthquake, and the close proximity of their epicentres to Christchurch city, this earthquake sequence presented a unique opportunity to assess the performance of URM buildings and the various strengthening methods used in New Zealand to increase the performance of these buildings in earthquakes. Because of the extent of data that was collected, a decision was made to initially focus exclusively on the earthquake performance of URM buildings located in the central business district (CBD) of Christchurch city. The main objectives of the data collection exercise were to document building characteristics and any seismic strengthening methods encountered, and correlate these attributes with observed earthquake damage. In total 370 URM buildings in the CBD were surveyed. Of the surveyed buildings, 62% of all URM buildings had received some form of earthquake strengthening and there was clear evidence that installed earthquake strengthening techniques in general had led to reduced damage levels. The procedure used to collect and process information associated with earthquake damage, general analysis and interpretation of the available survey data for the 370 URM buildings, the performance of earthquake strengthening techniques, and the influence of earthquake strengthening levels on observed damage are reported within.

Keywords: *unreinforced masonry, earthquake strengthening, 2010 Darfield earthquake, 2011 Christchurch earthquake, Christchurch earthquake CBD survey.*

SUSTAINABILITY: MASONRY'S CORNER STONE OR STUMBLING BLOCK?

Borchelt, J. Gregg¹

¹ President and CEO, Brick Industry Association, United States of America, borchelt@bia.org

Sustainability has become an essential part of the construction industry within the last decade. Manufacturers have changed products and production methods in response to this clarion call. Masonry materials exhibit many attributes that make them excellent choices based on sustainability criteria. These are expounded on by masonry material manufacturers and their associations, but do they match the opinions of others in the construction industry? A review of current statements and publications from masonry material manufacturers' websites provides an idea of what the masonry industry thinks of the sustainability of its products. In addition, websites of national associations representing masonry materials were examined to determine how the masonry industry is responding to the desire for more sustainable materials and buildings. Authors of papers at the World Sustainable Building Conference (SB11 Helsinki) provide access to their viewpoint of masonry as a sustainable material. This third-party collection represents how other members of the design and building industry view masonry. Those two viewpoints do not always coincide. The masonry industry faces several challenges to maintain its preeminence as the provider of sustainable materials.

Keywords: *sustainable, masonry, opinions, challenges.*

Articles

COMPOSITE LOAD BEARING BEHAVIOUR OF UNREINFORCED AND REINFORCED WALL CONSTRUCTIONS MADE OF CLAY UNITS FILLED WITH STANDARD CONCRETE

Graubohm, Markus¹; Schmidt, Ulf²; Hannawald, Joachim³; Brameshuber, Wolfgang⁴

¹ Dipl.-Ing., Institute of Building Materials Research (ibac), RWTH Aachen University, Germany, graubohm@ibac.rwth-aachen.de

² Dipl.-Ing., Materialprüfungs- und Versuchsanstalt Neuwied, Germany, schmidt@mpva.de

³ Ph.D., Institute of Building Materials Research (ibac), RWTH Aachen University, Germany, hannawald@ibac.rwth-aachen.de

⁴ Professor, Ph.D., Institute of Building Materials Research (ibac), RWTH Aachen University, Germany, brameshuber@ibac.rwth-aachen.de

Masonry walls which are exposed to wind loads or earthquake action must have a sufficient shear strength, and, if necessary, also flexural strength in the direction of the shear walls. Recently, the required safety against structural failure due to wind loads or earthquake action has been tightened in the European and German standards. Consequently, the verification of sufficient load bearing capacity is only possible if a larger shear strength can be taken into account.

The massive type of construction consisting of clay units filled with concrete is in Germany presently mainly used for the manufacturing of walls with a high density and hence with good sound insulation properties. Since neither compressive nor shear strength play a major role in this context, this construction method has so far only been admitted for use in Germany either as masonry made of clay units filled with standard concrete (in this case only the unit cross section may be applied for load transfer) or as clay formwork units for unreinforced or reinforced concrete columns (here only the concrete cross section may be taken into account). Up to now, according to the German standards DIN 1053-1 and DIN 1045-1 as well as the National Technical Approvals, the considerable advantages of a composite system consisting of concrete and clay unit may not be taken into account for the structural analysis of masonry because the required basic investigations have been missing so far.

It was the aim of this research project to develop a model for the compressive and shear design of walls made of clay units filled with unreinforced standard concrete and clay formwork units with and without reinforcement. In doing so, the concrete cross sections and the clay unit cross sections should be considered as composite section. To determine the load bearing capacity of the composite system, extensive experimental tests and numerical calculations on the basis of Finite Element Methods were performed.

Keywords: *Masonry, composite system, filled clay units, clay formwork units, Finite Element Method.*

CLAY BLOCK PRISMS UNDER COMPRESSIVE LOADS: TESTING AND MODELLING

Ramalho, Marcio Antonio¹; Taliercio, Alberto²

¹ Professor, School of Engineering of S.Carlos, University of S.Paulo, ramalho@sc.usp.br

² Professor, Politecnico di Milano, Italy, alberto.taliercio@polimi.it

This paper presents a comparison between the results of experimental and numerical analyses of clay block prisms under compression loads. The main goal of the study is to simulate the nonlinear mechanical response of the prisms, based on the behaviour of blocks and mortar joints, using a numerical non-local damage model specifically developed for quasi-brittle materials. An experimental program, with simple compression tests with displacement control, was carried out to determine the damage parameters for the individual components to characterize the numerical model. Prisms were also tested in simple compression to obtain their complete load-displacement diagrams to failure. Despite the simplicity of the experimental procedure, the obtained results show that the damage model employed is able to predict the strength of the prisms reasonably well, as well as their behaviour in the softening regime.

Keywords: masonry; compression; testing; damage, finite element.

CONTRIBUTION OF MORTAR COVERING ON COMPRESSIVE BEHAVIOR OF NON-LOADBEARING CLAY BRICK SMALL WALLS

**Tavares, Samá de Andrade¹; Sobrinho, Carlos Welligton de A. Pires²; Silva,
Fernando; Artur Nogueira³; Oliveira, Romilde Almeida⁴**

¹ MSc, Technological Institute of Pernambuco, sama@itep.br

² MSc, Professor, State University of Pernambuco, Civil Engineering Department, carlositep@gmail.com

³ DSc, Professor, Catholic University of Pernambuco, Civil Engineering Department, artur@unicap.br

⁴ DSc, Professor, Catholic University of Pernambuco, Civil Engineering Department,
romildealmeida@gmail.com

Resistant masonry is a building technique which main feature is the use non-loadbearing clay or concrete bricks. More than six thousand multi-storey residential buildings were built in Recife Metropolitan Region using such technique and several collapsed spontaneously in last 18 years. Twelve others were demolished because it was not possible to perform retrofit works due to their fragility and a hundred of others buildings does not have conditions to occupation. The paper analyzes the role played by mortar covering on the behavior of small clay walls subjected to compressive loading. Walls made with several types, mixes and thickness of mortar covering were studied in order one could formulate the understanding of the influence of such factors. Additionally, the effect of using welded meshes anchored with steel connectors embedded in the

mortar coating was also studied. Tests were performed in a servo-controlled machine to make possible to capture the complete behavior of the specimen during all loading process, including post-peak behavior. Obtained results showed a trend in increasing loading capacity of tested walls with the increase of mortar quality and thickness. It was also observed changes on the overall behavior of the walls when tested with welded meshes embedded in the mortar coating.

Keywords: *Non-loadbearing walls, retrofit in masonry, compressive behaviour of small walls.*

EXAMINATION OF THE PRESCRIBED CONCRETE BLOCK MASONRY COMPRESSIVE STRENGTHS IN THE CANADIAN MASONRY DESIGN STANDARD, CSA S304.1- 2004

Gayed, Mina¹; Korany, Yasser²; Sturgeon, Gary³

¹ B.Sc., Graduate Researching and Teaching Assistant, University of Alberta, Department of Civil and Environmental Engineering, mina.gayed@ualberta.ca

² PhD, Associate Professor of Structural Engineering and MCAA Chair in Masonry Systems, University of Alberta, Department of Civil and Environmental Engineering, yasser.korany@ualberta.ca

³ M.Sc., Consultant and Technical Services Engineer, Canadian Concrete Masonry Producers Association, bbstek@telus.net

The current Canadian masonry design standard, CSA S304.1-04, provides two approaches to determine a compressive strength (f'_m) for the design of masonry members: testing prisms with site representative materials or using prescribed values based on unit compressive strength and mortar type. Design engineers typically use the latter method since it is a more convenient and economical approach. However, there is ample evidence that prescribed values are significantly lower than strength values measured from prism testing. The research used to develop the current prescribed values was carried out decades back. Much has changed since then such as the quality of unit manufacturing, properties of units and mortar, and construction practices. The recalibration of the correlation between unit strength and prism strength is necessary to realize the full potential strength of masonry, and to deliver cost-effective masonry design.

One hundred hollow concrete masonry prisms were constructed and tested at the University of Alberta in Canada to examine the relationship between unit strength and prism strength. Concrete masonry units having nominal compressive strength values from 10 MPa – 40 MPa were used. All prisms were three courses in height, and built of standard 200 mm hollow concrete blocks in a stack bond pattern according to CSA S304.1-04 using either type S or type N mortar. Both masonry cement and Portland cement lime mortars were used. The test results revealed significant conservatism in the current prescribed strength values. The measured specified masonry compressive strength values were found to be 15% – 69% higher than the prescribed values.

Keywords: *Hollow masonry prisms, masonry design strength, Canadian design standard, prescribed strength values, masonry mortars, concrete block.*

PERMISSIBLE STRESS LEVEL OF BRICK MASONRY UNDER COMPRESSIVE CYCLIC LOADING

Alshebani, Milad¹

¹ PhD, Professor, Department of Civil Engineering, Tripoli University, Tripoli – Libya,
milad53@hotmail.com

Laboratory tests revealed that the behavior of brick masonry under compressive cyclic loading is characterized by three distinct stress-strain curves. These three curves are termed as envelope curve, common point curve and stability point curve. The envelope curve is obtained by superimposing the cyclic peaks on the monotonic stress-strain curve. The common point curve is the locus of intersection points of loading and unloading curves of the cycles. If for the same cycle, the loading and unloading is repeated several times, the intersection points of loading and unloading paths will stabilize at a lower bound. The locus of these stabilized points (lower bound points) of all cycles form the stability point curve. Therefore, the stability point curve can be used as a measure for the allowable stress for masonry under cyclic loadings. The proposed cyclic allowable stress level is associated with the accumulation of residual (plastic) strain levels as a result of cyclic loading history. The permissible stress level was found to be about two thirds of the cyclic peak stress of the specimen.

Keywords: *cyclic, permissible stress, residual strain, stability point.*

A STUDY OF WALL SURFACE TEMPERATURE VARIATIONS FOR HOUSING IN MODERATE CLIMATES

Alterman, Dariusz¹; Page, Adrian²; Hands, Stuart³; Moffiet, Trevor⁴; Moghtaderi, Behdad⁵

¹ PhD, Research Fellow, The University of Newcastle, Priority Research Centre For Energy,
dariusz.alterman@newcastle.edu.au

² PhD, Emeritus Professor, The University of Newcastle, Priority Research Centre For Energy,
adrian.page@newcastle.edu.au

³ Research Assistant, The University of Newcastle, Priority Research Centre For Energy,
stuart.hands@newcastle.edu.au

⁴ PhD, Research Associate, The University of Newcastle, Priority Research Centre For Energy,
trevor.moffiet@newcastle.edu.au

⁵ PhD, Professor, The University of Newcastle, Priority Research Centre For Energy,
behdad.moghtaderi@newcastle.edu.au

This paper describes an experimental investigation of internal and external surface temperature variations of heavy and lightweight walling systems under the influence of moderate weather conditions typical of the Australian climate. Four housing test modules incorporating various walling types were built on the University of Newcastle campus and the detailed thermal performance of each system was measured over a range of seasonal conditions. The temperature

gradients for various locations through the thickness of each wall assemblage are examined and discussed. The analysis helps to provide an increased understanding of the dynamic behaviour of various walling systems subjected to real weather conditions, with the preliminary study demonstrating that wall thermal resistance (R.value) is only a steady state parameter which is not capable of representing the thermal performance of lightweight and heavy walling systems as a sole descriptor. The investigations indicate that energy demands for Australian weather conditions are influenced by the combination of the thermal mass and the thermal resistance of the wall components, and both need to be considered if the thermal performance is to be realistically predicted.

Keywords: *thermal performance, thermal mass, thermal resistance, Australian housing.*

DEVELOPMENT OF CERAMIC BLOCKS FOR MASONRY CONSTRUCTIONS WITH THERMAL INSULATION FILLING ON THE BASIS OF EASILY RENEWABLE RAW MATERIALS AND BY-PRODUCTS

Jiri Zach¹; Jiri Brozovsky²; Jitka Hroudova³; Martin Sedlmajer⁴

¹ PhD, Brno University of Technology, Faculty of Civil Engineering, Institute of Technology of Building Materials and Components, zach.j@fce.vutbr.cz

² PhD, Assoc. Professor, Brno University of Technology, Faculty of Civil Engineering, Institute of Technology of Building Materials and Components, brozovsky.j@fce.vutbr.cz

³ Ing, Brno University of Technology, Faculty of Civil Engineering, Institute of Technology of Building Materials and Components, hroudova.j@fce.vutbr.cz

⁴ PhD, Brno University of Technology, Faculty of Civil Engineering, Institute of Technology of Building Materials and Components, sedlmajer.m@fce.vutbr.cs

At present the requirements for building materials have been growing in the sphere of their thermal-insulation and acoustic properties. In case of ceramic blocks the ways to further improvement of its insulation properties are quite limited. It is reduction of ribbon thickness or increase of width of masonry construction. Use of insulation filling integrated in ceramics block cavities is an alternative technology of production of insulation masonry blocks of high insulation properties. In these cases the ceramic frame ensures the mechanical stability of the block and integrated insulation layer in smaller or bigger part (depending on its part) the thermal properties and eventually also the acoustic and insulation ones. The paper describes possibilities of use of raw materials alternative sources (natural fibres from agriculture, selected fabric waste, ...) as integrated insulation layers in modern ceramic blocks of high performance properties.

Keywords: *masonry, ceramics block, thermal insulation, thermal insulating properties, acoustic insulation properties.*

EVALUATION OF DAMAGE EVOLUTION IN MASONRY DUE TO ENVIRONMENTAL PARAMETERS AND SALT CAPILLARY RISE

Gabrielli, Elena¹; Grüner, Friedrich²; Colla, Camilla³

¹ PhD student, University of Bologna (Italy), DICAM, elena.gabrielli4@unibo.it

² Dr. rer. nat., University of Stuttgart (Germany), MPA, friedrich.gruener@mpa.uni-stuttgart.de

³ Associate Professor, University of Bologna (Italy), DICAM, camilla.colla@unibo.it

Masonry constructions, historically used all over the world, largely show the effects of environmental decay in their structure and materials. Accurate studies on the causes of damage and on the consequences on physical, chemical and mechanical properties of masonry are still required. In the frame of the 7FP EU project SMooHS, a laboratory research is conducted aimed at provoking the damage, evaluating its evolution in brick walls and at establishing a correlation between environmental decay and loss of load-bearing capacity of masonry. Thus, two large specimens made of bricks and lime mortar have been built and placed outside the lab to address environmental degradation, in addition to brine capillary suction, using different salt solutions (sodium chloride and sodium sulphate). The decay effects on the two walls have been compared. The monitored climatic parameters (air T, RH, rainfall) have been used for determining the number of possible salt crystallization/hydration cycles occurred and, thus, to estimate the inner decay of the structure. In parallel, the masonry component materials have been physically and chemically characterized. Sonic tests in superficial transmission mode have been repeated after 2 seasons of aging, in order to estimate the decay history on the masonry materials.

Keywords: *Masonry, damage evolution, physical-chemical analyses.*

IMPROVEMENT THE THERMAL RESISTANCE OF LOAD- BEARING PERFORATED FIRED-CLAY BRICKWORK

Zoubair Lafhaj¹; Christophe Chapiseau²; Fayçal El Fgaier^{1,2}; Ibrahim Lemniei²

¹ Ecole Centrale de Lille, Laboratoire de Mécanique de Lille (CNRS UMR 8107), Villeneuve d'Ascq, 59651 Cedex, France

² Briqueteries du Nord, 9ème Rue, Port Fluvial, Lille, 59003 Cedex, France

The primary objective of this study was to improve the thermal resistance of perforated brickwork. The bricks, measuring 220 x 220 x 65 mm³ and used in load-bearing masonry, are produced by Briqueteries du Nord (BdN) located in northern France.

The study focus was twofold: first, modifying the perforation configuration of the brick to reduce thermal bridges, and second, inserting insulating material into the perforations. Two types of insulating materials were analyzed in this regard: perlite and cork. Three different binders were also studied for their performance in holding these materials in the perforations: grey cement 52.5, Baticem mortar 12.5 and lime.

A detailed experimental study was conducted in relation to this article with a view to identifying the insulator/binder combination with optimal thermal properties. Baticem mortar exhibited the highest thermal performance of the binders studied. Finally, a numerical simulation was carried out to study the effect of insulator quantity and thermal conductivity as well as perforation size on the thermal resistance of bricks.

Keywords: *Perforated brick, thermal resistance, perlite, binder.*

THEORETICAL ANALYSIS OF THERMAL PERFORMANCE OF CLAY AND CONCRETE MASONRY STRUCTURAL UNDER VARIOUS CONDITIONS

**Grabarz, Regina Candeloro¹; Souza, Léa Cristina Lucas²; Parsekian, Guilherme
Aris³**

¹ MSc Candidate, Federal University of São Carlos, Civil Construction Graduated Program,
regina.cg@hotmail.com

² PhD, Professor, Federal University of São Carlos, Civil Engineering Department, leacrist@ufscar.br

³ PhD, Professor, Federal University of São Carlos, Civil Engineering Department, parsekian@ufscar.br

Currently, masonry construction system has been widely used in Brazilian housing construction as it offers significant advantages in relation to building execution time consumption and costs. Considering the wide use of this system, it is important to assess whether the commonly wall thickness, material and rendering meets the levels of minimum thermal comfort required by the Brazilian performance codes. Analyzing the thermal performance of concrete and clay structural masonry walls, the thermal properties of these systems were calculated and its adequacy for different bioclimatic zones in Brazil has been verified. The results indicate that the structural clay masonry has better performance than the concrete masonry when compared to uncoated internal and external walls. As a conclusion, it is pointed out the regions in which clay and concrete masonry walls built in accordance to the common construction standards are thermically adequated.

Keywords: *Low-Income Housing, Structural Masonry, Thermal Performance.*

BEHAVIOUR OF MILLSTONE MASONRY VAULTS STRENGTHENED BY COMPOSITE MATERIALS

M. Saade¹, S. Kesteloot², C. Djelal³, L. Hamitouche⁴, I. Benslimane⁵

¹ PhD, Student, University of Artois, Civil Engineering Department, m.saade@structure-rehabilitation.fr

² PhD, Assistant Professor, University of Artois, Civil Engineering Department, stephan.kesteloot@univ-artois.fr

³ PhD, Research Engineer, Structure & Rehabilitation, chafika.dantec@univ-artois.fr

⁴ PhD, Research Engineer, Structure & Rehabilitation, l.hamitouche@structure-rehabilitation.fr

⁵ PhD, CEO, Structure & Rehabilitation, idriss.benslimane@structure-rehabilitation.fr

Sewerage systems first appeared in Paris in the middle of the 19th century; they are oval-shaped and made of masonry. For 15 years, the building of new structures has given way to a new era of rehabilitation of these sometimes dilapidated structures. Even if the majority of structures are still in working order, their general state will deteriorate inexorably, and as reconstruction is not always possible for cost and social impact reasons, rehabilitation is a solution adopted by many clients. It is necessary to resort to new rehabilitation techniques. In recent years, new materials have emerged such as high performance fiber-reinforced mortar and new techniques such as the bonding of composite materials. Reinforcement by bonding composite materials has many advantages compared to other techniques (shotcrete, precast components etc.).

The objective of the experimental campaign presented in this paper is to study the addition of a lining by means of mortar reinforced by thin composite material so as to restore masonry structures (sewerage systems). To that purpose, crushing tests on masonry vaults have been carried out. The application of a lining made of mortar reinforced with composite materials has allowed to increase the breaking load and delay the occurrence of the first cracks. The big advantage of this type of lining compared to a traditional type of strengthening, such as a reinforced shotcrete lining, is the considerable gain in terms of sustainability, rehabilitation and preservation of the hydraulic capacity of the structure.

This article presents the characterization of the materials. Moreover, the results of the breaking tests applied to masonry vaults are shown in this paper. A comparison with a traditional type of rehabilitation by a 6 cm-thick shotcrete lining will be performed.

Keywords: *composite materials, masonry, fiber coating, sustainability, rehabilitation, sewerage systems.*

CONSTRUCTION PROCESS NUMERICAL SIMULATION AND SEISMIC ASSESSMENT OF MALLORCA CATHEDRAL

Roca, Pere¹; Pelà, Luca²; Cervera, Miguel³; Clemente, Roberto⁴

¹ PhD, Professor, Technical University of Catalonia (UPC), EC Department, pere.roca.fabregat@upc.edu

² PhD, Lecturer, Technical University of Catalonia (UPC), EC Department, luca.pela@upc.edu

³ PhD, Professor, Technical University of Catalonia (UPC), RMEE Department, miguel.cervera@upc.edu

⁴ PhD, Researcher, Technical University of Catalonia (UPC), CIMNE, clemente@cimne.upc.edu

This paper presents a numerical study of Mallorca Cathedral carried out by means of a FE approach devised for the study of this complex historical construction. Previous studies, including inspection and historical research, have shown that part of the existing damage and deformation might have been experienced during the construction process itself, while later historical processes causing long-term deformation, may also have contributed significantly to the final deformation.

In order to analyse the possible influence of the construction process and long term deformation on the deformation of the structure, a numerical tool has been developed to carry out sequential-evolutionary analyses, involving the superposition of consecutive construction stages. A constitutive model has been implemented accounting for both viscoelasticity and mechanical damage by means of an enhanced continuum damage model. This tool has been used to carry out the sequential FE analysis of a typical bay structure of the main nave of the building. The proposed numerical tool has been also used to assess the seismic performance of the typical bay, in the transverse direction, through a nonlinear static analysis. The proposed numerical strategy seems effective to describe deformation and damage and could be applied to other similar historical masonry constructions.

Keywords: *Historical Construction, Continuum Model, Long-term Effects, Creep, Seismic Analysis, Localized Damage.*

DISCRETE ELEMENT MODELING OF THE WALLS OF THE PRINCE OF WALES FORT

Isfeld, Andrea Cathleen¹; Shrive, Nigel Graham²

¹ PhD, Student, University of Calgary, Civil Engineering Department, aisfeld@ucalgary.ca

² PhD, Killsm Memorial Professor, University of Calgary, Civil Engineering Department, ngshrive@ucalgary.ca

The Prince of Wales Fort, located in Churchill, Manitoba was constructed by the Hudson Bay Trading Company in the early 18th century. This Vauban style, rubble masonry fortification is the most northerly construction of its kind, and was intended to secure the fur trade in northern Canada. In the 1920's the fort received recognition as a National Historic Site by the Historic

Sites and Monuments Board of Canada. At that time, extensive repairs were required to part of the fort and commenced under the supervision of Parks Canada.

The fort's northern latitude has left it vulnerable to extreme temperatures and freeze thaw cycles over the last 250 years, resulting in a gradual breakdown and washout of the mortar within the escarp walls. Consequently, the walls currently exist as a partially-grouted rubble core, encased with ashlar face stones. The deteriorating core conditions have caused the walls to bulge outwards significantly in several areas and fail in others: an extensive restoration project is currently underway.

In order to understand the current conditions of the wall core, the wall has been modeled using the software package Logiciel de Mécanique Gérant le Contact (LMGC 90). Five models with simplified geometry of the wall cross-section have been used to determine the values of normal and tangential cohesion necessary to create stability within the wall sections. A relationship between the friction angle and the normal cohesion component required to obtain stability for each of the five models is presented graphically and related to the variations in the modes of failure.

Keywords: *Stone masonry, discrete element modelling, historic structures, analysis.*

STRUCTURAL ASPECTS OF TRADITIONAL CRETAN MASONRY

Glowacki, Kevin Thomas¹; Nichols, John Morgan²; Holland, Nancy Lee³

¹ PhD, Assistant Professor, Texas A&M University, Dept. of Architecture, kglowacki@tamu.edu

² PhD, Associate Professor, Texas A&M University, Dept. of Construction Science, jm-nichols@tamu.edu

³ PhD, Associate Professor, Texas A&M University, Dept. of Construction Science, nholland@tamu.edu

The island of Crete has a long tradition of stone masonry construction, beginning over 8000 years before present. As noted by architectural historians, the vernacular architecture of modern (pre-World War II) villages on Crete has many close parallels with house remains uncovered in the archaeological record of the Minoan Bronze Age (ca. 3000-1050 BCE). Archaeologists have used modern ethnographic comparisons effectively to shed light upon issues ranging from the interpretation of ancient house plans to a better understanding of construction techniques, the use of local resources, and the effects of abandonment processes on the build environment. A full-scale replica of a typical Cretan house from the 12th-11th century BCE (Late Minoan IIIC period) is planned for construction in College Station. The first stage of the building will comprise a single room, ca. 6.20 m by 5.20 m, constructed of stacked limestone with minimal earth mortar, timber ceiling beams and laths, a layer of brush, and topped with a flat clay overlay. The purpose of this paper is to outline the design and structural analysis of the building, and to discuss issues related to construction processes, climate, and ventilation that may apply to both archaeological/historical and modern contexts. Modern interest in this traditional type of building technique stems from the use of limestone blocks in construction practices. This study forms one element of a major study of limestone and its uses.

Keywords: *Cretan masonry, limestone construction, Minoan culture, vernacular architecture.*

CYCLIC IN-PLANE SHEAR BEHAVIOUR OF UNREINFORCED MASONRY WALL PANELS STRENGTHENED WITH NSM FRP STRIPS

Konthesingha, Chaminda¹; Masia, Mark²; Petersen, Robert³; Page, Adrian⁴

¹ PhD candidate, The University of Newcastle, Centre for Infrastructure Performance and Reliability,
Chaminda.Konthesingha@uon.edu.au

² PhD, Senior Lecturer, The University of Newcastle, Centre for Infrastructure Performance and Reliability,
Mark.Masia@newcastle.edu.au

³ PhD, Research Associate, The University of Newcastle, Centre for Infrastructure Performance and
Reliability, Robert.Petersen@newcastle.edu.au

⁴ PhD, Emeritus Professor, The University of Newcastle, Centre for Infrastructure Performance and
Reliability, Adrian.Page@newcastle.edu.au

An experimental study was conducted to assess the effect on strength, displacement capacity and ductility of reinforcing unreinforced masonry (URM) shear panels with near surface mounted (NSM) fibre reinforced polymer (FRP) strips. A total of eight wall panels (2 URM and 6 reinforced) were subjected to vertical pre-compression combined with increasing reversing cycles of in-plane lateral displacement. All of the wall panels had dimensions of 1200mm x 1200mm x 110mm (height x length x thickness). Three different FRP reinforcement schemes were used (two repeat specimens for each scheme). The study revealed that the FRP strengthening was effective in improving the ultimate load resisted by the wall panels (increases of up to 9%), the displacement capacity (133%) and ductility (108%) compared to the URM response. The reinforcing scheme which used a combination of vertical and horizontal FRP strips performed the best overall in terms of improving both the ultimate in-plane shear load resisted by the wall panels and the displacement capacity. The broader aim of the research is to identify techniques for improving the seismic performance of existing URM walls under in-plane shear loading.

Keywords: *Masonry, strengthen/retrofit, cyclic, shear, NSM, FRP.*

IN-SITU TESTING OF BRICK MASONRY WALLS STRENGTHENED WITH CFRP FABRIC

Gostič, Samo¹; Bosiljkov, Vlatko²; Jarc Simonič, Mojca³

¹ PhD, Building and Civil Engineering Institute ZRMK Ljubljana, Slovenia, samo.gostic@gi-zrmk.si

² PhD, Assistant Professor, University of Ljubljana, Faculty of Civ. and Geodetic Engineering,
vlatko.bosiljkov@fgg.uni-lj.si

³ Building and Civil Engineering Institute ZRMK Ljubljana, Slovenia, mojca.jarc-simonic@gi-zrmk.si

New requirements for strengthening buildings of cultural heritage assets, apart from its efficiency demands also reversibility of proposed methods. In this regard, one of the most

promising methods is application of carbon reinforced polymers (CFRP) fabric to the surface of the wall. Within the framework of European FP7 research project PERPETUATE new computation models for masonry and strengthening techniques will be developed. To support validation of models various test on masonry specimens will be performed.

In this article experimental results of in-situ shear tests of strengthened clay brick masonry walls with CFRP fabric will be presented. In load bearing walls with different thickness of 30 cm and 45 cm respectively, positioned within the building dated from around 1935 built with solid bricks in low strength lime-cement mortar, cuts were made to isolate six 100 cm wide and 200 cm high specimens. For the purpose of this study, two configurations of positions of CFRP stripes were compared with unstrengthened specimens: walls with strips of fabric placed on masonry surface in two diagonal directions and walls with strips placed in several horizontal levels providing the confinement effect to masonry brick rows. Specimens were tested by horizontal cyclic loading under the constant vertical load.

Following experimental tests, different failure mechanisms were observed and the contribution of applied CFRP strips to load bearing capacity and ductility has been found to be different depending from failure mechanisms. The advantage of the horizontally applied confinement demonstrated significant increase of both ductility and energy dissipation. The most important conclusion is that the new innovative strengthening approach favourably influence the behaviour of slender wall and that in the design of retrofitted clay masonry buildings the calculation models must check all possible failure mechanisms and not only the shear mechanism.

Keywords: masonry, FRP, strengthening, in-situ test, shear strength, ductility.

RELIABILITY OF UNREINFORCED MASONRY BRACING WALLS

Brehm, Eric¹; Lissel, Shelley L.²

¹ Dr.-Ing., Forensic Engineer, TÜV SÜD, Munich, Germany, eric.brehm@tuev-sued.de

² PhD, Associate Professor, Dept. of Civil Engineering, University of Calgary, sllissel@ucalgary.ca

Bracing walls are essential members in typical masonry structures. However, design checks are only performed rarely in Germany. The reason for this is a paragraph in the German design code DIN 1053-1 which allows for neglecting of this design check. This mentioned paragraph is based on construction methods different from the current state of the art. Additionally, design codes have mostly been calibrated on the basis of experience. Consequently, the provided level of reliability remains unknown.

In this paper, a systematic analysis of the provided level of reliability is conducted. Analytical models for the prediction of the shear capacity of the walls are analyzed and assessed with test data to identify the most realistic model. A complete stochastic model is developed and the reliability of typical bracing walls is determined. The difference between the theoretical level of reliability and the “actual” level of reliability is evaluated taking into account the realistic utilization of the walls. Subsequently, the derived level of reliability is presented and assessed.

Keywords: reliability, masonry, target reliability, probabilistic.

SEISMIC RETROFIT OF PARTIALLY GROUTED CONCRETE MASONRY WALLS WITH POLYMER-CEMENT MORTAR

Kikuchi, Kenji¹; Kuroki, Masayuki²; Nonaka, Hideko³; Eguchi, Tomohiro⁴

¹ PhD, Professor, Oita University, Department of Architectural Engineering, kikuchi@oita-u.ac.jp

² PhD, Assistant Professor, Oita University, Department of Architectural Engineering, mkuroki@oita-u.ac.jp

³ Research Associate, Oita University, Department of Architectural Engineering, hnonaka@oita-u.ac.jp

⁴ Graduate Student, Oita University, Department of Architectural Engineering, v0756015@oita-u.ac.jp

In the 1960s and 1970s, partially grouted concrete masonry buildings were constructed widely in Japan. The buildings have been used for more than 30 years passing through a drastic revision of seismic regulations in 1981. This paper addresses a seismic retrofit for existing partially grouted concrete masonry wall with polymer-cement mortar, PCM, which is an advanced material with high adhesive strength and durability. Four partially grouted masonry wall specimens were constructed first, and then three of them were retrofitted with reinforced PCM overlay applied on one of their surfaces, in which thickness and bar arrangement of the PCM overlay are different. The wall specimens were tested under constant gravity load and alternately repeated lateral forces. Test results demonstrate that the application of reinforced PCM overlay provides higher lateral load carrying capacity to the partially grouted concrete masonry wall. Ultimate shear strength of the masonry wall retrofitted with reinforced PCM overlay could be predicted approximately by employing existing methods for masonry and R/C walls.

Keywords: *partially grouted masonry, seismic retrofit, polymer-cement mortar.*

STRUCTURAL DESIGN OF SUPPLEMENTARY INJECTION ANCHORS INSIDE MASONRY

Gigla, Birger¹

¹ Dr.-Ing., Professor, University of Applied Sciences Lübeck, Germany, gigla@fh-luebeck.de

Supplementary injection anchors are used as a repairing-system inside historic masonry for transferring tensile-forces that cannot be transmitted by the masonry itself or for new connections. They basically consist of a tensile element - usually steel - inserted into a slightly larger borehole and the annulus is grouted with cement. The solid plug of injection material transfers the tensile forces to the masonry. Assuming successful grouting, considerable tensile forces can be transferred at short bond lengths. Supplementary Injection Anchors have been utilised since the 1920s and applied within a core philosophy of minimum intervention.

The field of application extends from the repair of small elements like stone corbels up to the reinforcing of walls and foundations that might require prestressed tendons. In certain practi-cal

situations, e.g. when connecting two shells of masonry, extremely short bond lengths are required. Connections are not only carried out inside masonry structures but also between masonry and reinforced concrete slabs or frameworks.

The paper summarizes the latest development of design recommendations for supplementary injection anchors inside masonry, based on more than 600 tests in laboratory and in situ. Main parameters to obtain the characteristic value of bond strength are compressive strength of grout, grouting technology and capillarity of the surrounding stone. The paper takes aspects of the application inside low strength masonry into special consideration.

Keywords: *Restoration, repair, rehabilitation and refurbishment, injection anchor.*

OUT-OF-PLANE SEISMIC PERFORMANCE OF UNREINFORCED MASONRY WALLS RETROFITTED USING POST-TENSIONING

Ismail, Najif¹; Schultz, Arturo E.²; Ingham, Jason M.³

¹ PhD Student, University of Auckland, Dept. of Civil and Environmental Engg.,
nism009@aucklanduni.ac.nz

² PhD, Prof., University of Minnesota, Dept. of Civil Engg., schul088@umn.edu

³ PhD, Assoc. Prof., University of Auckland, Dept. of Civil and Environmental Engg.,
j.ingham@auckland.ac.nz

The development of equations for a post-tensioning seismic retrofit design of URM walls is discussed and a summary of out-of-plane flexural testing is reported. A total of five (05) full scale unreinforced masonry (URM) walls, of which one was tested as-built and four were seismically retrofitted using post-tensioning, were structurally tested using an out-of-plane air bag rig. The out-of-plane loaded test walls had two different wall configurations that were representative of prevalent seismically deficient URM walls and were constructed using salvaged clay bricks and an ASTM type O mortar. Varying levels of post-tensioning were applied to the test walls using a single mechanically restrained sheathed and greased strand, inserted into a cavity at the centre of each test wall. Several aspects pertaining to the seismic behaviour of post-tensioned URM walls were investigated, including damage patterns, force-displacement behaviour, tendon stress variation, hysteretic energy dissipation, toughness, and initial stiffness. Finally, measured response was compared to calculated values and the proposed design equations were validated.

Keywords: *seismic, performance, masonry, retrofitting, post-tensioning.*

THE NEW ITALIAN GUIDE LINES FOR FRP STRENGTHENING OF MASONRY AND TIMBER STRUCTURES

Benedetti, Andrea¹; Sacco, Elio²;

¹ PhD, Professor, University of Bologna, DICAM Department, andrea.benedetti@unibo.it

² PhD, Professor, University of Cassino, DIMSAT Department, sacco@unicas.it

In year 2004 the National Research Council of Italy published the first English version of the well-known DT 200 guidelines “Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Existing Structures”. The document was based on the collaboration of more than twenty Italian professors working on monuments, structural strengthening, seismic protection, new materials and theoretical mechanics.

Seven years later, the basic ideas of the scientific community on the mechanics of FRP debonding are well diffused and settled, but many new application systems and techniques have displaced the boundary of the real world far from our basic knowledge.

In the meanwhile, a lot of experiments lead us to gather a tremendous set of data which are of very difficult comparison due to the variety of the construction materials and testing procedures even in Europe only. Although the code calibration based over a consistent database of such experiments is far to come, the actual picture shows that the most part of the European guidelines (Bulletin 14 of Fib among the others), and the Italian ones in particular, gave rise to robust applications, with sensible safety margins.

In the paper, some proposed modification to the DT 200-2004 document and the underlying experimental database used for revision of masonry clauses are presented. Finally some comments are added in order to present the interaction of technical documents with a complex haotic reality such the one of L’Aquila city after the 2009, April 6th earthquake.

Keywords: masonry, strengthening, FRP, guidelines, seismic mitigation.

ANALYSIS OF INFLUENCING FACTORS ON COMPOSITE ACTION FOR REINFORCED GROUTED CONCRETE BLOCK WALL-BEAM

Zhai, Ximei¹; Guo, Yanfeng²; Gao, Song³

¹ PhD, Professor, Harbin Institute of Technology, China, School of Civil Engineering, xmzhai@hit.edu.cn

² Postgraduate, Harbin Institute of Technology, China, School of Civil Engineering, 85195962@qq.com

³ Postgraduate, Harbin Institute of Technology, China, School of Civil Engineering, gaosong66@gmail.com

The nonlinear Finite Element Analysis (FEA) program ANSYS is adopted to research the mechanical behaviors of wall-beam made of reinforced grouted concrete block masonry wall and reinforced concrete (RC) supporting beam. Based on the verified simulating means by

comparison between test and simulation results of six reinforced grouted concrete block wall-beams, an extensive parametric study is conducted to analyze the effect of principal factors on bearing capacity for the reinforced concrete block wall-beam, including the material strength of grouted block masonry wall, the size and position of the wall opening, the height, the span and the reinforcement ratio of longitudinal steel for the RC supporting beam, the rebar ratio of the grouted wall. The results show that block masonry wall and cast-in-place RC supporting beam work together by core columns with vertical reinforcement, and the reinforced block wall-beam acts like a RC deep beam. The compressive strength of grouted block masonry wall, span and the reinforcement ratio of longitudinal steel of the RC supporting beam are main influence factors of bearing capacity for wall-beam. The opening can weaken the arch action and change the arch transfer path which leads to the reduction of its capacity. For the simply-supported supporting beam, the depth-to-span ratio can be reduced to at least 1/14.

Keywords: concrete block, wall-beam, reinforced masonry, bearing capacity, finite element analysis.

DEVELOPMENT OF RELIABILITY ASSESSMENT SOFTWARE FOR EXISTING MASONRY BUILDINGS SUPPORTED BY REINFORCED CONCRETE FRAMES

Gu, Xianglin¹; Sun, Dongjie²; Sun, Kai³; Peng, Bin⁴

¹ PhD, Professor, Tongji University, Department of Building Engineering, gxl@tongji.edu.cn

²Post Graduate Student, Tongji University, Department of Building Engineering, sundongjie@hotmail.com

³ Master, Tongrui Civil Engineering Technology Company, sunkai@reases.com.cn

⁴ PhD, Associate Professor, University of Shanghai for Science and Technology, School of Environment and Architecture, binpeng@usst.edu.cn

A Masonry Assessment software Package (MAP) with three modules of pre-processing, core analyzing, and post-processing was developed based on the characteristics of the masonry building structures supported by reinforced concrete frames. The software can be used to calculate the internal forces, bearing capacity, deformation and cracking width of masonry walls, beams, columns in an existing building considering the interaction between the masonry structure and the supported reinforced concrete frame structure. Based on the calculation and the inspection results, the reliability grades of both elements and the structure in the building can be assessed automatically, and finally the assessment report text and graphic display contents can be output. Through the application of the software for the reliability assessment of an existing building structure, the software was verified and the results showed that the software is applicable for the reliability assessment of existing masonry buildings supported by reinforced concrete frames and it is a convenient assistant tool for engineers. In this paper, the details of development technology, application and verification for the software are introduced.

Keywords: Masonry structure, frame, reliability, software, existing buildings.

MACRO MODELING OF THE ARCH EFFECT: A PARAMETRIC STUDY

Moraes, Rafael Santos de¹; Serafim, Jorge Augusto²; Parsekian, Guilherme Aris³

¹ Civil Engineering, MSc. Candidate, Federal University of São Carlos, Civil Engineering Department, ra-moraes@ufscar.br

² Civil Engineering, MSc. Candidate, Federal University of São Carlos, Civil Engineering Department, jaserafim@ufscar.br

³ PhD, Professor, Federal University of São Carlos, Civil Engineering Department, parsekian@ufscar.br

The early studies about arch effect on masonry were carried out in the 50's period when methods for determination of stresses in the masonry and supporting beam were developed. Most of them used steel beams and columns, with few examples on reinforced concrete as common nowadays. These methods take into account parameters as inertia of the beam, span, modulus of elasticity and the geometry of the wall. The evaluation of this effect through analytical and graphical methods makes the determination of these stresses in this system arduous and still permitting doubt to arise due to the divergence of results between them. Nowadays, with the availability of computational programs of structural analysis this task tends to be less arduous and more precise. For this purpose, this paper has the aim of modelling, using a FE software, some masonry walls laid on the concrete beams for evaluation of arch effect, investigating the influence of variable beam cross section, span and the resistance of the structural block employed and compare obtained results in these modeling with the values determined through analytical methods. From the results, it was noticed that the method proposed by Stafford-Smith and Pradolin (1983) presented good results for reinforced concrete beams in comparison with the model in finite elements.

Keywords: *Arch effect, Structural masonry, Numerical modeling.*

THE EFFECT OF THE POSITION OF THE SUPPORTS ON THE BEHAVIOUR OF COMPOSITE MASONRY WALLS

Martens, D.R.W.¹; Vermeltfoort, A.T.²

¹ Professor, Eindhoven University of Technology, Department of Architecture Building and Planning, d.r.w.martens@tue.nl

² PhD, Associated Professor, Eindhoven University of Technology, Department of Architecture Building and Planning, a.t.vermeltfoort@tue.nl

Many buildings are designed with large open spaces at the ground floor, while at higher storeys the floor plan is split up in smaller rooms by walls. When these separation walls are load bearing masonry walls, the vertical loads have to be transferred into the columns on the ground floor via a floor-beam structure. If the interface between the wall and the concrete structure exhibits sufficient bonding composite action will occur.

The literature review and numerical simulations described in this paper show that the position of the supports is important for the load bearing capacity of the point supported masonry walls. In order to investigate this effect, experiments were conducted on twelve identical walls, made on a scale of 1:5 from calcium silicate units. The load was applied with a water filled hose to obtain an equally distributed load. The position and the width of the supports were varied and the strain distribution near the supports was measured in detail. In the experiments shear failure became more critical in cases with larger cantilevers. Results from the numerical simulations and experiments will be used to develop design guidelines.

Keywords: *Deep beam, water filled hose, composite action, shear, arching action.*

PRACTICAL ASPECTS OF TESTING COMPOSITE ACTION IN MASONRY WALLS

Vermeltfoort, A.T.¹

¹ PhD, Ass. Prof., Eindhoven University of Technology, Dept. of the Built Environment,
a.t.vermeltfoort@tue.nl

In the past decade, over 100 masonry walls were experimentally tested in the laboratory of Eindhoven University of Technology to investigate composite action between concrete lintels and masonry. Most of them were in plane loaded to failure. A few test-walls were heated and others were loaded for a considerable time to investigate creep behaviour. In all these tests the detailing of the support conditions and load introduction were of importance, as well as measurements of loads, deflections and strains. This paper describes the experiences with different methods to apply load, to support masonry walls and to heat masonry. Alternatives based on the experiences with the performed masonry wall tests are discussed and compared. For some cases suggestions for practical improvements are given. The ideas described in this paper can be helpful for the design of new experiments.

Keywords: *Load-cell, water filled hose, measuring instruments, composite action.*

A MIX DESIGN METHODOLOGY FOR CONCRETE BLOCK UNITS

Frasson Jr., Artêmio¹; Casali, Juliana Machado²; Oliveira, Alexandre Lima³; Prudêncio Jr., Luiz Roberto⁴

¹ Master, Federal University of Santa Catarina, Civil Engineering Department

² PhD, Professor, Federal Technological University of Paraná, Civil Construction Department, casali@utfpr.edu.br

³ PhD, Professor, Federal Technological Institute of Santa Catarina, alexandre@ifsc.edu.br

⁴ PhD, Professor, Federal University of Santa Catarina, Civil Engineering Department, prudenciouk@hotmail.com

The use of concrete masonry units for high-rise load bearing construction has created a need for concrete block with high compressive strength. To achieve high strength levels, block producers generally define concrete mixtures by a trial and error process. The most common procedure is to produce some trial mixtures possessing different cement content using the equipment available in the block plant and test the strength of blocks. This approach is costly, time consuming and generally leads to expensive solutions for using large amounts of cement. Besides, it makes difficult to test new combinations of aggregates and admixtures once disturbs very much the plant routine. In this paper is presented a mix design procedure for structural concrete blocks based on laboratory tests. Initially a reference mixture is studied. In this phase it is possible to vary the type and proportion of aggregates, admixtures and water content in order to achieve a suitable face texture with lower energy of compaction. After that, several mixtures are produced varying the cement content and density. Cylindrical specimens was produced with these mixtures and tested in compressive strength. With the results, it is elaborated a mix design chart where the desired compressive strength can be obtained by varying the aggregate/binder ratio and density. The last phase is testing some selected mixtures in actual block machine, determining both density and compressive strength. With the results it is possible to make the final adjustments in the mix proportions. The application of this procedure in a block plant of the south of Brazil led to satisfactory results showing that is possible to forecast of the mechanical resistance of the concrete blocks starting from laboratory studies in cylindrical specimens and also demonstrated the importance of the control of several parameters related to the productive process for the compressive strength of the units.

Keywords: *mix design, concrete block, dry concrete, vibrocompression machines.*

EXPERIENCES AND ANALYSIS ON MASONRY MATERIALS SUBJECTED TO HIGH-TEMPERATURES

Andreini, Marco¹; De Falco, Anna²; Sassu, Mauro³

¹ Msc, University of Pisa, Department of Civil Engineering, marco.andreini@dic.unipi.it

² PhD, Lecturer, University of Pisa, Department of Civil Engineering, a.defalco@ing.unipi.it

³ PhD, Associate Professor, University of Pisa, Department of Civil Engineering, m.sassu@unipi.it

An experimental procedure for tests on specimens made of several materials is performed to detect the mechanical properties depending from temperature. About 200 cylindrical specimens (diameter D=100 mm, height H=200 mm) of several materials (clay, lightweight concrete, aerate autoclaved concrete, mortar) are tested from 20°C to 700°C. The free thermal strain and the decay of axial strength are determined; proposals for the stress-strain curves and the secant modulus of elasticity in function of temperature are illustrated.

The data base from tests are able to calculate the collapse domains (bending moment - axial force - time of exposure to nominal fire) which represent a simple model for the assessment of masonry panel sections subjected to fire action.

Keywords: *Fire action, high-temperatures, masonry behaviour, masonry testing.*

HYGROTHERMAL CHARACTERISTICS OF PUMICE AGGREGATE CONCRETE USED FOR MASONRY WALL BLOCKS

Kus, Hülya

Dr.Eng., Assoc. Professor, Istanbul Technical University, Faculty of Architecture, kushu@itu.edu.tr

In recent years, computer simulation programs have been increasingly utilized for performance analysis of building and its parts. Despite the databases incorporated into the simulation programs, it is sometimes required to have measured data related to material properties in order to get more accurate results and thus to make better interpretations and assessments. In the context of an extensive research, water vapour transmission and hygroscopic moisture adsorption properties of pumice aggregate concrete composite material were measured for such purposes. In this paper, tests are described in detail and the measurement results are presented. Beside careful consideration and long periods of time required for conducting reliable tests, the heterogeneous material characteristics in particular necessitate further tests and analysis on hygrothermal properties.

Keywords: *Hygrothermal characteristics, pumice aggregate concrete, vapour transmission, sorption.*

USE OF NATURAL SISAL FIBRE IN CONCRETE BLOCKS FOR STRUCTURAL MASONRY

Soto, Indara Izquierdo¹; Ramalho, Marcio Antonio²; Izquierdo, Orieta Soto³...

¹ PhD Student, EESC – University of São Paulo, Department of Structural Engineering, indara@sc.usp.br

¹ PhD, Professor, EESC – University of São Paulo, Department of Structural Engineering,
ramalho@sc.usp.br

¹ PhD Student, EESC – University of São Paulo, Department of Structural Engineering, orieta@sc.usp.br

There is great interest in the use of natural fibres as reinforcement to obtain new construction materials due to its low cost, high availability and reduced energy consumption for its production. This paper evaluates the incorporation of sisal fibres of 20 mm and 40 mm in length and volume fraction of 0.5% and 1% for concrete masonry structural blocks, and determines the use of these units to build prisms and mini-walls. Laboratory tests were carried out to characterize the physical properties of the fibre, blocks and mortar, in addition to the axial compression tests of the units, prisms, and mini-walls. The sisal had low apparent density and high water absorption, which is a common feature of such material due to the high incidence of permeable pores. The physical properties of the blocks with and without addition complied with the standard requirements established to validate their use. The axial compression test results showed that the fibre-reinforced mini-walls obtained values very close to or even higher than those obtained for the mini-walls without fibres, demonstrating better performance than the blocks and prisms.

Keywords: Composites, sisal fibre, concrete block, compressive strength.

REPLACEMENT OF PORTLAND CEMENT WITH SUPPLEMENTAL CEMENTITIOUS MATERIALS IN MASONRY GROUT

Fonseca, Fernando S.¹ and Siggard, Kurt²

¹ PhD, S.E. Associate Professor, Brigham Young University, Department of Civil and Environmental Engineering, ffonseca@et.byu.edu

² Director, Concrete Association of California and Nevada, kurt@cmacn.org

A comprehensive testing program was developed to determine the viability of replacing high amounts of Portland cement in masonry grout with other cementitious materials. Various combinations of class F fly ash and ground granulated blast furnace slag were used to replace Portland cement. The objective was to determine if required minimum grout strengths could be maintained with high levels of these supplemental cementitious materials.

In Phase I specimens were dry and wet cured while in Phases II, III, IV, V they were wet cured. In Phase I mixes were proportioned by volume while in the other Phases they were proportioned by weight. Mixes in Phases I and II were batched with 0%, 20%, 30%, 40%, 50% and 60% fly

ash. Mixes in Phase III were batched with 50%, 60%, 70% and 80% fly ash-ground granulated blast furnace slag. In phase IV mixes were batched with 45%, 55%, and 65% fly ash. In phase V mixes were batched with 65%, 75%, and 85% fly ash-ground granulated blast furnace slag. Fly ash in mixes III and V was limited to 25%.

Based on the tests results grouts with up to 40% class F fly ash and 80% class F fly ash-ground granulated blast furnace slag can essentially be treated as conventional masonry grout.

Keywords: Grout, Cementitious Materials, Strength, Fly Ash, Slag, Portland Cement.

ANALYSIS OF THE CONTRIBUTION OF MASONRY INFILL IN THE OVERALL STIFFNESS OF CONCRETE FRAMES

Désir, Jean Marie¹; Thiago Pedreschi Busi², Ramires Lucas³

¹ DSc, Professor, Federal University of Rio Grande do Sul, Civil Engineering Department,
jean.marie@ufrgs.br

² Master Student, Federal University of Rio Grande do Sul, Civil Engineering Department,
thiagobusi@gmail.com

³ PhD student, Federal University of Rio Grande do Sul, Civil Engineering Department,
lucasramires@yahoo.com.br

Concrete frame with masonry infill has been the subject of many studies, both experimental as numerical, to assess the contribution of the masonry in the structural behaviour of buildings. Several authors have presented formulations based on experimental studies for the consideration of masonry infill through an equivalent diagonal as in the theory of strut and tie. The comparison of values obtained with the different expressions they propose, shows that there is not a consensus over the right value to adopt what reinforces the need to deepen the subject. A parametric study involving the ratio of panel dimensions, the ratio of beam and column stiffness of the frame shows that there is a range of values of the strut that coincides with the recommendation of some international standards. This paper presents a simulation of the behaviour of a multi-story concrete frame via the finite element method, using a homogenization technique to define the elastic characteristics of masonry. The homogenization parameters are validated through a comparison with values obtained from tests on blocks, mortar and prisms. Subsequently, we analyzed the frame with and without the infill, to evaluate the contribution of the masonry in the stress and strain distributions and to compare these results with those obtained with the theory of equivalent diagonal strut. The results show that there is a range of ratio (equivalent width/height of the panel) to which the two methods give similar results.

Keywords: Concrete frame, masonry infill, equivalent diagonal strut.

FRICTIONAL ENERGY DISSIPATION AND DAMPING CAPACITY OF FRAMED SEMI-INTRLOCKING MASONRY INFILL PANEL

Totoev, Yuri Zarevich¹; Lin, Kun²

¹ PhD, Senior Lecturer, University of Newcastle, Centre for Infrastructure Performance and Reliability,
yuri.totoev@newcastle.edu.au

² MEng, PhD student, Harbin Institute of Technology, Shenzhen Graduate School, linkun.hit@hotmail.com

A new system for masonry infill panels is being developed in the Masonry Research Group at the University of Newcastle. It uses masonry panels made of dry stack semi-interlocking units capable of relative sliding in-plane of a wall and interlocked to prevent relative sliding out-of-plane of a wall. These new panels are suitable for both infill and confined masonry. The major objective for developing this new masonry system is to improve the earthquake performance and wind resistance of framed structures with masonry panels acting as energy dissipation devices (EDD). An experimental program is being carried out to evaluate the behaviour of different framed masonry panels. It was found in the initial testing program that new panels have significant energy dissipation capacity due to friction between masonry units. For example, a maximum damping ratio of 0.03 was calculated for a bare RC frame from hysteresis force-displacement curves. This was improved by infilling the frame with the dry stack masonry panel producing a new average damping ratio of 0.17. Theoretically, based on the coefficient of friction between contacting masonry units, this capacity could be improved even further. This paper describes the response of a prototype semi-interlocking panel to in-plane cycling with particular emphasis on the frictional energy dissipation and damping.

Keywords: *Dry stack, interlocking, masonry, infill, confined, EDD.*

INTERPRETATION OF IN-PLANE RESPONSE AND DEFINITION OF DAMAGE LEVELS FOR MASONRY INFILLED RC FRAMES

Hak, Sanja¹; Morandi, Paolo²; Magenes, Guido³

¹ PhD student, Rose School, Pavia, shak@roseschool.it

² PhD, Post-Doctoral Research Fellow, Università degli Studi di Pavia and EUCENTRE,

paolo.morandi@unipv.it

³ PhD, Associate Professor, Università degli Studi di Pavia and EUCENTRE, guido.magenes@unipv.it

Since a wide range of material types and building techniques is commonly being adopted for the construction of masonry infills in Europe and worldwide, involving significant sources of uncertainties, a unified approach for the definition of accurate performance criteria is difficult to be achieved. Thus, experimental studies present one of the fundamental sources for the valuation

of strength, stiffness and deformation properties for masonry infills. In the present work a method for the interpretation of experimental results representing the cyclic in-plane response of single-bay, single-storey masonry infilled RC frames is proposed, aimed to allow the comparison of different infill typologies and facilitate the calibration of infill models for numerical applications. Based on a numerical simulation of the in-plane response of the infilled frames, representing the masonry infill as a compressive diagonal strut pinned at its ends to the intersection of beam and column centrelines, the approach is applied to some in-plane experimental tests on infilled RC frames carried out in the past. Based on the comparison of experimental and numerical results for infilled and bare frames, a calibration of the numerical model can be performed with particular attention to the evaluation of the strain properties characterizing the nonlinear behaviour of the strut. Having in mind the importance of in-plane damage limitations for masonry infills, performance levels for infilled RC frames can be defined as a function of increasing masonry infill damage in terms of values of strains in the equivalent strut and related inter-storey frame drifts.

Keywords: *Masonry infills, RC frames, in-plane seismic response, experimental results, damage limit states.*

MASONRY INFILLED STEEL FRAMES UNDER COMBINED IN-PLANE LATERAL AND AXIAL LOADING

Liu, Yi¹; Manesh, Pouria²

¹ PhD, Associate Professor, Dalhousie University, Civil Engineering Department, yi.liu@dal.ca

² Master student, Dalhousie University, Civil Engineering Department, pouria.manesh@dal.ca

Nine specimens were tested to investigate the in-plane behavior and capacity of concrete masonry infilled steel frames. Three specimens were subjected to a lateral load applied at the frame top beam level whereas the remaining six specimens were tested under combined in-plane axial and lateral loading. Specimens included non-grouted, partially grouted and fully grouted infills. Test results showed that the presence of axial load resulted in a marked increase in the lateral resistance of the infilled frame for both partially and fully grouted infills. Its effect on the stiffness, however, is only significant for fully grouted infills. Grouting increased both the lateral resistance and stiffness of the infilled frames. The comparison of test results with design values suggests that the current Canadian design guidelines provide a markedly conservative design of masonry infills whereas the American design standard gives an improved estimate of infill stiffness and strength. However, both standards need to address the effect of axial load on the lateral resistance of masonry infills.

Keywords: *concrete masonry infill, steel frame, in-plane behaviour, lateral loading, axial compression, diagonal strut, design standard, experimental study.*

SOLUTIONS FOR INFILLED MASONRY BUILDINGS: SHAKING TABLE TESTS

Leite, Joao¹; Lourenco, Paulo B.²

¹ MSc, PhD Student, University of Minho, ISE, joaoleite@civil.uminho.pt

² PhD, Full Professor, University of Minho, ISE, pbl@civil.uminho.pt

Infilled masonry can be seen as an old research issue, but recent seismic activities, such as the 2009 Aquila earthquake in Italy, showed seismic engineers and structural designers that current infill solutions may not work as expected. In this seismic action, the analysis of the damages in buildings constructed in the last 20 years, designed according to modern standards, may lead to the worrying conclusion that the design Limit States were not fulfilled.

Taking this into account, a research program was conducted as a partnership between the University of Minho, Portugal, and the National Laboratory for Civil Engineering (L.N.E.C.), Portugal, which included a shaking table experimental program. The objective of this program was to study the seismic behaviour of the most common infill solution in Portugal, the unreinforced double leaf clay brick masonry, and two reinforced solutions referenced in the standard Eurocode 8: i) single leaf clay brick with bed joint reinforcement, connected to the bounding frame; ii) single leaf clay brick with steel net in the plaster, connected to the bounding frame. The present paper details the first two tested solutions, along with the discussion of the results, focusing on the obtained collapse modes of the infills and the measured accelerations for those modes.

Keywords: infill, concrete frame, reinforcement, shaking table, collapse mode.

PROPOSED EXPERIMENTAL STUDY TO COMPARE THE SEISMIC PERFORMANCE OF REINFORCED CONCRETE AND REINFORCED MASONRY STRUCTURAL WALLS

El-Azizy, O.¹; El-Dakhakhni, W.W.² and Drysdale, R.G.³

¹ MASc. Candidate, Department of Civil Engineering, McMaster Univ., Hamilton, Canada. .
elazizo@mcmaster.ca

² PhD, Martini, Mascarini and George Chair in Masonry Design, McMaster Univ., Canada.
eldak@mcmaster.ca

³ PhD, Professor Emeritus, McMaster Univ., Hamilton, Canada. drysdale@mcmaster.ca

This paper highlights the details of a proposed research program focused on comparing the seismic performance of Reinforced Concrete (RC) to Reinforced Masonry (RM) structural (shear) walls. Six RC structural walls were constructed to be tested under simulated seismic loading in order to compare their behavior to the behavior of three previously reported RM structural walls (Shedid et al. 2010). All the half-scale three-storey walls were 3,990mm high by 1,802 mm long. The wall cross sections varied between rectangular, flanged and end-confined configurations.

The RC walls were designed and detailed to act as ductile structural walls according to the Canadian concrete design code, CSA A23.3-04. Two hydraulic actuators, used to simulate gravity loads on the walls, maintained 160 kN load on the walls throughout testing. The paper outlines the test matrix, setup, instrumentation, and specimen design and construction. To date, one rectangular RC wall was tested and compared to the corresponding RM wall. The paper presents the comparative results in terms of the failure mode, extent of damage, hysteresis loops, strength degradation, displacement ductility and the top drift percentage. The test results indicated similar ductile capabilities of both RC and RM walls. In addition, both walls have almost the same percentage top drift at the ultimate load of 0.62%. Thus, within the context of displacement- and performance-based designs, the two walls are essentially identical and may be assigned similar seismic force modification factors within the context of force-base design.

Keywords: *Ductility, Hysteresis loops, NBCC, RC, RM, Structural Walls, Top drift.*

NEW SEISMIC CONSTRUCTION CATEGORIES FOR REINFORCED CONCRETE BLOCK STRUCTURAL WALLS: ANALYSIS

Shedid, Marwan¹; El-Dakhakhni, Wael² and Drysdale, Robert³

¹ PhD, Assistant Professor, Ain-Shams University, Cairo, Egypt. shedidmm@mcmaster.ca

² PhD, Martini, Mascarin & George Chair in Masonry Design, McMaster Univ., Canada.
eldak@mcmaster.ca

³ PhD, Professor Emeritus, McMaster University, Hamilton, Canada. drysdale@mcmaster.ca

This sequel paper contains detailed analyses of an experimental study reported in a companion paper that was conducted to evaluate the ductility, stiffness degradation and energy dissipation characteristics of rectangular, flanged, and end-confined reinforced masonry (RM) shear walls failing in flexure. The test program consisted of seven 2- and 3-story RM shear walls, with aspect ratios of 1.5 and 2.2, tested under reversed cyclic lateral displacements simulating seismic loading effects. Documentation of the wall base curvatures, and ductility levels attained are presented. This paper focuses on determining the extent of plasticity over the wall height, identifying the trend of stiffness degradation, and quantifying the amount of hysteretic damping. The relationship between the hysteretic damping and the ratio of the post-yield to the yield displacement was found to be almost linear for the test walls. In addition, the wall stiffnesses degraded rapidly to about 60% of their gross stiffness at very low drift levels (0.1% drift). Extent of plasticity over the wall height was about 75% of the wall length. The data presented in this paper is expected to facilitate better understanding of RM wall behavior under in-plane load to researchers, practicing engineers, and code developers. The results demonstrated the benefits of the increased curvature and displacement ductility values gained by adding flanges and boundary elements to rectangular walls and are expected to facilitate adoption of the flanged and end-confined wall categories in North American masonry codes as a cost-effective technique to enhance the seismic performance of masonry construction.

Keywords: *Boundary elements, Concrete masonry, Ductility, Flanges; Seismic tests; Shear walls.*

NEW SEISMIC CONSTRUCTION CATEGORIES FOR REINFORCED CONCRETE BLOCK STRUCTURAL WALLS: EXPERIMENTS

Shedid, Marwan¹; El-Dakhakhni, Wael² and Drysdale, Robert³

¹ PhD, Assistant Professor, Ain-Shams University, Cairo, Egypt. shedidmm@mcmaster.ca

² PhD, Martini, Mascarin & George Chair in Masonry Design, McMaster Univ., Canada.
eldak@mcmaster.ca

³ PhD, Professor Emeritus, McMaster University, Hamilton, Canada. drysdale@mcmaster.ca

In this paper, a series of reinforced concrete-block shear walls with aspect ratios of 1.5 and 2.2 were tested under displacement-controlled cyclic loading. The response of rectangular, flanged, and end-confined walls, designed to have the same lateral resistance when subjected to the same axial load, is discussed. In general, high levels of ductility accompanied by relatively small strength degradation were observed in all walls with a significant increase in ductility and displacement capabilities for the flanged and end-confined walls compared to the rectangular ones. For both aspect ratios evaluated, the drift levels at 20% strength degradation were 1.0, 1.5, and 2.2% corresponding to the rectangular, the flanged, and the end-confined walls, respectively. The ductility values of the proposed flanged and end-confined walls were, respectively, 1.5 and 2 times those of their rectangular wall counterparts (with the same overall length and aspect ratio). In addition to the enhanced ductility, a saving of more than 40% in the amount of vertical reinforcement was achieved using the proposed alternative strategies while maintaining the same lateral wall resistance. Existing design clauses were used to predict the wall capacities using the American and the Canadian masonry codes and showed excellent agreement. This will facilitate adoption of the new construction categories with minimal modifications to existing code clauses. The test results indicate that higher ductility than the currently endorsed values by North American codes should be used for rectangular walls. Moreover, higher values should be expected when the proposed strategies are adopted which would significantly reduce the seismic demand on reinforced concrete-block shear wall construction.

Keywords: *Boundary elements, Concrete masonry, Ductility, Flanges; Seismic tests; Shear walls.*

SEISMIC BEHAVIOR COMPARISON OF CONFINED MASONRY WALLS OF CLAY AND CONCRETE BRICKS

San Bartolomé Angel¹; Angles, Paola²; Quiun, Daniel³

¹ Professor, Pontifical Catholic University of Peru, Civil Engineering Department, asanbar@pucp.edu.pe

² Civil Engineer, Pontifical Catholic University of Peru, a20012009@pucp.edu.pe

³ Professor, Pontifical Catholic University of Peru, Civil Engineering Department, dquiun@pucp.edu.pe

An experimental research was performed to compare the seismic behaviour of two confined masonry walls, when subjected to cyclic lateral load tests. The first wall was made using typical clay brick units, and the second one featured new concrete units. Both types of bricks were industrially made. The confined walls of concrete bricks have not been tested previously, and they are not yet included fully in the recent Peruvian Masonry Code of 2006.

The paper contains a description of the unit properties, the different mortars used for laying the bricks, and the plain masonry properties obtained by testing four prisms of each brick type under axial compression plus four small walls subjected to diagonal compression.

The walls were full size, 2.3m square and the thickness correspond to the brick thickness of 130 mm. The cyclic lateral load tests were conducted on both walls using ten steps, ranging from 0.5mm to 20mm of topmost horizontal displacement, for comparison of the seismic behaviour.

The conclusions obtained are limited to the few specimens tested. However, it was obtained that the new concrete brick units may be used for confined walls in buildings up to five stories.

Keywords: *Confined masonry, bricks, tests, seismic behaviour, Code.*

AXIAL CAPACITY OF DRY-STACKED ENDURA MASONRY WALLS

Fonseca, Fernando S.¹ and Murray, Eric B.²

¹ PhD, S.E. Associate Professor, Brigham Young University, Department of Civil and Environmental Engineering, ffonseca@et.byu.edu

² P.E., LEI Consulting Engineers and Surveyors, eric@lei-eng.com

Testing was conducted on ten dry-stacked surface-bonded masonry walls, ENDURA walls, at Brigham Young University to determine their axial capacity. ENDURA walls are dry-stacked concrete masonry units with eccentrically placed reinforcement and a surface bonding cement applied to both faces of the walls. The surface coat provides a physical bond between the blocks, and is also applied for aesthetic purposes. Polystyrene insulation inserts are placed in all ungrouted hollow block cells. ENDURA system relies on shims and the surface bonding coat to ensure that the wall is level and plumb. The walls tested were 3.00 meters high by 2.44 meters wide. Each of the walls was built using a different configuration of block type, reinforcement

spacing, and number and spacing of grouted cavities. Also, some walls were constructed with a thin mortar layer on the bed joints. A steel frame with two hydraulic jacks was used to load the walls. All walls were tested to failure by applying a uniformly distributed axial load at the top of the walls. The research is in its infancy but preliminary results indicate that the number of grouted cells influences the capacity of the walls more than the vertical spacing of the reinforcement. Preliminary results are mixed as far as the use of a thin mortar layer on the bed joints is concerned: some walls experienced an increase in strength while others experienced a decrease in strength; these results simply indicate that further research is needed.

Keywords: *Masonry Walls, Dry-Stack Masonry Construction, Axial Strength.*

CHARACTERISATION OF FLEXURAL BOND STRENGTH IN THIN BED CONCRETE MASONRY

Thamboo, Julian Ajith¹; Dhanasekar, Manicka²; Yan, Cheng³

¹ PhD student, Faculty of Built Environment and Engineering, Queensland University of Technology
julian.thamboo@student.qut.edu.au

² Professor, Faculty of Built Environment and Engineering, Queensland University of Technology
m.dhanasekar@qut.edu.au

³ Associate Professor, Faculty of Built Environment and Engineering Queensland University of Technology
c2.yan@qut.edu.au

This paper presents an experimental investigation of the flexural bond strength of thin bed concrete masonry. Flexural bond strength of masonry depends upon the mortar type, the techniques of dispersion of mortar and the surface texture (roughness) of concrete blocks. There exists an abundance of literature on the conventional masonry bond containing 10mm thick mortar; however, the 2mm polymer glue mortar bond is not yet well researched. This paper reports a study on the examination of the effect of mortar compositions, dispersion methods and unit surface textures to the flexural bond strength of thin bed concrete masonry. Three types of polymer modified glue mortars, three surface textures and four techniques of mortar dispersion have been used in preparing 108 four point flexural test specimens. All mortar joints have been carefully prepared to ensure achievement of 2mm layer polymer mortar thickness on average. The results exhibit that the flexural bond strength of thin bed concrete masonry much is higher than that of the conventional masonry; moreover the unit surface texture and the mortar dispersion methods are found to have significant influence on the flexural bond strength.

Keywords: *Thin bed concrete masonry, Flexural bond strength, polymer modified mortar, Surface texture, Concrete block.*

COMPRESSIVE STRENGTH OF THIN LAYER MORTAR BED JOINTS MASONRY MADE OF POLISH CALCIUM SILICATE UNITS

Drobiec, Łukasz¹; Jasiński, Radosław²; Piekarczyk, Adam³

¹ PhD, Silesian Technical University, Department of Building Structures, Lukasz.Drobiec@polsl.pl

² PhD, Silesian Technical University, Department of Building Structures, Radoslaw.Jasinski@polsl.pl

³ PhD, Silesian Technical University, Department of Building Structures, Adam.Piekarczyk@polsl.pl

This paper describes results of prisms constructed with masonry thin layer mortar joints specimens made of calcium silicate units group 1 produced by polish manufacturers. Specimens were made of 14 types of 18 cm and 25 cm thick masonry units. A total of 41 specimens were tested. Results showed that characteristic and design compressive strength of this type masonry is higher than strength calculated according to polish Eurocode 6 National Annex regulations. Therefore, authors propose to increase the value of constant K factor which is used for determination of compressive strength of masonry. The modified characteristic and design compressive strength of this type of masonry would be one of the lowest among EU countries but better matching the test results.

Keywords: *Calcium silicate, thin layer mortar joints, compressive strength, K factor.*

SUSTAINABLE DRY INTERLOCKING BLOCK MASONRY CONSTRUCTION

BANSAL DEEPAK¹

¹ Dy General Manager (Projects), HUDCO, Hudco Bhawan, Delhi 110003, INDIA, & Research Scholar with TERI University, New Delhi, India. Email: dbansal1969@gmail.com

There is a need to identify innovative technologies to supplement age-old concrete and burnt clay brick mortar based construction for masonry work. Today we need technologies which are sustainable in terms of one or more of the following parameters i.e. use of locally available resources – material & manpower, cost effectiveness, eco-friendly, easy to adopt in construction practice, can be cast – in situ to reduce transportation, faster to build and energy efficient.

The Indian masonry design standard (IS 1905-1987) does not deal with dry interlocking block masonry, hence does not prescribe the design values for this masonry like basic compressive strength, tensile strength & shear strength. However the same code recognizes other types of masonry and recommends that a prism test of different masonry may be done and these values may be accepted for designing the masonry.

This block masonry by Hydraform interlocking (this is a typical case in this study, but can be generic) has been tested in the field as well as by experiments and has been found to have better strength than the conventional brick masonry (burnt clay bricks in English bond) using cement sand mortar (1:6). The basic compressive strength is much more than the minimum values given in the Indian masonry design standard (IS 1905-1987). These blocks have low embodied energy

compared to burnt clay brick, and can be specifically designed as per requirements, resulting in promotion of green construction technology.

The paper addresses the technical specifications, raw material options, construction procedure, structural performance, embodied energy and conformity with the building standards.

Keywords: *Interlocking Block Masonry, Embodied Energy, Crushing Strength, Flyash.*

STUDY OF THE INFLUENCE OF COMPRESSIVE STRENGTH AND THICKNESS OF! CAPPING-MORTAR ON COMPRESSIVE STRENGTH OF PRISMS OF STRUCTURAL CLAY BLOCKS

Lima, Flávio Barbosa¹; Lima, Alexandre Nascimento²; Assis, Wayne Santos³

¹ PhD, Professor, Federal University of Alagoas, Technology Center, fblima@lccv.ufal.br

² MsC, Professor, Federal University of Alagoas, Sertão Campus, alexnlima@gmail.com

³ PhD, Professor, Federal University of Alagoas, Technology Center, wayne@lccv.ufal.br

Currently, structural masonry is one of the most commonly used structural systems in some countries, like Brazil. Among its components, the capping-mortar is seen as the weakest. This paper presents the results of a study that analyses the influence of the compressive strength and thickness of the bedding mortar on the mechanical performance of ungrouted prisms built with clay blocks, using a 3k factorial design and others statistical techniques, including the construction of response surface. Blocks of the same compressive strength were used. Tests were performed on prisms consisting of two blocks with three different thicknesses and three different compressive strengths of the bedding mortar. From the found results, the influence of these parameters was quantitatively verified and statistical models representing the individual and joint effects of variables were built.

Keywords: *structural masonry, clay block, mortar.*

SHAKE TABLE TESTING AND ANALYTICAL MODELING OF FULLY-GROUTED REINFORCED CONCRETE BLOCK MASONRY SHEAR WALLS

Mojiri, Saeid¹; Tait, Michael J.²; and El-Dakhakhni, Wael W.³

¹ MSc, Graduate student, McMaster University, Civil Engineering Department, mojiris@mcmaster.ca

² PhD, Joe NG/JNE Consulting Chair in Design, Construction and Management in Infrastructure Renewal, McMaster University, Civil Engineering Department, taitm@mcmaster.ca

³ PhD, Martini, Mascarin and George Chair in Masonry Design, McMaster University, Civil Engineering Department, eldak@mcmaster.ca

This paper presents the details of a proposed shake table experimental program for investigation of seismic performance of reduced-scale fully-grouted reinforced concrete block shear walls. It describes the steps taken to date in terms of preparation of model wall specimens, test setup and selection of the model earthquake records. A preliminary analytical model is also proposed for estimation of seismic response of the walls and selected preliminary results including dynamic properties, lateral deformation, absorbed and dissipated energy, and ductility prediction based on nonlinear time history analysis utilizing the proposed analytical models are discussed.

Keywords: *Analytical models, Reinforced masonry, Seismic performance, Shake table testing.*

DEFINITION OF EQUIVALENT DAMPING FOR MASONRY STRUCTURES IN SUPPORT OF DISPLACEMENT BASED DESIGN

Luca, Nicolini¹; Francesca, da Porto²

¹ PhD student, University of Padova, Dept. of Civil, Environmental, Architectural Eng., nicolini@dic.unipd.it

² PhD, Ass. Prof, University of Padova, Dept. of Civil, Environmental, Architectural Eng., daporto@dic.unipd.it

In the last years, several researches have established the importance to correlate design limit states to performance levels defined by displacement, in order to obtain a better control on expected damage after an earthquake.

The displacement spectra proposed by code for damping values higher than the nominal value of 5% of critical are generally obtained, as in the case of Eurocode 8 and the Italian Technical Code (2008), by applying a scaling factor to the elastic response spectras 5% damped. This factor is defined as a function of equivalent viscous damping, which depends on hysteretic energy dissipation.

The paper presents a procedure for determining the hysteretic damping for reinforced masonry structures. The method makes use of the equivalent linear system, whose vibration period is determined by nonlinear dynamic analysis on single degree of freedom idealized system, by using

synthetic spectrum compatible time histories. The analyses are performed using an hysteretic model calibrated on experimental results obtained from cyclic shear compression tests that were carried out by the University of Padova.

Keywords: *masonry, displacement-based, energy dissipation, equivalent damping, dynamic analyses.*

PUSHOVER ANALYSIS OF A MODERN AGGREGATE OF MASONRY BUILDINGS THROUGH MACRO-ELEMENT MODELLING

Marques, Rui¹; Vasconcelos, Graça²; Lourenço, Paulo B.³

¹ MSc, PhD Student, University of Minho, Department of Civil Engineering, marquesmnc@sapo.pt

² PhD, Assistant Professor, University of Minho, Department of Civil Engineering, graca@civil.uminho.pt

³ PhD, Professor, University of Minho, Department of Civil Engineering, pbl@civil.uminho.pt

The masonry building aggregates are a typology of construction typical of historical town centres, where a complex structural system with longitudinal and transversal walls is arranged at different ground and roof levels. Currently, the recuperation of the masonry as a structural solution will depend, in significant part, on its use in the construction of housing blocks, which can present many of the features of a typical building aggregate. The behaviour of this construction typology should be assessed under seismic loads, since it has been shown to be vulnerable to such type of loading. In this work, the case of a modern aggregate of masonry buildings, which is constituted by adjacent buildings at different levels, is studied under simulated seismic loading through nonlinear static (pushover) analysis on a macro-element model idealized for the aggregate. A developed concrete block masonry system is adopted as the structural solution. The aggregate is evaluated regarding its seismic performance by considering three different configurations: a set of dwellings with independent behaviour, a levelled conglomeration of buildings, and an unlevelled aggregate. A comparison between the predicted performances of solutions with unreinforced and truss type horizontally reinforced masonry is made in terms of both base shear-displacement response and damage pattern. The main conclusions are that the structural irregularity in elevation implies loss of displacement capacity, and that the horizontal truss reinforcement allows only qualitatively an improvement of the structural ductility, given a more distributed damage and a higher deformation capacity.

Keywords: *Modern masonry, structural irregularity, pushover analysis, macro-element modelling, truss reinforcement*

SEISMIC BEHAVIOR OF REDUCED-SCALE TWO-STOREY REINFORCED CONCRETE MASONRY STRUCTURAL WALLS

Siyam, M.¹; El-Dakhakhni, W.W.² and Drysdale, Robert³

¹ MAsc. Candidate, Department of Civil Engineering, McMaster Univ., Hamilton, Canada.
siyamm@mcmaster.ca

² PhD, Martini, Mascarin and George Chair in Masonry Design, McMaster Univ., Canada.
eldak@mcmaster.ca

³ PhD, Professor Emeritus, McMaster Univ., Hamilton, Canada. drysdale@mcmaster.ca

The current study aims at evaluating the seismic performance parameters of reinforced masonry structural walls failing in flexure. The parameters include displacement ductility, plastic hinge length and stiffness degradation of the walls which are of major significance in quantifying the walls performance under seismic excitation. In addition, the test results will contribute to the database necessary for the shift towards performance-based seismic design methodologies in North America, as laid out by the Federal Emergency Management Agency, FEMA-445 document (ATC, 2006) as well as the plans of the Canadian Standing Committee on Earthquake Design (SC-ED) for the National Building Code of Canada (NBCC) 2020 edition. The test program consists of six rectangular, flanged and coupled walls, all tested in displacement-controlled quasi-static cyclic loading. Only results from the rectangular walls is discussed in this paper as the other walls are yet to be tested. Wall hysteresis, curvature profiles and the ductility level attained showed significantly better performances than what is currently perceived by the NBCC (2010). In addition, the walls experimental curvatures was significantly higher than theoretical values calculated using CSA S304.1 which led to curvature ductility values greater than 9.0 for all the walls. Subsequently, all walls had a ductility-related force modification factor, R_d , value of at least 4.0 using the equal-displacement approach. The latter demonstrates the ductile capabilities of such walls when properly designed to resist strong seismic forces.

Keywords: *Shear walls, Ductility, Reinforced Masonry, Aspect ratio, Cyclic loading, Plastic hinge length, Stiffness Degradation.*

IDENTIFICATION OF PERFORMANCE-BASED DAMAGE INDICATORS OF REINFORCED CONCRETE BLOCK STRUCTURAL WALLS WITH END CONFINEMENT

Banting, Bennett¹; El-Dakhakhni, Wael²

¹ PhD Candidate, Department of Civil Engineering, McMaster University, Hamilton, Canada.
bantinbr@mcmaster.ca

² PhD, Martini, Mascarin and George Chair in Masonry Design, McMaster University, Canada.
eldak@mcmaster.ca

New masonry construction techniques reflecting new seismic performance categories need to be developed within a performance-based seismic design context for their adoption in the next generation of seismic design codes worldwide. In North America, a reinforced masonry (RM) structural wall system that incorporates special boundary confinement in the plastic hinge region presently lacks specific design requirements in the MSJC (2011) and CSA S304.1 (2004b). This paper presents experimental and analytical results from a series of specially detailed RM structural walls subjected to fully reversed cycles of displacement-controlled loading. All specimens were detailed with lateral reinforcing ties confining a grouted core and four vertical reinforcement bars located in each of the compression toes at the wall ends as a minimum level of detailing for boundary confinement. The design and detailing of the specimens represented a range of parameters that would be anticipated to vary within low- to medium-rise RM buildings. These parameters included the wall height, length, aspect ratio, level of applied axial load, amount of vertical flexural reinforcement and the presence of inter-storey simulated floor slabs. Results of the experimental program are presented according to the drift-damage relationship of each wall with special focus on identifying various damage states within the confined boundary element wall category. The results of this research program have been presented as high quality experimental fragility functions for four identified damage states. The occurrence of moderate and extreme levels of damage in the walls reported had an increase in the median drift demand by a significant margin of 1.07% and 1.04% drift, respectively, compared to fragility functions of traditional flexural RM shear walls reported in literature.

Keywords: *Wall Confinement, Damage States, Fragility Functions, Reinforced Masonry, Seismic Effects, Shear Walls.*

HYBRID MASONRY SEISMIC SYSTEMS

Abrams, Daniel¹; Biggs, David²

¹ Willett Professor of Engineering, University of Illinois at Urbana-Champaign, USA, d-abrams@illinois.edu

² Principal, Biggs Consulting Engineering PLLC, Troy, New York, USA, biggsconsulting@att.net

Hybrid masonry is a new structural concept for buildings that incorporates the in-plane strength and stiffness of reinforced concrete masonry with the ease of erecting conventional steel framing. Since the masonry structural panels can also serve as architectural elements hybrid masonry has

the promise to be highly competitive with conventional lateral force resisting systems including reinforced masonry or concrete shear walls, steel braced frames or concrete or steel moment-resisting frames. This new method has been introduced in the eastern United States for low-rise office and commercial buildings, and has been found to result in reduced cost and expedited construction sequencing since structural and architectural components can be integrated. Coordinated research is currently underway at the University of Illinois at Urbana-Champaign, Rice University and the University of Hawaii at Manoa to investigate seismic behaviour and response of this construction type. This paper provides an introduction to this innovative seismic structural system, and presents an overview of research results done to date.

Keywords: *dynamic response, earthquake, seismic, hybrid masonry, research, structural design.*

3D INTERACTION DOMAINS FOR UNREINFORCED MASONRY PANELS SUBJECTED TO ECCENTRIC COMPRESSION AND SHEAR

Parisi, Fulvio¹; Augenti, Nicola²

¹ PhD, Post-Doc, University of Naples Federico II, Department of Structural Engineering, fulvio.parisi@unina.it

² Professor, University of Naples Federico II, Department of Structural Engineering, augenti@unina.it

Flexural strength of unreinforced masonry (URM) cross-sections is typically predicted by means of two-dimensional (2D) interaction domains. Alternatively, three-dimensional (3D) interaction domains can be used to include the balance of the whole masonry panel in the limit state equations of an extreme section.

In this paper 3D domains are presented to describe the interaction between shear force, axial force and its eccentricity for prismatic URM panels with rectangular cross-section. For both elastic and ultimate limit states, sectional equilibrium equations corresponding to a given axial strain diagram are merged with those of the entire masonry panel for cracked and uncracked conditions separately. Such domains are defined in a dimensionless format in order to be independent of the compressive strength of masonry. Limit state equations were derived for five different stress-strain relationships, to investigate the influence of masonry behaviour in uniaxial compression under the assumption of zero tensile strength. In this paper the general formulation is specialised for a strength-degrading constitutive model to emphasise the effects of strain softening.

Finally, the 3D domains were sectioned with planes corresponding to different levels of axial force and axial force eccentricity in order to derive 2D interaction domains expressed respectively in terms of shear force versus axial force eccentricity and shear force versus axial force. It is shown that any increase in the axial force eccentricity causes a rotation of the shear force versus axial force domain, resulting in an allowable axial force lower than that associated with concentric compression.

Keywords: *Unreinforced masonry panels, flexural strength domains, eccentric compression, shear.*

DEVELOPMENT OF A FIBER MODEL FOR LOAD BEARING MASONRY MEMBERS

Giovanni Guidi¹, Francesca da Porto²

¹ PhD, University of Padova, Dept. Structural and Transportation Engineering, guidi@dic.unipd.it

² PhD, Ass. Prof, University of Padova, Dept. Structural and Transportation Engineering, daporto@dic.unipd.it

In the last few years, the possibility of being able to control damage based on the probability of occurrence of an earthquake and designing on the basis of different performance levels, has arose. Masonry is still a widespread construction system for low-rise residential buildings even in earthquake prone countries; hence masonry needs to develop these design concepts.

Experimental tests were performed in recent years at the University of Padova on different masonry systems, both reinforced, and unreinforced with different joint types. The tests were aimed at characterizing the masonry behaviour under combined in-plane cyclic loading, and they were used to develop an analytical model that reproduces the experimental results.

This model is a formulation of a fiber element and is cast in the general framework of the mixed method. It includes effects of shear deformation, diagonal shear failure mechanism and it follows the response in the post-peak phase. The model is able to interpret the performances of masonry panels linking them with limit states resulting from integration of cross-section equilibrium equations.

Keywords: *unreinforced masonry, reinforced masonry, analytical modelling, displacement capacity.*

NUMERICAL ANALYSIS OF UNREINFORCED FLANGED WALLS SUBJECTED TO BIAXIAL BENDING

Vladimir G. Haach¹, Marcio A. Ramalho² and Marcio R. S. Corrêa³

¹ PhD, Professor, School of Engineering of São Carlos, University of São Paulo, Department of Structures, vghaach@sc.usp.br

² PhD, Professor, School of Engineering of São Carlos, University of São Paulo, Department of Structures, ramalho@sc.usp.br

³ PhD, Professor, School of Engineering of São Carlos, University of São Paulo, Department of Structures, mcorrea@sc.usp.br

Masonry walls of a building are subjected to horizontal loading caused by seismic or wind actions besides of the vertical loading. This horizontal loading may act in a different direction of the orthogonal axes of symmetry of the structural elements generating biaxial bending. Walls in masonry buildings usually have transversal walls, also called flanges. Those flanges increase the stiffness of the structural system and significantly improve the lateral capacity of the buildings mainly in case of biaxial bending. However, it is well known that these improvements only happen if the connection of walls is ensured. This work address the influence of flanges in the behavior of unreinforced masonry walls subjected to biaxial bending. A numerical study using a

3D-model is performed with the DIANA® software program based on the Finite Element Method. A parametrical analysis is carried out in order to define the influence of some parameters on the behavior of masonry walls with flanges subjected to biaxial bending, such as geometry wall, boundary conditions and the angle of horizontal loading application. The results indicated that flanges have considerable influence on the behavior of masonry walls under flexure and shear in case of the biaxial bending.

Keywords: *connection, interlocking, flange, shear, flexure.*

NUMERICAL SIMULATION OF URM WALLS SUBJECTED TO OUT-OF-PLANE SOLICITATIONS USING A “UNIT AND INTERACTION” MICRO-MODELING APPROACH

Bultot, Elodie¹; Van Parys, Laurent²

¹ Research Assistant, University of Mons, Risk Research Team, Mons, Belgium,
elodie.bultot@umons.ac.be

² PhD, Professor, University of Mons, Risk Research Team, Mons, Belgium,
laurent.vanparys@umons.ac.be

In most places in the world, unreinforced masonry buildings represent a large part of both patrimonial structures and contemporary buildings. Despite this wide usage, it has been clearly recognized that this kind of structure may be highly vulnerable to lateral solicitations such as the ones caused by wind loads or earthquakes. This paper presents the results of numerical investigations focusing on the mechanical behaviour of unreinforced brick masonry walls subjected to horizontal, vertical and diagonal bending induced by out-of-plane solicitations. The proposed study is carried out using a FE micro-modelling approach (SIMULIA – Dassault Systems) based on a “unit and interaction” concept. This concept, initially developed for an efficient computation of arch systems, is here transposed to wall systems: each masonry unit is modelled and the behaviour of head and bed joints is taken into account through specific contact laws managing both the normal and tangential effects.

Following a short introduction to the subject, the “unit and interaction” concept is detailed, insisting on strong and weak aspects and outlining the particular interest for studying the effects of out-of-plane solicitations. Then the paper illustrates how the developed FE models are likely to predict the response of masonry walls under out-of-plane loading: the paper proposes a comparison of obtained results with data reported in the literature. Finally, the paper outlines how the results of this preliminary study will be used in the analysis of walls subjected to two-way bending, where similar failure mechanisms contribute to the overall wall behaviour.

Keywords: *URM, out-of-plane solicitation, FEM, micro-modelling, contact laws.*

A SHEAR RESPONSE SURFACE FOR THE CHARACTERIZATION OF UNIT-MORTAR INTERFACES

Parisi, Fulvio¹; Augenti, Nicola²

¹ PhD, Post-Doc, University of Naples Federico II, Department of Structural Engineering, fulvio.parisi@unina.it

² Professor, University of Naples Federico II, Department of Structural Engineering, augenti@unina.it

Shear behaviour of unit-mortar interfaces is typically characterized through the Mohr-Coulomb failure model and shear stress versus shear strain diagrams. In porous stone masonry types such as tuff masonry, dilatancy plays also a key role and shear strength of unit-mortar interfaces at zero confining normal stress is non-zero due to the slip surface's roughness.

To characterize nonlinear shear behaviour for tuff masonry assemblages, direct shear tests were carried out under different pre-compression levels. This paper summarises the experimental program discussing the main results. Empirical formulas are presented to define shear failure at both peak and residual stress levels. Shear deformation capacity, strength degradation, mode II fracture energy, and dilatancy coefficient were computed.

Multiple regression analysis was applied to derive a shear response surface including both stress-strain diagrams and the frictional strength model. Constraints on the continuity of both the shear response surface and its first partial derivatives were imposed to nonlinear regression analysis, in order to represent shear softening behaviour in the inelastic range. The surface was defined in a dimensionless space to be used, in principle, for other stone masonry interfaces. This empirical model allows to simulate the shear behaviour over the whole range of allowable strains, and hence the stress-strain diagram at any confining stress level.

The experimental results and the proposed empirical models could be employed in both micro-modelling numerical strategies and simplified nonlinear analysis methods based on the macro-element idealisation of masonry walls with openings.

Keywords: Unit-mortar interface, direct shear tests, dilatancy, mode II fracture energy, shear softening, shear response surface.

COMPARISON OF IN-PLANE SHEAR STRENGTH OF REINFORCED CONCRETE MASONRY WALLS

Hoque, Nusrat¹; Lissel, Shelley L.²

¹MSc Student, Dept. of Civil Engineering, University of Calgary, nusrat_hoque@yahoo.com

²PhD, Associate Professor, Dept. of Civil Engineering, University of Calgary, slissel@ucalgary.ca

Masonry has long been used in construction practice due to its easy construction method, low cost and material availability. However, the performance of masonry, in particular unreinforced masonry, during earthquakes is quite poor and that makes it less popular in earthquake prone areas. Masonry is often used in construction of shear walls intended to resist seismic loading thus the in-plane shear strength has been a research interest for masonry researchers around the world in order to come to a safe but more realistic estimate of the strength. In masonry design codes in

various countries, the in-plane shear strength modelled with different equations which tend to greatly overestimate the strength leading to inefficient and expensive construction. There is also no general agreement on the parameters that can affect the strength and this also reflects in the variability of assumed contribution of the different parameters. In this paper three design equations have been chosen for study. These equations are compared using data from various sources to determine which equations account for the contribution of various parameters and with how much accuracy. Subsequently, modifications to the most suitable equations have been proposed and also compared with the test results.

Keywords: *In-plane shear, aspect ratio, design equations, grouted.*

EFFECT OF CONSTRUCTION METHOD ON SHEAR RESISTANCE OF CONCRETE MASONRY WALLS

Oan, Ahmed Faisal¹; Shrive, Nigel²

¹ PhD, Candidate, University of Calgary, Civil Engineering Department, afoan@ucalgary.ca

² Professor, University of Calgary, Civil Engineering Department, ngshrive@ucalgary.ca

Bed joint reinforcement is used in concrete masonry walls to improve resistance against both in- and out-of-plane lateral loading. There is no doubt that the use of joint reinforcement enhances the post-cracking performance of masonry walls, but there are divergent results in the literature as to whether the use of joint reinforcement increases or decreases the overall shear resistance of masonry walls. It could be that the method of construction is the cause of the discrepancy in results, so an experimental program was executed to study the effect of two different ways of placing the bed joint reinforcement in the walls. The first method was to lay the bed joint reinforcement on the dry blocks with the mortar subsequently being placed on top, whereas the second method was to place the mortar on the face-shells and then embed the joint reinforcement in the mortar. The first method is the method used on site in Canada, while the second method would supposedly give better results as there should be no un-bonded area under the reinforcement.

Tests were carried out on 12 walls (1.6 m long by 1.4 m high) under in-plane vertical and lateral loading. The two methods of construction were each applied to three partially grouted and three ungrouted walls. Statistical analysis of the results with the T-test showed that there was no difference in the shear strength obtained between the two ways of laying the bed joint reinforcement in the walls.

Keywords: *Construction methods, masonry, shear resistance.*

EXPERIMENTAL ASSESSMENT OF THE SHEAR RESPONSE OF AUTOCLAVED AERATED CONCRETE (AAC) MASONRY WITH FLAT TRUSS BED-JOINT REINFORCEMENT

Mandirola, Martina¹; Penna, Andrea²; Rota, Maria³; Magenes, Guido⁴

¹ European Centre for Training and Research in Earthquake Engineering, Pavia,
martina.mandirola@eucentre.it

² Assistant Professor, University of Pavia, Department of Structural Mechanics and European Centre for
Training and Research in Earthquake Engineering, Pavia, andrea.penna@unipv.it

³ PhD, European Centre for Training and Research in Earthquake Engineering, Pavia,
maria.rota@eucentre.it

⁴ Associate Professor, University of Pavia, Department of Structural Mechanics and European Centre for
Training and Research in Earthquake Engineering, Pavia, guido.magenes@unipv.it

Experimental campaigns carried out in the past showed that the presence of flat truss bed-joint reinforcement provides a general improvement to the performance of masonry panels in resisting actions in the horizontal plane. The truss-like elements are effective both in terms of improved resistance and reduction of damage and, therefore, in the enhanced displacement capacity. The limited number of experimental tests available in the literature hardly allows the derivation of quantitative conclusions on the real benefit of the presence of horizontal reinforcement to the seismic performance of a specific masonry type. Such tests are indeed performed on reduced scale prototypes and do not sufficiently cover the possible combinations of slenderness, axial load and boundary conditions. The experimental campaign presented in this work includes a set of in-plane cyclic tests on autoclaved aerated concrete (AAC) masonry panels with thin horizontal and vertical joints filled with glue-mortar, made both in unreinforced and reinforced masonry with flat truss bed-joint reinforcement. The direct comparison of the results, along with specific tests performed on wallettes, allowed to obtain some further reference on the effectiveness of the horizontal reinforcement on the enhancement of the global seismic performance of AAC masonry buildings.

Keywords: *Autoclaved aerated concrete masonry, thin horizontal joint, flat truss bed-joint reinforcement, experimental tests, strength criteria.*

EXPERIMENTAL STUDY OF SHEAR PROPERTIES OF INSULATING PERFORATED CONCRETE BRICK MASONRY MATERIALS

Li, Xiang¹; Gao, Zhinan²; Gu, Xianglin³; Song, Xiaobin⁴; Li, Yihong⁵

¹ PhD, Associate professor, Tongji University, Department of Building Engineering, lixiang@tongji.edu.cn

² Postgraduate student, Tongji University, Department of Building Engineering, txfs@163.com

³ PhD, Professor, Tongji University, Department of Building Engineering, gxl@tongji.edu.cn

⁴ PhD, Assistant professor, Tongji University, Department of Building Engineering,
xiaobins@tongji.edu.cn

⁵ Master, Vice director, Shanghai Inspection Centre for Buildings, li_yihong@sohu.com

In order to develop an energy-saving building system, a new type of insulating perforated concrete brick was developed and shear tests on this kinds of masonry materials were carried out. The test results indicate that with the help of stainless pins, the face block and the insulation board can work well with the bearing brick in a perforated concrete brick. The shear strength of insulating perforated concrete brick masonry is higher than that of concrete hollow block masonry with the same brick strength and mortar strength, but is lower than that of fired perforated brick masonry, and the shear strength of masonry under compression can be determined with the Mohr-Coulomb criterion in a certain range. Based on the test results, calculation equations of the shear strength for the materials were deduced.

Keywords: *insulating perforated concrete brick, masonry, shear property.*

ASSESSMENT OF THE AS3700 RELATIONSHIP BETWEEN SHEAR BOND STRENGTH AND FLEXURAL TENSILE BOND STRENGTH IN UNREINFORCED MASONRY

Masia, Mark J.¹; Simundic, Goran²; Page, Adrian W.³

¹ PhD, Senior Lecturer, The University of Newcastle, Centre for Infrastructure Performance and Reliability,
mark.masia@newcastle.edu.au

² ME, Structural Testing Manager, The University of Newcastle, Centre for Infrastructure Performance and Reliability, goran.simundic@newcastle.edu.au

³ PhD, Emeritus Professor, The University of Newcastle, Centre for Infrastructure Performance and Reliability, adrian.page@newcastle.edu.au

A pilot study was conducted to assess the accuracy and relevance of the mathematical relationship provided in Australian Standard AS3700-2011 Masonry Structures for determining

the shear bond strength (cohesion) of masonry based on its flexural tensile bond strength. Flexural tensile strengths were determined using bond wrench tests in accordance with AS3700 and shear bond strengths (initial shear strengths) were determined using triplet tests in accordance with European Standard EN1052-3 for comparison with the AS3700 mathematical relationship. A range of masonry units and mortar types typical of Australian construction practice were investigated. It was found that the two properties are correlated and that the AS3700 relationship is conservative for all of the masonry combinations tested in the current study. The level of conservatism is small and so based on the results of the current study, no changes to the AS3700 provisions are recommended.

Keywords: *Masonry, shear, tensile, bond.*

MODELLING THE FLEXURAL TENSILE STRENGTH OF MASONRY

Schmidt, Ulf¹; Hannawald, Joachim²; Koster, Matthias³; Graubohm, Markus⁴; Brameshuber, Wolfgang⁵

¹ Dipl.-Ing., Materialprüfungs- und Versuchsanstalt Neuwied GmbH, Germany, schmidt@mpva.de

² PhD, Institute of Building Materials Research (ibac), RWTH Aachen University, Germany, hannawald@ibac.rwth-aachen.de

³ PhD, Institute of Building Materials Research (ibac), RWTH Aachen University, Germany, koster@ibac.rwth-aachen.de

⁴ Dipl.-Ing., Institute of Building Materials Research (ibac), RWTH Aachen University, Germany, graubohm@ibac.rwth-aachen.de

⁵ PhD, Professor, Institute of Building Materials Research (ibac), RWTH Aachen University, Germany, brameshuber@ibac.rwth-aachen.de

The load bearing capacity of masonry with respect to out-of-plane horizontal loads, like for example earth pressure or wind loads, is decisively affected by its flexural tensile strength. The flexural load bearing behaviour of masonry, in turn, is determined by a large number of influences, e. g. the material properties of its components masonry unit and mortar, the bond behaviour between the masonry unit and the mortar, and, in the case of a horizontally spanning wall, the dimensions of the units, the length of the overlap, the masonry thickness, whether the cross joints are filled with mortar or not and so on. In order to characterize the resistance of masonry to out-of-plane horizontal loads and to investigate the different influencing factors, a numerical model on the basis of Finite Element Methods (FEM) was developed where different material laws were assigned to the masonry units and the joints. The material laws of the masonry units and the joints used in the FE calculations, in particular the post-failure behaviour, were previously determined on the basis of small-sized test specimens. The model was validated by comparing the numerical results with experimental data obtained by flexural tensile tests on small masonry walls. For this purpose extensive deformation measurements were carried out on the tested masonry walls and the influence of an additional vertical load applied (normal stress) on the flexural strength was analysed. In an extended sensitivity analysis different material properties of the masonry components and varying geometric boundary conditions, e. g. filled/unfilled head joints, different overlaps, and masonry thicknesses, were investigated. The calculated stress

distributions in the masonry walls immediately reveal the inherent failure mechanisms which are hardly accessible by means of experimental investigations alone. On the basis of the numerical results calculation equations to evaluate the flexural tensile strength of masonry were derived.

Keywords: masonry, flexural tensile strength, Finite Element Model.

IN-PLANE SHEARED UNREINFORCED MASONRY WALLETES – PROPOSITION OF FAILURE CRITERION

Kubica, Jan¹

¹ PhD, DSc, Professor, Silesian University of Technology, Dept of Structural Engineering,
jan.kubica@polsl.pl

A trial of synthesis of both experimental and theoretical investigations (carried out during last 20 years), concerning the behaviour of unreinforced masonry walls subjected to shearing or shearing with precompression in direction perpendicular to bed joints, as well as in direction parallel to this joints is presented in this paper. Horizontal shearing of masonry walls is mainly connected with two types of loading, namely horizontal wind action and seismic or dynamic influences, whereas vertically shearing takes place when building is subjected to irregular vertical ground displacements (e.g. irregular settlements).

The phenomenon of in-plane behaviour of unreinforced masonry walls under such types of loading is analysed and discussed. Moreover, a short description of shear tests of masonry wallettes, carried out at the Faculty of Civil Engineering of the Silesian University of Technology is also presented. These investigations were covered tests of masonry wall specimens built of several types of masonry units (clay solid bricks, clay hollow blocks and AAC blocks) and general purpose cement-lime mortar or thin joint mortar. The results obtained in presented investigations were analysed and discussed.

The analysis of a problem of stress and strain states is discussed based on these experimental data. Moreover, the relationships of shear stresses in relation to compressive stress level τ_{vi} (σ_c) and failure envelopes were also elaborated and presented. On the basis of this relationship the failure criterion for stress analysis, mainly for unreinforced masonry walls vertically sheared with precompression is proposed and compared with available test data.

Keywords: Failure criterion; in-plane loaded masonry; state of stress; state of strain.

INFLUENCE OF DISTINCT REINFORCING SCHEMES ON THE SHEAR RESISTANCE OF MASONRY

Vasconcelos, G.¹; Alves, P.², Lourenço P.B.³

¹ PhD, Assistant Professor, University of Minho, Department of Civil Engineering, graca@civil.uminho.pt

² MSc Student, University of Minho, Department of Civil Engineering, pedro_face@hotmail.pt

³ PhD, Professor, University of Minho, Department of Civil Engineering, pbl@civil.uminho.pt

One of the major concerns about the use of unreinforced masonry in seismic prone regions is its inadequate behavior under seismic loads, which has been shown from recent earthquakes. In fact, it has been seen that unreinforced masonry buildings present commonly considerable in-plane damage, which is associated to the low shear resistance of unreinforced masonry and to low capacity to dissipate energy. The improvement of the overall behavior of structural masonry under shear can be achieved by the addition of horizontal and vertical reinforcement.

This paper presents the results of a series of diagonal compression tests carried out on concrete block masonry with distinct types of reinforcement's arrangements. It was seen that the better configuration for the reinforcement arrangement is the combination of vertical and horizontal reinforcements leading simultaneously to the improvement of shear strength and ductility.

Keywords: concrete block masonry, diagonal compression tests, truss type reinforcements, shear strength.

LIMESTONE PRISMS – SHEAR STRENGTH STUDY

Holland, Nancy L.¹; Nichols, John M.²

¹ PhD, Associate Professor, Texas A&M University, Construction Science Department, nholland@tamu.edu

² PhD, Associate Professor, Texas A&M University, Construction Science Department, jmnichols@tamu.edu

Limestone has been used as building material for millennia, with examples including the Narbonne Cathedral. Texas has approximately 2000 limestone quarries that produce sawn stone for use as a building envelope material. As the construction industry responds to the issue of green construction, it is expected that limestone block will form an increasing proportion of the external wall cladding material on all types of buildings. A test procedure is being developed to measure the shear capacity of limestone prisms. This paper outlines the basic elements of the procedure and compares the test protocol to the equivalent ASTM and Canadian standards. A set of shear results for limestone samples obtained from three different quarries in Texas are reported in this paper.

Keywords: Limestone, shear tests, housing.

COMPARATIVE ANALYSES THROUGH SIMPLIFIED METHOD, PLANE FRAMES AND SPACE FRAMES FOR DESIGN OF STRUCTURAL MASONRY BUILDINGS

Quim, Francisco¹; Lima, Adriano²; Silva, Nilson³

¹ M.Sc., Eng., TQS Informática Ltda., Development Department, francisco@tqs.com.br

² Eng., TQS Informática Ltda., Development Department, adriano@tqs.com.br

³ Eng., TQS Informática Ltda., Development Department, nilson@tqs.com.br

Due to the increasing development of structures engineering and different building systems that have emerged over the years in the building industry, the structural engineer needs to incorporate numerical analysis and tools in order to increase the agility and quality to the usual routine of work, to maintain the competitiveness of their work. Although the analysis of masonry structural projects has a very simple modeling, computational tools should be incorporated in order to translate the reality of the behavior of this constructive method as an essential part of the structural projects development. Thus, this study aimed to a comparative analysis between the simplified processes of calculation considered a conservative model and the two-dimensional frames and space frames that provides a better distribution of actions seeking to improve the representativeness of the model. For this a computational calculating and detailing of masonry structural program - CAD/Alvest was used. Verifications with the NBR 10837:1989 and NBR 15961:2011 were also performed and compared. For the model of space frames the master node technique was used, and lintels collaborating were also considered for the overall stability of the structure.

Keywords: *Analysis of structures, Structural masonry, Space frames.*

ECONOMIC METHODS FOR CONFINING EDGES OF REINFORCED MASONRY WALLS

Quiun, Daniel¹; San Bartolomé Angel²; Moscol, Abel³

¹ Professor, Pontifical Catholic University of Peru, Civil Engineering Department, dquiun@pucp.edu.pe

² Professor, Pontifical Catholic University of Peru, Civil Engineering Department, asanbar@pucp.edu.pe

³ Graduate Student, Pontifical Catholic University of Peru, moscol.ah@pucp.edu.pe

An experimental research was carried out to investigate the effectiveness of economic methods for confining the edges of reinforced masonry walls. The wall edges are usually subjected to high compressive stresses caused by flexure moments due to earthquakes. The comparison considered also the confinement provided by the well known perforated steel plates, which gave good results, but is very costly. The experimental procedure used masonry prisms of concrete blocks filled with grout, The tested specimens included the following: a perforated A-36 steel plate (type A); a

welded thin wire mesh (type B); a stirrup-type A-36 steel plate in each cell (type C); and non-reinforced prisms (type D).

The results gave that type D prisms had a fragile failure, which shows that confinement is necessary. Type A and B prisms gave similar ductility index, with a 20% more capacity for type A, and more than 400% cost than type B. Type C did not have an adequate performance. Therefore, it was concluded that it is possible to use an economic confining method, based on a welded wire mesh in the edges of reinforced masonry walls made of concrete blocks.

Keywords: *Confinements, reinforcement, ductility, concrete blocks, economy.*

EXPERIMENTAL ANALYSIS OF SHEAR WALLS SUBMITTED TO VERTICAL AND HORIZONTAL LOADS

Nascimento Neto, Joel Araújo¹; Corrêa, Márcio Roberto Silva²

¹ PhD, Senior Lecturer, Federal University of Rio Grande do Norte, Civil Engineering Department, joelneto@ct.ufrn.br

² PhD, Associate Professor, São Carlos Engineering School, University of Sao Paulo, mcorrea@sc.usp.br

The masonry construction system is widely used in the world, mainly in developing countries. In Brazil the construction of tall masonry buildings of up to 23 floor levels is usual, which emphasizes the importance of refining the analysis models commonly used in structural designs. Therefore, full knowledge of shear wall behavior is the first stage to developing more accurate mathematical models. Thus, the authors of this work developed an experimental program in 1:3 small scale shear wall models submitted to vertical and horizontal forces. Moreover, these experiments were performed with perforated and non-perforated-panels. In general, the research studies commonly show results that evaluate strength and stiffness loss of panels with openings related to the ones without opening and with the same overall dimensions. However, in the present study the panels with openings consisted of two shear walls without an opening (individual panels) and joined by a lintel, resulting in panels with different overall dimensions from the individual ones. The obtained results showed horizontal forces versus horizontal displacement curves and also the individual stiffness of each panel. This investigation enables quantifying the expressive increasing stiffness due to the lintels, thus enabling to improve the individual shear wall model adopted by structural engineers.

Keywords: *Structural masonry, Shear walls, Experimental analysis, Small scale model.*

THE INFLUENCE OF ARCHITECTURE FLEXIBILITY IN MASONRY STRUCTURE DESIGNING

Mamede, Fabiana Cristina¹; Freitas, Augusto Guimarães Pedreira²

¹ Msc, Civil Engineer, Pedreira Engenharia Ltda, fabiana@pedreira.eng.br;

² Civil Engineer, Pedreira Engenharia Ltda, augusto@pedreira.eng.br

For the last few years, a big increase in the Brazilian Real Estate Market, together with Government's program resulted in a great demand for popular buildings. To fulfil the demand of building with lower costs, a very used system is the structural masonry. The highly competitive and demanding market required differentiation in the apartments, thus making development of projects with some flexibility, such as: openings for pass-through, kitchen balcony, hydraulic walls, and enlarge living rooms. These flexibilities brought the use of non-structure walls or even of taking out a whole wall. This has to be considered in the designing of structures and has direct consequences in its behaviour. The purpose of this paper is to present and compare the consequences of architecture flexibility in masonry structure designing for load distribution, wall resistance, use of materials and the interference in foundation. The procedure used in this work is a computational simulation of a structural masonry project in CAD/TQS Alvest system for a five floor building with four two-bedroom apartments in each floor. Three different situations were considered: architecture with no flexibility, with little flexibility considering an opening for a kitchen balcony, and a greater flexibility taking out a wall to enlarge a living room and to make a hydraulic wall. The results show that all flexibilities cause changes in project; however the ones that are considered small are diluted in the cost of the project, while the greater ones increase significantly and make great impact in the final cost of the structure.

Keywords: *Design, masonry, architecture flexibility.*

SHEAR TRANSFER CAPACITY OF ALTERNATIVE MATERIALS FOR HORIZONTAL SLIP JOINTS IN MASONRY

Totoev, Yuri Zarevich¹; Simundic, Goran².

¹ PhD, Senior Lecturer, University of Newcastle, Centre for Infrastructure Performance and Reliability, yuri.totoev@newcastle.edu.au

² MEng, Laboratory Manager, University of Newcastle, Centre for Infrastructure Performance and Reliability, goran.simundic@newcastle.edu.au

Masonry structures contain slip joints between concrete slabs and their supporting masonry walls to accommodate differential movements due to concrete slab shrinkage or thermal effects. Traditionally slip joints consist of one or two layers of a membrane type material placed between the masonry and the concrete. These materials are usually an embossed polythene, greased steel or bitumen-coated aluminium.

According to Australian Standards all structures must be designed for earthquake loading. Therefore the slip joints must satisfy two apparently conflicting requirements - slip under long-term loads and transmit short-term earthquake loads. Tests at the Universities of Newcastle and Adelaide have indicated that these types of joints exhibit substantial shear capacity under short-term loads. The performance of these joints under induced long-term strains (i.e. differential movement effects) and their potential to behave as slip joints have also been established in thermal expansion tests developed at the University of Newcastle.

It was found that, of all currently used slip joint materials, embossed polythene satisfies both major structural requirements best. It is, however, desirable for the design of shear wall systems to have a wider range of materials available. The purpose of current tests is to check long term shear transfer capacity of alternative materials. Test results will be presented.

Keywords: *Masonry, slip joint, differential movement, embossed polythene.*

CREEP TESTS OF DRY AND SATURED CLAY BLOCK MASONRY PRISMS

Carvalho, Jenner M.¹; Ramos, Luís F.²; Lourenço, Paulo B.³; Roman, Humberto R.⁴

¹ Dr. Professor, Federal Institute Education of Bahia, Applied Sciences Department,
jemicarvalho@gmail.com

² PhD, Assistant Professor, University of Minho, Civil Engineering Department, lramos@civil.uminho.pt

³ PhD, Professor, University of Minho, Civil Engineering Department, pbl@civil.uminho.pt

⁴ PhD, Professor, Federal University of Santa Catarina, Civil Engineering Department,
humberto@ecv.ufsc.br

This work has as main objective to provide the creep coefficient and modulus of elasticity of clay block masonry prisms. For this purpose tests were conducted in specimens in dry and saturated conditions under compression. The first stage was the physical characterization of materials, followed by the preparation of the specimens and subsequent testing the compressive strength of blocks, mortar and prisms. Tests on prisms showed low values of strength and a brittle rupture. This happened close to the maximum strength, when the webs of the upper and lower blocks of the prisms started to collapse and soon after the mortar began cracking, leading to an explosive collapse. Brittleness was more pronounced in dry prisms. From the test results it was possible to obtain values for the final creep coefficient and to calculate the modulus of elasticity in the long term. The results indicated that the ultimate creep coefficient for the saturated condition remained in the range recommended by Eurocode 6, although the value for the dry condition was a little above. Regarding the elastic modulus, it was noticed that there is a decrease of the saturated prisms when compared with the dry prisms.

Keywords: *Testing, creep, uniaxial compression, clay block masonry.*

DEFORMATION CAPACITY OF STRUCTURAL MASONRY: A REVIEW OF EXPERIMENTAL RESEARCH

Salmanpour, Amir Hosein¹; Mojsilović, Nebojša²; Schwartz, Joseph³

¹ MSc, Graduate student, ETH Zurich, Institute of Structural Engineering, salmanpour@ibk.baug.ethz.ch

² PhD, Senior Scientist, ETH Zurich, Institute of Structural Engineering, mojsilovic@ibk.baug.ethz.ch

³ PhD, Professor, ETH Zurich, Institute for Technology in Architecture, schwartz@arch.ethz.ch

A research project on the deformation capacity of unreinforced masonry is underway at the Institute of Structural Engineering of ETH Zurich. The development of the basic building blocks for the deformation-based design of masonry structures is the objective of the present research project, which should be seen as a first step in an initiative to investigate the limits of the deformation capacity of structural masonry.

This paper presents a summary review of previous experimental studies on the deformation capacity of structural masonry. This review is the first phase of a three year long research program, launched by the authors, whose objective is highlighted above. The review included tests on unreinforced, unconfined masonry walls made of clay bricks and bed joints with general purpose mortar. The tests are presented in the form of a database, along with relevant parameters of the material, geometry, loading and type of failure. The presented test results are discussed and a set of conclusions is given. The findings of this review will be incorporated into the abovementioned research project.

Keywords: *Clay block masonry, deformation capacity, load tests, shear wall, structural masonry, URM.*

PRESTRESS LOSS IN WALL-FLOOR CONNECTIONS OF POST-TENSIONED SHEAR WALLS OF CASIEL-TLM MASONRY

Meer, Lex J. van der¹; Martens, Dirk R. W.²; Vermeltfoort, Ad T.³

¹ PhD student, Eindhoven University of Technology (TU/e), Group of Masonry Structures, l.j.v.d.meer@tue.nl

² Professor, TU/e, Chair of Masonry Structures, d.r.w.martens@tue.nl

³ PhD, Associate Professor, TU/e, Group of Masonry Structures, a.t.vermeltfoort@tue.nl

At Eindhoven University of Technology, a project was set up to investigate the mechanical behaviour of high-strength calcium silicate element masonry with thin-layer mortar (CASIEL-TLM masonry), post-tensioned vertically with unbonded tendons. To improve moment and shear capacity of a shear wall with respect to windloading, the bottom storey or storeys of medium-rise buildings (5-15 storeys) can be post-tensioned including the wall-floor connections. An important aspect of the project is the accurate assessment of prestress loss, in particular prestress loss due to

creep and shrinkage of the high-strength CASIEL-TLM masonry, including the wall-floor connection. To investigate this aspect, three series of large specimens (175 x 175 x 1100 mm³) were tested for a period of 300 days each. The first and third series focussed on the CASIEL-TLM masonry itself. The second series concerned the wall-floor connection, which contains a 30 mm kicker course joint. This layer of mortar is used for smooth and plumb set-out of the wall. The results of the second series are presented in this paper. The specimens consisted of from bottom to top, 435 mm CASIEL, 200 mm concrete, 30 mm kicker course mortar and again 435 mm CASIEL. Three unloaded control specimens were used to measure shrinkage, two specimens were used to measure creep at 4.25 MPa and two specimens to measure prestress loss at 4.25 MPa. The measured prestress loss after 300 days was 29% for the test setup used. Translated to building practice, predicted prestress loss after 50 years would be 13% for a typical prestressed wall. This amount of prestress loss is modest and shows that CASIEL-TLM masonry, including the wall-floor connections, is suitable for post-tensioning.

Keywords: *Post-tensioned masonry, shear wall, prestress loss, creep, shrinkage, experimental research.*

FAILURE MODE, DEFORMABILITY AND STRENGTH OF MASONRY WALLS

Mohamad, Gihad¹; Lourenço, Paulo Brandão²; Rizzatti, Eduardo¹; Roman, Humberto Ramos³; Nakanishi, Elizabete Yukiko⁴

¹ Dr., Professor, Federal University of Santa Maria, Civil Engineering Department, gihad.civil@gmail.com; edu_rizzatti@yahoo.com.br

² PhD, Professor, University of Minho, Civil Engineering Department, pbl@civil.uminho.pt

³ PhD, Professor, Federal University of Santa Catarina, Civil Engineering Department, humberto@ecv.ufsc.br

⁴ Dra., Professora, Federal University of Pampa, Civil Engineering Department, elizabete_nakanishi@hotmail.com

For materials such as concrete, the understanding of the failure mode, deformability and strength of block masonry walls are important to simulate the behaviour of the assembly. Still now, there are difficulties on determine experimentally results of the interaction between the materials, as concrete block, mortar and the interface between vertical and bedding joint. Because of this, experimental tests of masonry walls were built to get the deformability, failure modes and compressive strength of the masonry. Experimental tests of tensile and compression on blocks had been done. With the conclusion of experimental tests it is possible to verify that the vertical mortar joint was the main responsible for initiated the failure mechanisms of masonry and further studies of masonry built with high adherence mortar are necessary to improve the ratio between compressive strength of wall and blocks.

Keywords: *Masonry, Deformability, Walls, Failure Mode.*

STRESS-STRAIN BEHAVIOR OF CONCRETE BLOCK MASONRY PRISMS UNDER COMPRESSION

**Mohamad, Gihad¹; Lourenço, Paulo Brandão²; Roman, Humberto Ramos³;
Barbosa, Claudius de Souza⁴; Rizzatti, Eduardo¹**

¹ Dr., Professor, Federal University of Santa Maria, Civil Engineering Department, gihad.civil@gmail.com;
edu_rizzatti@yahoo.com.br

² PhD, Professor, University of Minho, Civil Engineering Department, pbl@civil.uminho.pt

³ PhD, Professor, Federal University of Santa Catarina, Civil Engineering Department,
humberto@ecv.ufsc.br

⁴ Dr., Professor, São Paulo University, São Carlos School of Engineering, Structural Department,
claudiusbarbosa@yahoo.com.br

The aim of this work is to critically assess a stress-strain model using experimental masonry prisms constructed from different blocks and mortar. The following conclusion may be drawn from this work: mortar is mostly responsible for the non-linear behavior of masonry. The initial tangent modulus, obtained taking into account the compressive strength, provides a strongly non-linear relationship between elasticity modulus and compressive strength.

Keywords: *Concrete Block, Masonry Prisms Stress-Strain.*

DEVELOPMENT AND USE OF A NEW TYPE OF CONCRETE MASONRY UNIT

Massetto, Leonardo Tolaine¹; Tauil, Carlos Alberto³; Guimarães, Mário Sergio⁴

¹MSc, Civil Engineer, leonardo@glasser.com.br

² Architect Carlos Alberto Tauil, carlosalberto.tauil@gmail.com

³ Comercial Manager, Glasser Pisos e Pré-Moldados, mario@glasser.com.br

In the early 1990's a concrete block industry developed a new type of concrete masonry unit. The main changes are the cells geometry modification and the block walls thickness reduction. Laboratory tests attested that components mechanical strength and other block properties were consistent with Brazilian Standards. But the block wasn't able to be used as structural masonry unit due to the reduction in block walls thickness.

At this time São Paulo Municipality launched a wide urban redevelopment project and the replacement of "favelas" for multi storey buildings, named Cingapura Project. It was based on 5 storey (Ground Floor + 4 Storey) structural masonry buildings. It was implemented in several city regions totaling over 130.000 m² (square meters) constructed area and around 3.000 apartments.

To evaluate the new block technical viability as structural masonry element for the Cingapura Project, the company conducted a large test program. Compression tests were performed on grouted (reinforced) and hollow walls, diagonal tension tests on hollow walls, and flexion-compression tests on hollow walls. As complement, site load tests were conducted on buildings

made of structural masonry block and also on the new block, providing satisfactory structural performance. The study's findings were sufficient to allow the new block use in São Paulo housing project and many other similar typology buildings. The product was a success and is being widely used until nowadays.

This paper presents the new block development stages and presents the study results summaries. During the period of Brazilian Standard NBR 6136/2006 revision, the study comprehensiveness and strength supported the development of a new class of concrete hollow blocks (Blocks "C" class).

Keywords: CMU manufacturer, innovation, masonry, special masonry unit.

DEVELOPMENT OF MASONRY MODULAR PRODUCTION SYSTEM

Massetto, Leonardo Tolaine¹; Sabbatini, Fernando Henrique²; Tauil, Carlos Alberto³; Guimarães, Mário Sergio⁴

¹ MSc, Civil Engineer, leonardo@glasser.com.br

² PhD, Professor, São Paulo University, Civil Engineering Department, Fernando.sabbatini@poli.usp.br

³ Architect Carlos Alberto Tauil, carlosalberto.tauil@gmail.com

⁴ Comercial Manager, Glasser Pisos e Pré-Moldados, mario@glasser.com.br

To increase concrete hollow blocks sales and profits, in the early 2000's, a major Brazilian concrete block industry launched in São Paulo market a Modular Production System for Nonloadbearing Walls (for partition and exterior walls). This technological innovation was named SVM (Modular Masonry System, in portuguese) and combine all materials supply (blocks, mortar and accessories), construction workforce, tools and equipments supply, and design technical support. As differentials, the company ensure structural performance, building schedule (agreed on contract), and agreed price. This new product was developed in São Paulo, Brazil, where the industry conducted more than 50 building sites with this technology.

This paper presents all aspects related to product development (quality manuals, project guidelines, building procedures, product development and R&D), management and commercial development (partnership shaping, commercial strategies, management procedures), plus the building phases and control (workforce training, technological selection, management and production control).

Conclusions demonstrate the economic viability of this building system. The system also raised awareness about concrete block masonry performance characteristics, since it remains largely used as nonloadbearing walls.

Keywords: CMU manufacturer, masonry innovation, construction system.

DIGITALLY AUGMENTED MASONRY: APPLICATIONS OF DIGITAL TECHNOLOGIES TO THE DESIGN AND CONSTRUCTION OF UNCONVENTIONAL MASONRY STRUCTURES

Al-Haddad, Tristan¹; Gentry, T. Russell²; Cavieres, Andres³; Thai, Trang⁴

¹ Assistant Professor, Georgia Institute of Technology, School of Architecture, tristan.al-haddad@coa.gatech.edu

² PhD, Associate Professor, Georgia Institute of Technology, School of Architecture, russell.gentry@coa.gatech.edu

³ PhD Candidate, Georgia Institute of Technology, School of Architecture, andres.cavieres@gatech.edu

⁴ PhD Candidate, Georgia Institute of Technology, School of Electrical Engineering, trang.thai@gatech.edu

This paper broadly considers the question of linking the representation of a structure to the actual process of physical construction through advanced parametric CAD and digital construction tools and technologies. The intent of this research is twofold: first to develop methodologies to assist architects and engineers working with parametric representations of complex masonry projects such that construction constraints can be used as embedded design parameters during schematic design; and second to explore how digital technologies are able to assist masons during the physical construction of complex masonry walls. This paper is an extension of previous research on masonry design rules and computational representations towards the development of digitally enabled assistive technologies for construction of complex masonry structures.

Keywords: *Parametric Modeling, Digital Fabrication, Augmented Reality, Variability, Non-Standard Construction.*

HISTORY AND DEVELOPMENT OF CMU MARKET IN BRAZIL FOR THE LAST 40 YEARS

Massetto, Leonardo Tolaine¹; Tauil, Carlos Alberto²; Guimarães, Mário Sergio³

¹ MSc, Civil Engineer, leonardo@glasser.com.br

² Architect Carlos Alberto Tauil, carlosalberto.tauil@gmail.com

³ Comercial Manager, Glasser Pisos e Pré-Moldados, mario@glasser.com.br

In Brazil, structural masonry with concrete blocks began in the 1960s. During the 1970s has occurred a big prosperity of this building system development. At the time, housing constructions developed and many industries were built. High production machineries were imported and the national industry for block production equipment began to develop. The technical development

also occurs rapidly. Emerge the initial structural masonry design (calculation) offices. The initial symposiums and conferences take place and allow quickly technological development. The 1980s decade had a big stagnation and the construction barely increased. From 2006 the Brazilian construction sector enters a period of high growth. Credit offer and governmental programs promote middle and low classes focused constructions, were there's a large housing deficit. Concrete blocks structural masonry returns to be large used and the block demand grows every year. In this perspective, this paper aim to do a brief historical review about the Structural Masonry Building System in Brazil, since its initial years till today. Through extensive literature research and mainly through interviews, with big names who participated (and are participating till today) of this development, information were collected for this work. The paper focus, on chronological way, this evolution aspects contemplating: technological development, companies, professionals and technical publications. The article shows that the structural masonry development in Brazil was achieved with some professionals great effort and determination. Besides, in a high demand moment (since 2006), the technological development allowed this Building System consolidation as a viable alternative and highly competitive.

Keywords: CMU manufacturer, innovation, masonry, structural masonry history.

EFFECTS OF DEWATERING ON LONG TERM MOVEMENT CHARACTERISTICS OF LIME MORTARS

**Kioy, Stella¹; Walker, Peter²; Ball, Richard³; Fodde, Enrico⁴; Peter, Ulrike⁵;
Lesueur, Didier⁶**

¹ Student, University of Bath, Architecture and Civil Engineering Department, S.M.Kioy@bath.ac.uk

² PhD, Professor, University of Bath, Architecture and Civil Engineering Department,
P.Walker@bath.ac.uk

³ PhD, Lecturer, University of Bath, Architecture and Civil Engineering Department, R.J.Ball@bath.ac.uk

⁴ PhD, Lecturer, University of Bath, Architecture and Civil Engineering Department, E.Fodde@bath.ac.uk

⁵ PhD, R&D Engineer – Building Construction, Lhoist Recherche et Développement,
Ulrike.Peter@lhoist.com

⁶ PhD, Materials R&D Manager, Lhoist Recherche et Développement, Didier.Lesueur@lhoist.com

The lower strength and stiffness of lime mortars, compared to cement mortars, can be regarded as beneficial for the movement characteristics of the masonry. Traditional solid lime mortared masonry typically have much fewer, if any, movement joints compared to higher strength (but thinner) cement mortared walls. The modern revival in lime mortar use offers the potential to revise specifications of movement joints in modern masonry construction. However, there are presently little experimental data on which to base any design recommendations. This paper summarises findings from an experimental study on the effects of dewatering, by the brick during construction, on the movement characteristics of lime mortar specimens. The specimens have been prepared for simulating dewatering effects of bricks on mortar development using prismatic (40mm x 40mm x 160mm) and cylindrical specimens (18mm diameter x 36mm long). The effects of dewatering on strength development and creep performance are reported and supported by microstructural development of materials. This research is part of a wider programme aimed

at improving understanding of movement characteristics of lime mortars and masonry looking at the effects of different brick properties and mortar mix designs. In order to improve the understanding of movement in lime mortars, the creep testing method is compared to those documented by other researchers.

Keywords: *hydrated lime, mortars, dewatering, creep.*

EXPERIMENTAL CHARACTERIZATION OF MORTAR BY TESTING ON SMALL SPECIMENS

Benedetti, Andrea¹; Pelà, Luca²

¹ PhD, Professor, University of Bologna, DICAM Department, andrea.benedetti@unibo.it

² PhD, Lecturer, Technical University of Catalonia (UPC), DEC Department, luca.pela@upc.edu

The experimental characterization of mortar mechanical properties in existing masonry constructions is considerably complex. Whereas bricks parameters can be assessed with a sufficient precision, the mortar properties are very difficult to obtain and the results are highly dispersed. For instance, the in-situ techniques based on the measurement of the amount of energy required to drill a small cavity provide very scattered values that should be handled cautiously. Also, the characterization of existing mortar joints by means of surface testing may be difficult, since the surface decay or even the presence of new restoration mortar may spoil the results. On the other hand, tests on small mortar cubes or double punch tests usually lead to inaccurate estimates of mechanical characteristics, since the confining effect exercised by bricks on the mortar layer is completely disregarded. Another difficulty is the extraction of undisturbed specimens from the joints of existing brickwork.

Such problems can be overcome by laboratory destructive testing on small specimens including both bricks and mortar. This activity is suitable for existing historic buildings, since it does not inflict severe damage on the structural element.

This work presents the results of a comprehensive experimental program on cores including a central mortar layer along a symmetry plane. Such specimens were easily extracted by different panels of an existing historical building using a common core drill. The cores were subjected to splitting test with a particular set-up, providing 30°, 45° or 60° inclinations of the mortar layer with respect to the loading plane. This test induces a mixed compression–shear stress state in the central mortar layer. The experimental results have been interpreted using different failure criteria in order to assess the mechanical properties of mortar.

Keywords: *Mortar Characterization, Laboratory Testing, Splitting Test.*

USE OF POZZOLAN IN REINFORCEMENT MORTAR FOR NON-STRUCTURAL MASONRY

Mota, João Manoel de Freitas¹; Oliveira, Romilde Almeida²

¹ MSc, Doctorate Student, Federal University of Pernambuco, Civil Engineering Department,
joão@vieiramota.com.br

² D.Sc., Permanent Professor, Federal University of Pernambuco, Graduate Program Civil Engineering,
Professor, Catholic University of Pernambuco, Civil Engineering Department,
romildealmeida@gmail.com

In the metropolitan area of Recife (Brazil), the existence of several buildings known as “caixão” with up to four floors and built with non-structural block is perceived. These non-structural masonries have been used for structural purposes and were designed without technological basis and relevant technical standards. The materials used, basically the blocks, do not have satisfactory performance. Several surveys were carried out in order to better understand the behavior of these buildings and establish a way of strengthening aiming at an adequate performance in service, and ensuring conditions for durability. It was verified that the mortar coating contributes to the hardness of the walls. This suggests the use of mortar with addition of pozzolan with steel as reinforcement, due to substantial increases in the mechanical properties and related durability. This study evaluates the influence of the metakaoline pozzolan in mortars through experimental studies. The mechanical properties and other related durability at 28 days and 90 days were evaluated. The results indicate that the addition of metakaoline mortars improves the properties studied.

Keywords: *non-structural masonry, reinforced mortar, pozzolan.*

POISSON OF BEDDING MORTAR UNDER MULTI-AXIAL STRESS CONDITIONS

Mohamad, Gihad¹; Lourenço, Paulo Brandão²; Roman, Humberto Ramos³; Rizzatti, Eduardo¹; Sartori, Tatiane⁴

¹ Dr., Professor, Federal University of Santa Maria, Civil Engineering Department, gihad.civil@gmail.com;
edu_rizzatti@yahoo.com.br;

² PhD, Professor, University of Minho, Civil Engineering Department, pbl@civil.uminho.pt

³ PhD, Professor, Federal University of Santa Catarina, Civil Engineering Department,
humberto@ecv.ufsc.br

⁴ Federal University of Santa Maria, Master Science Student on Production Engineering Department,
tatianesartori@yahoo.com.br

The main goal of this work is the understanding of triaxial compression capacity of bedding mortar. It was observed by the experimental tests that the behavior of the stress and strain response is highly nonlinear and depends on the increase of lateral stress. In all studies presented here, the ultimate strength envelope of triaxial mortar can be represented by a linear function with

similar angular coefficients. It was observed a significant reduction in the Poisson ratio of mortar with increasing confined stress. This decrease is apparently exponential for mortars types 1:1:6 and 1:2:9 (proportion on volume of cement:lime:sand) and linear for mortars type 1:0.25:3 and 1:0.5:4.5. A simple model is proposed to represent modification of the Poisson ratio throughout the normalized stress range.

Keywords: *Poisson behavior, Bedding mortar and Multi-axial stress state.*

SUSTAINABLE MASONRY: THE IMPORTANCE OF MORTAR QUALITY

F. Verhelst¹, E. Kjaer², W. Jaeger³, B. Middendorf⁴, K. Van Balen⁵, P. Walker⁶

¹ EuLA, Mortar task force, Frederik.verhelst@lhoist.com

² Chief engineer, Danish Technological Institute, ehk@teknologisk.dk

³ Prof. Dr.-Ing., Technische Universität Dresden, Structural Design, w.jaeger@jaeger-ingenieure.de

⁴ Prof. Dr., TU Dortmund University, Department of Building Materials, bernhard.middendorf@tu-dortmund.de

⁵ Prof. Dr., Katholieke Universiteit Leuven, Civil engineering, koenraad.vanbalen@bwk.kuleuven.be

⁶ Professor, Director of the BRE Centre for Innovative Construction Materials, Department of Architecture and Civil Engineering, University of Bath, p.walker@bath.ac.uk

Looking to historic as well as to modern buildings, we notice the durability of masonry structures. A well-built masonry structure provides a long term sustainable solution by virtue of its durability, adaptability and maintainability.

However, building practice is rapidly changing in the last decade with increasing expectations on behalf of thermal performance of our buildings. Building speed, quality and durability need to be combined if masonry wants to survive in the future mainstream construction industry. Materials will not only need to be durable and sustainable but will also have to contribute to the long lasting performance in relation to energy consumption.

These evolving requirements are creating more stringent expectations towards masonry. Walls are becoming increasingly slender and invoke the need to become less brittle, more elastic, stress resistant and offering better compatibility between mortar and brick (adhesion and relative strength). The masonry sector is in front of major challenges to maintain and renew its traditional image of solid, durable and sustainable building technology.

Lesson for modern masonry practice can be found from current studies of traditional work and materials.

The complex stress state in the mortar explains the ductile behaviour of masonry with low compressive strength, highly deformable mortars.

Inspired by these observations, this evolution is discussed and developed to seek how masonry and its components can answer to these requirements to be a sustainable mainstream building material with future.

Keywords: *Sustainability, durability, masonry, mortars, standards, lime.*

CONSTRUCTION TECHNOLOGY OF INTERNAL GYPSUM BLOCK PARTITIONING

Lordsleem Jr., Alberto Casado¹; Neves, Maria Luíza Rodrigues²

¹ PhD, Professor, University of Pernambuco, Civil Engineering Department, acasado@poli.br

² MSc, Civil Engineering, University of Pernambuco, Civil Engineering Department,
mluizaneves@yahoo.com.br

The latest interest in the execution of internal gypsum block partitioning is emerging as an alternative to brick walls. However, there is still great lack of knowledge about its production technology, as well its behavior, and the fledgling research is conducted in Brazil on this issue, unlike other countries where its use has a historical tradition. In this context, this paper aims to systematize the existing knowledge on the construction method of internal gypsum block partitioning in multi-floor buildings. The research methodology consisted of examining the state of the art, in an attempt to characterize the materials, components, equipment and tools required to build gypsum block partitioning. The case studies are next discussed to describe the current stage of the process and production design; and to identify the materials, tools and building techniques employed in the service works in progress. The aim is to contribute to the advancement of knowledge of partition production technology and, mainly, to further the development of internal partitioning with gypsum block.

Keywords: *Building technology, internal partitioning, gypsum blocks.*

CONTRIBUTION TO THE ADOPTION OF READY WOODEN DOORS IN THE DESIGN OF STRUCTURAL MASONRY BUILDINGS

Grabarz, Regina Candeloro¹; Parsekian, Guilherme Aris²

¹ MSc Candidate, Federal University of São Carlos, Civil Construction Graduated Program,
regina.cg@hotmail.com

² PhD, Professor, Federal University of São Carlos, Civil Engineering Department, parsekian@ufscar.br

In Brazil, the construction industry has experienced moments of great development in recent years, reflecting high demand for products in this booming market, indicating a need for increase productivity and reduces waste of physical and financial resources, through the adoption of techniques and systems that seek to industrialization and rationalization of building. Recently published the Brazilian Code NBR 15873:2010, modular coordination standard for buildings, represent a great influence on the development of all sectors of construction towards industrialization and rationalization, especially when united with the structural masonry construction system. This research proposes a study aiming to contribute to the use of modular coordination in the design of structural masonry, by investigating the dimensional standards appropriate to the element wood door. With this information we to intend diagnose and analyze the dimensional standard of wood door sold in Brazil, in order to verify their application in design

of structural masonry making use of modular coordination. Comparing the Brazilian standard dimensions with the suggested by the research for structural masonry, there was a significant difference, in height 25 mm and in width 30 mm, invalidating the dimensional proposal of the Brazilian standard, NBR 15930-2:2011 (wooden ready doors), to fit in structural masonry buildings. Pointing to the adoption of measures not rationalized as the need to fill the gaps with adjacent materials and to provide service and ahead of time for such work.

Keywords: *Structural Masonry, Ready Wooden Doors, Modular Coordination.*

DESIGN AND SERVICE PROCESSES FOR PRODUCING VERTICAL NON-LOADBEARING MASONRY: SCOPE ANALYSIS

Lordsleem Jr., Alberto Casado¹; Melhado, Silvio Burratino²

¹ PhD, Professor, University of Pernambuco, Civil Engineering Department, acasado@upe.poli.br

² PhD, Professor, University of São Paulo, Civil Engineering Department, silvio.melhado@poli.usp.br

The design for producing non-loadbearing masonry offers high potential for improving the design process in building construction. However, one of the problems worth mentioning is the lack of accurate definition of the range of its scope, causing doubts about what, when and how it should be prepared, developed and delivered by the designers. The main purpose of this paper is to investigate and analyse the application of the scopes of the designs and services of vertical non-loadbearing masonry in building construction using case studies in the cities of Recife and São Paulo in Brazil. The results obtained have shown that achieving (conformity) the reference scope adopted – the Brazilian Association of Design Managers and Coordinators (AGESC) handbook – averaged 61% (builders) and 56% (designers). Lastly, it gives guidelines on scope of how to use the AGESC handbook on design and services of vertical non-load-bearing masonry, describing potential uses and stressing the contributions to greater integration between expectations and resulting products, to more rationally facilitate the design and execution of non-loadbearing masonry in building construction.

Keywords: *Design, non-loadbearing masonry; scope; building construction.*

SEISMIC BEHAVIOR OF CONFINED MASONRY WALLS REINFORCED WITH WELDED STEEL AND DUCTILE STEEL

San Bartolomé Angel¹; Quiun, Daniel²

¹ Professor, Pontifical Catholic University of Peru, Civil Engineering Department, asanbar@pucp.edu.pe

² Professor, Pontifical Catholic University of Peru, Civil Engineering Department, dquiun@pucp.edu.pe

An experimental research was performed to investigate the possibility of using industrially prepared welded steel bar assemblies in the columns of confined masonry buildings, instead of the conventional ductile deformed bars. The tests were performed at the Laboratory of Structures of the Catholic University of Peru. Six full scale confined masonry walls were built varying the type of steel assemblage in the confining columns. In three of these walls, ductile deformed bars were used, with 9.5mm, 12.7mm and 16.0 mm diameter. In the other three walls, welded steel bar assemblies were used, which are equivalent to the ductile ones. All the walls were tested under cyclic lateral load for comparison of the seismic behaviour.

Among the conclusions obtained, concerning the failure type, a flexural failure was observed in two of the walls with less amount of vertical reinforcement in the columns; the other four walls had a shear failure predominantly. In all cases, the walls with equivalent steel assemblies had similar behaviour. In overall, it was found that it is possible the use of welded bar assemblies instead of the traditional bars, provided a similar tension yield force in the columns, which let us save around 16% in steel.

Keywords: *Confinements, reinforcement, columns, welded, assemblies.*

EXPERIMENTAL EVALUATION OF THE COEFFICIENT OF RESTITUTION OF ROCKING STONE MASONRY FAÇADES

Costa, Alexandre A.¹; António Arêde²; Andrea Penna³; Aníbal Costa⁴

¹ PhD student, Faculty of Engineering, University of Porto, Department of Civil Engineering, aacosta@fe.up.pt

² PhD, Associate Professor, Faculty of Engineering, University of Porto, Department of Civil Engineering, aarede@fe.up.pt

³ PhD, Researcher, European Centre for Training and Research on Earthquake Engineering, andrea.penna@eucentre.it

⁴ PhD, Full Professor, University of Aveiro, Department of Civil Engineering, agc@ua.pt

Masonry façades are known to behave poorly under seismic actions being one of the main goals of worldwide research to simulate adequately the dynamic behaviour of these elements. The simulation of masonry façades as rigid bodies with dynamic characteristics is one of the possible solutions to assess the dynamic behaviour of existing structures. Taking this into account, an

experimental test procedure is presented to assess one main parameter (coefficient of restitution) that influences the global response of a rocking system.

The test procedure is fully described concerning the experimental test apparatus and monitoring devices, as well as the obtained experimental results and their correlation to theoretical values. Finally, some conclusions are drawn regarding the efficiency of the test procedure and the obtained values for the coefficient of restitution.

Keywords: *Coefficient of restitution, rocking, stone masonry, out-of-plane.*

ENERGY DISSIPATION AND STIFFNESS IDENTIFICATION OF UNREINFORCED MASONRY

Zimmermann, Thomas¹; Strauss, Alfred²; Konrad Bergmeister³

¹ Research Ass., University of Natural Resources and Life Sciences, Institute for Structural Engineering, zimmermann.thomas@boku.ac.at

² Associate Professor, University of Natural Resources and Life Sciences, Institute for Structural Engineering, Alfred.strauss@boku.ac.at

³ Professor, University of Natural Resources and Life Sciences, Institute for Structural Engineering, Konrad.Bergmeister@boku.ac.at

Old masonry buildings are a huge part of European cities' appearance. The image of these buildings and structures varies from region to region, but all of them are representing previous standards of architecture and engineering.

To determine the safety of these structures against earthquakes is a complex challenge. It depends on the resistance of the structure, the seismic action and on many of uncertain structural details. Therefore the seismic impact itself and the behaviour of masonry under seismic loads is of high interest.

The design of masonry structures to resist earthquakes is normally a combination of experience and modern engineering knowledge, which is based on experimental research. Normally the design of a building is released in order to structural requirements and the seismic resistance which is verified by calculations according to valid standard, i.e. in Europe, Eurocode 8. A lot of research and experimental work has been done in seismic behaviour of masonry structures in the last decades. Thereby new methods for seismic resistance evaluation and design, as well as new seismic resistant technologies and construction systems have been developed. Nevertheless these research studies and methods are mainly focused on new brick material. In case of new masonry structures the criteria against earthquake impacts, according to Eurocode 8 standard, can be easily fulfilled. On the other hand it is rather difficult to fulfil the Eurocode 8 demands and reliability requirements for old masonry structures and heritage buildings without adequate strengthening.

Laboratory tests on large unreinforced masonry walls have been performed to determine characteristic material parameters, like energy dissipation, stiffness and stiffness degradation, available resistance capacity and behaviour factor, of old masonry. The objective of this paper is to present and discuss the experimental program, as well as the results of these tests amongst others.

Keywords: *masonry, energy dissipation, stiffness, seismic behavior.*

IMPROVED NEUTRON-BASED SYSTEM FOR NDE OF SALT CONTAMINATION AND MOISTURE IN HISTORIC MASONRY

Amde M. Amde¹ and Richard A. Livingston²

¹ PhD, Professor, University of Maryland, Department of Civil and Environmental Engineering, College Park, Maryland, USA, @umd.edu

² PhD, Adjunct Professor, University of Maryland, Department of Material Science and Engineering, College Park, Maryland, USA, @umd.edu

Cycles of soluble salt deliquescence and dehydration in historic brick masonry in response to cycles of fluctuating moisture levels are known to have damaging effects over time. Nondestructive determination of the depth and degree of salt contamination and determination of moisture content in historic masonry are among some of the measurements that are needed to design appropriate remedial action. The focus of the paper is on an improved portable nondestructive evaluation system based on prompt gamma neutron activation (PGNA). The system works by irradiating a section of a structure with neutrons from a portable neutron generator. The gamma rays of characteristic energies resulting from interaction with target elements such as hydrogen, chlorine, sulfur, sodium and potassium are detected. The results can be used to map the spatial distribution of soluble salts in the structure. Several case studies and applications of the improved nondestructive evaluation system are discussed. It is concluded that the improved portable nondestructive evaluation system is a useful tool for quantitative analysis of elements associated with moisture, salt and other materials in historic masonry structures.

Keywords: *Nondestructive evaluation, historic masonry, brick masonry, gamma rays, salt contamination, neutron activation.*

INSPECTION AND LIFETIME ASSESSMENT FOR ARCH BRIDGES

Krawtschuk, Alexander¹; Strauss, Alfred²; Wendner, Roman³; Zeman Oliver⁴

¹ PhD Student, University of Natural Resources and Life Sciences Vienna, Department of Civil Engineering, alexander.krawtschuk@boku.ac.at

² Assoc. Professor, University of Natural Resources and Life Sciences Vienna, Department of Civil Engineering, alfred.strauss@boku.ac.at

³ Visiting Research Fellow, Northwestern University, Department of Civil and Environmental Engineering, r-wendner@northwestern.edu

⁴ Student Assistant, University of Natural Resources and Life Sciences Vienna, Department of Civil Engineering, oliver.zeman@boku.ac.at

Arch bridges made from nature stone nowadays are the oldest structures which are still in use on road and railway lines. With an average age of more than hundred years, these structures often are

seen as historical important buildings. Most of them had been constructed during the great building period of roads and railways from the 1840ies to 1900. Lots of the considered nature stone bridges are constructed as circle or three center curve, some of them also in a parabolic form or catenaries or cycloide. The height of the apex cover varies in a large range. If masonry was appropriated, usually sand, chalkstone or clay bricks were used. For most bridges no observations of the material parameter are available, as a result the stone and the mortar strengths are unknown. Under the usage of the German railway company, there are more than 8000 arch bridges yet, although at local roads there is an additional unknown number of them. In Austria, the railway network, especially along the southern railway line has around 1000 arch bridges in usage. In whole Europe, the stock of masonry railway bridges is estimated with around 70.000. In the course of route expansion plans in the past especially arch bridges have been replaced by new steel or reinforced concrete structures. Considerations of preservation, the budgetary situation of the rail and road operators, as well as a sustainable, resource efficient usage of resources and existing infrastructure are motivations to maintain and – if necessary – toughen up existing arch bridges. Therefore, the issues of sustainability, durability and serviceability become more important.

Keywords: Arch bridge, railroad, FE modelling, monitoring system, life time assessment.

UNCERTANTIES IN THE ASSESSMENT OF THE SEISMIC VULNERABILITY OF STONE MASONRY BUILDINGS

Bosiljkov, Vlatko¹; Cotič, Patricia²; Uranjek, Mojmir³ and Kržan, Meta⁴

¹ Assist. Prof., Univ. of Ljubljana, Fac. of Civ. and Geod. Eng., Ljubljana, Slovenia, vbosiljk@fgg.uni-lj.si

² Res. Assist., Institute for mathematics, physics and mechanics, Ljubljana, Slovenia,
patricia.cotic@imfm.si

³ PhD, Building and Civil Engineering Institute ZRMK Ljubljana, Slovenia, mojmir.uranjek@gi-zrmk.si

⁴ Res. Assist., University of Ljubljana, Faculty of Civil and Geodetic Engineering, meta.krzan@fgg.uni-lj.si

Following extensive on-site campaign of testing existing stone masonry building severely damaged during the earthquake in NW Slovenia in 2004, reliable set of parameters for the seismic assessment of masonry buildings were gained. Nonlinear seismic analysis of the structure was then evaluated by means of push-over method considering two different responses of structure: storey (SREMB) and global response mechanisms (3MURI). Material parameters for seismic analysis were determined according to the current design practice and according to in-situ test results. Additionally, following crack-pattern survey, local seismic assessment of the structure was made by using FaMIVE method, considering various kinematic mechanisms. Local seismic assessment provides more conservative results, implying that prior effective global response assessment proper detailing and tying of structural elements should be provided. Models for nonlinear seismic analysis are more susceptible depending on the set of material parameters used for the seismic analysis. Results gained from global analysis of structure seem to be more realistic in comparison to storey mechanisms response. By comparison of calculated frequencies of the structure and measured free-field frequencies of soil sediments for Bovec basin it was concluded that some of the damage was amplified due to resonance effect. This implies that prior intervention/strengthening of the building this phenomenon should be investigated, as some of the

strengthening techniques might not be effective as they were predicted solely by numerical modelling.

Keywords: *seismic assessment, masonry structure, stone masonry, in-situ test, non-linear analysis.*

OUT-OF-PLANE IN SITU CYCLIC TESTING OF UNREINFORCED STONE MASONRY WALLS WITH DISTRIBUTED LOADS

Aníbal Costa¹; Alexandre A. Costa²; António Arêde³; Fábio Garcia⁴; Tiago Ferreira⁵; Humberto Varum⁶

¹ PhD, Full Professor, University of Aveiro, Department of Civil Engineering, agc@ua.pt

² PhD student, Faculty of Engineering, University of Porto, Department of Civil Engineering, aacosta@fe.up.pt

³ PhD, Professor, Faculty of Engineering, University of Porto, Department of Civil Engineering, aarede@fe.up.pt

⁴ MsC, Researcher, University of Aveiro, Department of Civil Engineering, fabio.garcia@ua.pt

⁵ PhD student, University of Aveiro, Department of Civil Engineering, tmferreira@ua.pt

⁶ PhD, Professor, University of Aveiro, Department of Civil Engineering, hvarum@ua.pt

The present paper reports an in situ experimental test campaign carried out on existing buildings, in order to investigate the seismic behaviour of traditional masonry walls subject to out-of-plane loads. For the testing proposes, an experimental test setup based on a self-equilibrated scheme was developed and optimized to be applied in situ in two specimens on original and strengthened conditions. The obtained results are presented and carefully discussed namely from the reinforcement solutions' efficiency point-of-view, as well as compared to previous experimental data obtained for the same type of masonry walls.

Additionally, a simplified linearized displacement-based procedure was adapted in order to characterize the nonlinear force-displacement relationship for unreinforced traditional masonry walls and to analytically predict the experimental test results. The confrontation between the experimental and the analytical results are presented and discussed.

Keywords: *in situ test, cyclic tests, masonry walls, out-of-plane, strengthening, displacement-based.*

PUSHOVER SEISMIC ANALYSIS OF QUASI-STATIC TESTED CONFINED MASONRY BUILDINGS THROUGH SIMPLIFIED MODEL

Marques, Rui¹; Lourenço, Paulo B.²

¹ MSc, PhD Student, University of Minho, Department of Civil Engineering, marquesmnc@sapo.pt

² PhD, Professor, University of Minho, Department of Civil Engineering, pbl@civil.uminho.pt

The confined masonry typology has been traditionally used for building, and also selected for the reconstruction of recently earthquake-damaged cities, in developing countries responding to the seismic-economic couple. However, most of the procedures in design codes adopted for these countries are force-based, which appear to be inadequate for loading cases under severe earthquakes, where the response in displacement plays the essential role for ultimate (life preservation) limit state. In this work, a worldwide review is made of the experimental response of confined masonry buildings, from which a first storey, shear-dominated, mechanism is mostly identified. Then, two full-scale confined masonry structures with regular and irregular plan configurations, quasi-static tested, are analysed under push-over loading of simplified models of the buildings. The idealized models are based on the use of frame and discrete spring elements, allowing to consider the interaction between the masonry panel and the r.c. confining elements. A comparison between the results of tests and the analytical predictions is made, particularly concerning the base shear-displacement response and the damage patterns. The accuracy of the predictions is very satisfactory, allowing to capture the base shear-displacement response envelope and the general damage trend on the buildings, and thus making the method able for performance-based design procedures.

Keywords: *Confined masonry, building response, quasi-static tests, pushover analysis, simplified model.*

SHAKE-TABLE TESTING OF A 3-STORY, FULL-SCALE, REINFORCED MASONRY WALL SYSTEM

Stavridis, Andreas¹; Mavridis, Marios²; Ahmadi, Farhad³; Shing, Benson⁴; Klingner, Richard⁵; and McLean, David⁶

¹ PhD, Post-doctoral Researcher, University of California at San Diego, La Jolla, California, USA, astavridis@ucsd.edu

² Graduate Research Assistant, University of California at San Diego, La Jolla, California, USA, mavroui@gmail.com

³ Graduate Research Assistant, University of Texas, Austin, Texas, USA, farhad@mail.utexas.edu

⁴ PhD, Professor, University of California at San Diego, La Jolla, California, USA, pshing@ucsd.edu

⁵ PhD, Professor, University of Texas, Austin, Texas, USA, klingner@mail.utexas.edu

⁶ PhD, Professor, Washington State University, Pullman, Washington, mclean@wsu.edu

Between January 12 and February 8, 2011, a 3-story, full-scale, reinforced masonry shear-wall specimen was tested on the large outdoor shake-table at the University of California at San Diego. In this summary report, the characteristics of the specimen are reviewed; its development is described; and its performance in the shake-table testing is summarized. The specimen was very strong and stiff, and suffered little damage when subjected to ground motions with intensities exceeding the maximum considered earthquake (MCE) level. Its performance validates the requirements of the 2008 Masonry Standards Joint Committee (MSJC) Code (used throughout the USA) for design and detailing of special reinforced masonry shear walls.

Keywords: codes and standards, design, earthquakes.

SHAKING TABLE STUDY ON UNREINFORCED MASONRY BUILDINGS

Li, Xiang¹; Li, Qiang²; Zhang, Weiping³; Gu, Xianglin⁴; Lu, Jinbiao⁵

¹ PhD, Associate Professor, Tongji University, Department of Building Engineering, lixiang@tongji.edu.cn

² Postgraduate student, Tongji University, Department of Building Engineering, lane_richard@126.com

³ PhD, Professor, Tongji University, Department of Building Engineering, weiping_zh@tongji.edu.cn

⁴ PhD, Professor, Tongji University, Department of Building Engineering, gxl@tongji.edu.cn

⁵ Bachelor, Director, Shanghai Inspection Centre for Buildings, jzjg2010@163.com

Shaking table tests were carried out on three 1/10 scale models of unreinforced masonry structures. The dynamic properties, responses of acceleration and deformation on the different levels of earthquake were studied. Cracking patterns and collapse modes of the buildings were recorded by a laser generator and digital cameras. It was found that the inter-storey drifts angle could be 1/100 at least before an unreinforced masonry building collapse, and the connection of longitudinal wall and transverse wall was a key factor to affect the collapse mode of the structure under severe earthquakes.

Keywords: unreinforced masonry structure, collapse, shaking table test, out-of-plane stability.

SHAKING TABLE TEST TO ASSESS THE OUT-OF-PLANE BEHAVIOUR OF A STONE MASONRY BUILDING

Costa, Alexandre A.¹; António Arêde²; Alfredo Campos Costa³; Andrea Penna⁴; Aníbal Costa⁵

¹ PhD student, Faculty of Engineering, University of Porto, Department of Civil Engineering, aacosta@fe.up.pt

² PhD, Associate Professor, Faculty of Engineering, University of Porto, Department of Civil Engineering, aarede@fe.up.pt

³ PhD, Senior Researcher, Laboratório Nacional de Engenharia Civil, alf@lnec.pt

⁴ PhD, Researcher, European Centre for Training and Research on Earthquake Engineering, andrea.penna@eucentre.it

⁵ PhD, Full Professor, University of Aveiro, Department of Civil Engineering, agc@ua.pt

The work presented in this article describes a performed shaking table test which was fully oriented to assess the out-of-plane behaviour of a stone masonry building. The tested building, constituted by three leaf stone masonry walls, represents part of an existing structure from Faial island (Azores, Portugal) which was damaged during the 1998 Azores earthquake. All the testing procedure is described, namely the tested building and used monitoring devices, as well as the selection of the input ground motion used on the shaking table test. Finally, some conclusions are presented regarding the obtained results and observed behaviour with some recommendations for seismic assessment of similar structures.

Keywords: *Shaking table, stone masonry, out-of-plane.*

EMPIRICAL FLEXURAL BEHAVIOR APPROACH OF ADOBE MASONRY

Daniel Torrealva¹, Mario Solís², Patricia Santillán¹, Gonzalo Montoya²

¹ Engineering Department, Pontificia Universidad Católica del Perú, dtorrea@pucp.edu.pe

² School of Engineering, Universidad de Sevilla (Spain), msolis@us.es

Adobe masonry is one of the most widespread low cost material used for housing in the world. Unfortunately, it shows very low mechanical strength and it is mainly used in seismic. Therefore, there is a requirement for sustainable and efficient reinforcement techniques, as well as design guidelines based on scientific research to apply them. It is necessary to build healthy and safe earthen houses, as well as to preserve earthen constructions heritage sites, which most of them are in danger of collapse.

Polymeric geogrids have proven to be an efficient reinforcement technique. The dynamic response of geogrid reinforced adobe constructions has been analyzed in dynamic seismic simulation tests. When comparing with non reinforced constructions, they significantly increase the strength of the construction and reduce the danger of collapse under a seismic load.

This paper presents an empirical approach for the assessment of the flexural behavior and flexural strength of adobe masonry, considering the effect of geogrid reinforcement. The approach is based on the analysis of experimental results of bending tests of adobe walls reinforced and non reinforced with geogrids. Analytical models for the flexural behavior were initially based on the constitutive laws of the individual materials. Then, they have been simplified and updated so they agree with experimental moment-curvature relationships.

The analytical approach show that it is necessary to consider the tensile behavior of adobe in order to obtain a realistic moment-curvature relationship. However, in the ultimate state of the wall, tensile strength of adobe can be neglected, and the ultimate flexural strength of the wall is defined by the cracking of adobe under compression or the breakage of the geogrid under tension.

The paper includes a simplified method for the assessment of the ultimate strength of adobe walls, based on similar methods used for reinforced concrete.

Keywords: *adobe masonry, seismic reinforcement, flexural behavior, geogrid reinforcement.*

BENDING CAPACITY OF DRY STACKED LIGHTWEIGHT CONCRETE BLOCK MASONRY

Molnár, Miklós¹; Jönsson, Johan²;

¹ PhD, Assistant Professor, Lund University, Department of Building and Environmental Technology,
miklos.molnar@kstr.lth.se;

² PhD, Assistant Professor, Lund University, Department of Building and Environmental Technology,
johan.jonsson@kstr.lth.se;

Dry stacked light weight concrete block masonry is increasingly used due to its superior productivity compared to standard block masonry. Low bending capacity parallel to the bed joints is however a major drawback. This paper presents the results of an experimental study which has been carried out to improve the bending capacity of dry stacked lightweight concrete block masonry. The effects of following measures have been studied: 1) the blocks have been provided with additional holes forming continuous vertical canals and grouted with concrete; 2) both faces of the dry stacked block masonry have been reinforced with a steel wire mesh embedded in render. The bending capacity has been determined in four-point bending tests. Compared to standard dry stacked masonry the bending capacity increased by: 1) 20 % when the additional, continuous vertical canals were filled with concrete grout; 2) more than five times when steel wire mesh embedded in render was used.

Keywords: *bending capacity, dry stacked, lightweight concrete, grouting, steel wire mesh reinforcement.*

MSJC PROVISIONS FOR THE DESIGN OF MASONRY DEEP BEAMS

Fonseca, Fernando S.¹ and Mathew, Sunup²

¹ PhD, S.E. Associate Professor, Brigham Young University, Department of Civil and Environmental
Engineering, ffonseca@et.byu.edu

² Director of Technical Services, Interstate Brick Company, sunup.mathew@paccoast.com

The theory used for the design of slender beams has a limited applicability to deep beams, resulting in designs that are generally not conservative. Shear warping of the cross section and a combination of diagonal and flexural tension stresses in the body of a deep beam require that deep beam theory be used for design of such members. The Masonry Standards Joint Committee has recently proposed a definition of deep beams as well as design provisions and requirements,

which were approved by appropriate committees and by the public and have been incorporated in the 2011 Building Code Requirements and Specification for Masonry Structures. This article summarized the work conducted by the Flexural and Axial Load subcommittee of the Masonry Standards Joint Committee in developing the deep beam requirements.

Keywords: Codes, Regulations, Deep Beams, Design.

THE DEVELOPMENT OF MASONRY REINFORCED BY BOND BEAMS AND BOND COLUMNS TO RESIST LATERAL LOAD

Geoff, Edgell¹; Andrew, Best²

¹ PhD, Director, CERAM, geoff.edgell@ceram.com

² Group Director, Buro Happold, andrew.best@burohappold.com

In 2009 the Design Guide for Masonry Reinforced by Bond Beams to resist Lateral Loads was published. This represented the culmination of a series of tests on full size walls, small beams and low height walls. The tests demonstrated that large walls could be subdivided into smaller panels by the use of bond beams and that the lateral load resistance was considerable and comparable to walls subdivided by wind posts. The system has now been further developed to include the use of reinforced hollow blockwork columns, which enables walls to be subdivided by both horizontal and vertical reinforced elements. This paper describes the column tests and the development of a revised and extended design guide. A major application of the system is at the Aquatic Centre for the 2012 Olympic Games in London. In this iconic structure the internal blockwork walls are up to 7 m high and are required to accommodate numerous openings for services. The system enables this to be done in an elegant and efficient way and the paper describes how this was achieved.

Keywords: blockwork, lateral loading, bond beams, columns.

EVALUATION OF TECHNICAL CONDITION OF MANSORY STRUCTURES

Jiri Brozovsky¹; Jiri Zach¹

¹ PhD, Assoc. Professor, Brno University of Technology, Faculty of Civil Engineering, Institute of Building Materials and Components Civil Engineering Department, brozovsky.j@fce.vutbr.cz

² PhD, Brno University of Technology, Faculty of Civil Engineering, Institute of Building Materials and Components Civil Engineering Department, zach.j@fce.vutbr.cz.

It is necessary to know exactly the technical state of structures before any masonry rehabilitation works takes place. It means that it is necessary to investigate physical state of particular structure

and properties of building materials. Proper technical investigation includes geometric shape of structure, built in materials, state of surface layers, failures and moisture of masonry. Main property of building materials, which is tested, is compressive strength and according to its results it is possible to classify materials to class and make. For diagnosis of masonry structures we exploit mainly visual evaluation, probe testing, nondestructive methods and in some cases also tests on samples taken from the structure. Important role plays also genesis of masonry materials in particular regions. This knowledge allows informative estimation of built-in materials, in case that it is not possible to carry out any tests on these materials.

Keywords: masonry, testing, non-destructive testing, strength, solid bricks, calcium silicate masonry units.

EVALUATION OF THE EFFECTIVENESS OF MASONRY CONSOLIDATION TREATMENTS BASED ON SCRATCHING TOMOGRAPHY

Dagrain, Fabrice¹; Scaillet, Jean-Christophe²; Modestou, Sevasti³; Ioannou, Ioannis⁴

¹ PhD, University of Mons, Department of Civil Engineering and Structural Mechanics,
fabrice.dagrain@umons.ac.be

² Graduate in Construction, Cellule d'Appui et Contrôle Technique, Direction de la Restauration, Service
Publique de Wallonie, DGO4, jeanchristophe.scaillet@spw.wallonie.be

³ Graduate Researcher, University of Cyprus, Department of Civil and Environmental Engineering,
modestou.sevasti-eleni@ucy.ac.cy.

⁴ Assistant Professor, University of Cyprus, Department of Civil and Environmental Engineering,
ioannis@ucy.ac.cy.

A challenge in the restoration of historical buildings is the correct identification of materials which need to be strengthened in order to guarantee their durability and the evaluation of the results of consolidation treatments which may be applied during their repair. Methods which make such a complex characterization possible are rare. This paper presents an investigation carried out at the University of Mons (Belgium) in collaboration with the Technical Support and Control Unit, Restoration Directorate, of the Walloon Region, aiming to evaluate the effectiveness of consolidants used to strengthen stone masonry. The characterization of the materials is based on a novel semi-destructive scratching method which allows tomographic representation of the strength of the damaged and treated areas. This paper describes the experimental methodology and presents results from laboratory experiments as well as a case study.

Keywords: Consolidation treatment, ethyl silicate, lime wash, scratching test, stones.

RADIATION FROM MASONRY PRODUCTS – MEASUREMENT AND ASSESSMENT

Dieter Rosen¹

¹Technical Director Association of the German Brick and Tile Industry, 53113 Bonn, rosen@ziegel.de

The radiation emanating from standard building materials is extremely low compared to the annual dose of radiation to which the German population is usually exposed. The average radon-222 concentration in room air measures around 50 Bq/m³ in Germany. For new buildings, a design level, corresponding to an average radon gas concentration of 200 Bq/m³ is currently recommended. In future, this value is to be assured with appropriate measures in building design. Building materials only contribute to the radon concentration in indoor air with radon exhalation that is generally lower than 10 Bq/m³. For this reason, in the case of increased radon concentrations in buildings, the determining factor tends to be the sealing effect of building materials rather than these themselves as a source of natural radiation.

The radioactivity of building materials is generally evaluated in the different member states on the basis of a recommendation of the European Commission, the Radiation Protection 112, issued in 1999. The Basic Safety Standards Directive (BSS) published in September 2011 as a Commission proposal that takes up the evaluation concept on the basis of the calculation of an activity concentration index I. If the index evaluation is also to be used in consumer information, e.g. in connection with CE marking, an adjustment of the “dose modeling” to product properties such as density and component thickness is necessary.

Keywords: radon exhalation, gamma radiation, activity concentration index, gamma ray spectrometry.

MECHANICAL PROPERTIES OF MASONRY SAMPLES FOR THEORETICAL MODELING

Sayari Arash¹

¹ PhD, Assistant Professor, Islamic Azad University, Sanandaj Branch, Iran, sayari_51@yahoo.com

Due to different geometries and material properties, masonry is considered as an anisotropic composite material. Mechanical properties of the masonry walls are very important parameters that affect the behaviour of masonry walls under loading.

The mechanical properties of masonry are more complicated than mechanical properties of other construction materials. Elastic modulus (or Young's modulus) is one of the most important parameters in determination of the stiffness of structural elements prior to cracking and is calculated according to the linear part of stress-strain curves. In addition, in order to develop the theoretical modelling, mechanical properties including elastic modulus (Young's modulus) and compressive strength must be taken into account.

In this research, different experiments are designed to measure the elastic modulus and compressive strength of masonry and mortar samples. The results are compared with the published results in this subject area.

Keywords: Masonry, Mechanical properties, Elastic modulus, compressive strength.

QUANTIFYING THE IMPACT OF SOIL DEFECTS ON PLAIN MASONRY BUILDINGS THROUGH A GLOBAL INDICATOR BASED ON A CONTROL-PROFILE APPROACH

Van Parys, Laurent¹; Kaufmann, Olivier²; Bultot, Elodie³

¹ PhD, Professor, University of Mons, Risk Research Team, Mons, Belgium,
laurent.vanparys@umons.ac.be

² PhD, Professor, University of Mons, Risk Research Team, Mons, Belgium,
olivier.kaufmann@umons.ac.be

³ Research Assistant, University of Mons, Risk Research Team, Mons, Belgium,
elodie.bultot@umons.ac.be

Due to the specific weaknesses exhibited by un-reinforced masonries (URM), most of the movements affecting the foundations of a building are likely to induce structural pathologies. Such foundation movements may usually take place as a response to natural or anthropic phenomena inducing local soil defects. In this global framework, it appears useful to dispose of a calculation tool likely to detect and objectively quantify the impact of a feared soil defect on the structure of a given masonry building. Such a tool could be used for prescribing optimal architectural configurations (design approach) as well as for computing eventually required steel reinforcements for some URM parts in the building (retrofitting approach).

After a presentation of contemporary challenges associated with soil-structure interactions, the paper details the original recourse to an automatic control-profile method relying on a simplified FE calculation of the building (continuous elastic material): the global stress state inside the model is scanned through a distributed network of arbitrary control-profiles that constitutes the backbone for detecting an eventual impact and, once the case, for computing a related global indicator. In practice, the proposed algorithm associates, to each control-profile and on the basis of a σ -stress and/or τ -stress profile, a solicitation-based code. The code may, for instance, be expressed in relationship with a fictive pattern of required reinforcement in the profile (standardized approach). Thanks to such particular codes, it becomes possible to objectively compare general stress states for given buildings under given loadings when they are (or not) perturbed by a given soil defect. Once an impact has been detected, it may be quantified through a smart recourse to the computed fictive reinforcement.

The paper illustrates each aspect of the proposed method on the case of a 17th century masonry building located in a city where significant karstic activity has been recognized.

Keywords: *FEM, soil defect, settlement, karstic phenomenon, soil-structure interaction.*

THE INFLUENCE OF MORTAR BEDDING ON THE COMPRESSIVE STRENGTH OF CONCRETE BLOCK MASONRY STRUCTURES

Izquierdo, Orieta Soto¹; Corrêa, Márcio Roberto Silva²; Soto, Indara Izquierdo³

¹ PhD Student, EESC - University of São Paulo, Department of Structural Engineering, orieta@sc.usp.br

² PhD, Associate Professor, EESC - University of São Paulo, Department of Structural Engineering, mcorrea@sc.usp.br

³ PhD Student, EESC - University of São Paulo, Department of Structural Engineering, indara@sc.usp.br

Currently, structural masonry still has some advantages in the construction industry when compared with conventional systems. However, to use this system better, it should be further studied. This research studies the change in compressive strength of structural masonry of concrete blocks due to the type of mortar bedding, comparing full and face-shell bedding. To characterize the materials, experimental tests and compressive strength tests of the units, prisms, and wallettes were also conducted. All materials complied with the standard requirements for their correct use in the experimental tests. The results of the compressive tests of the elements showed that the bedding type significantly influenced the compressive strength of masonry, with full mortar bedding showing better performance. The specimens with full mortar bedding showed higher compressive strengths. Prisms and wallettes with face-shell bedding presented a more fragile failure, showing thick vertical cracks along the cross webs.

Keywords: *Mortar type, adjustment dimensional parts, contact area, structural masonry.*

INVESTIGATION ON USING OF MORTAR AS INFILLING MATERIAL ON CLAY BLOCKWORK

Nascimento, Marcio Rogério¹; Leite, Francisco Cláudio Morato²; Albuquerque, Viviany Melchior³; Roman, Humberto Ramos⁴; Hemckmeier, Roberto⁵; Santos, Marcelo Vieira⁶

¹ MSc, Pos-Grad Student, Federal University of Santa Catarina, Civil Engineering Department, marcioprojetos@hotmail.com

² MSc, Pos-Grad Student, Federal University of Santa Catarina, Civil Engineering Department, morato@uel.br

³ Pos-Grad Student, Federal University of Santa Catarina, Civil Engineering Department, vivianymelchior@hotmail.com

⁴ PhD, Professor, Federal University of Santa Catarina, Civil Engineering Department, humberto@ecv.ufsc.br

⁵ Under-Graduate Student, Federal University of Santa Catarina, Civil Engineering Department, robertohsc@hotmail.com

⁶ Under-Graduate Student, Federal University of Santa Catarina, Civil Engineering Department,
marcelo_vds@hotmail.com

The new Brazilian Standard ABNT NBR 15812-2 (2010) for clay block structural masonry allows the use of mortar to fill the hollow block instead of grout. This may play important role to increase the position of this type of material in the construction market. The aim of this study was to evaluate the efficiency of clay block structural masonry with mortar as infilling material on compression. Three types of industrial dry mortars (Multipli-use, 5 and 10 MPa) and hollow clay blocks with declared nominal resistances of 6, 9, 12 and 15 MPa were used. Preliminary results of compressive strength of molded prisms reveals the technical feasibility of using mortar as infilling material.

Keywords: *Structural masonry, clay blockwork, mortar, grout, prism.*

NUMERICAL SIMULATION OF CONCRETE BLOCK MASONRY UNDER COMPRESSION

Mohamad, Gihad¹; Lourenço, Paulo Brandão²; Roman, Humberto Ramos³; Rizzatti, Eduardo¹; Sartori, Tatiane⁴

¹ Dr. Federal University of Santa Maria, Civil Engineering Department, gihad.civil@gmail.com;
edu_rizzatti@yahoo.com.br;

² PhD, Professor, University of Minho, Civil Engineering Department, pbl@civil.uminho.pt

³ PhD, Professor, Federal University of Santa Catarina, Civil Engineering Department,
humberto@ecv.ufsc.br

⁴ Federal University of Santa Maria, Master Science Student on Production Engineering Department,
tatianesartori@yahoo.com.br

The main goal of this work is evaluate numerical model to reproduce the compression test of concrete block prisms, through a constitutive model of materials using the theory of plasticity and compare its results with experimental tests to preview the stress, strain and failure mode of the masonry. The post peak behavior of the material under tensile followed an exponential law and, under compression, a parabolic criterion was specified for the ascendant and descendent parts of the stress diagram and the hardening parameter. The mortar was connected to the block by the interface, for which the discrete model was employed, where the cracking occurred when the normal stress exceeded the tensile strength of the material.

Keywords: *Non-linear Behavior, Concrete Block Masonry, Interface Elements.*

NUMERICAL SIMULATIONS OF MASONRY LABORATORY TESTS: A SENSITIVITY ANALYSIS OF THE COMPRESSIVE BEHAVIOUR

Sousa, Rui ¹; Sousa, Hipólito²

¹ Msc, Researcher, GEQUALTEC, Faculty of Engineering, University of Porto, Civil Engineering Department, ruysousa@fe.up.pt

² PhD, Professor, GEQUALTEC, Faculty of Engineering, University of Porto, Civil Engineering Department, hipolito@fe.up.pt

The main objective of this paper is to demonstrate how computer simulations of laboratory tests can be useful for studying the compressive behaviour of masonry systems, made with materials with different properties, without consuming too many laboratory resources.

This paper describes a sensitivity analysis applied successfully to a case study, namely in a shell bedded masonry system made with lightweight concrete units that was developed in Portugal for single leaf walls. The sensitivity analysis consisted in computer simulations of simple compressive tests on masonry through the use of 3D Finite Element Method and non-linear constitutive model, which was calibrated through a small number of laboratory tests carried on masonry samples and masonry materials. In the analysis some variations on the properties of the masonry materials (units and joints) was considered, and the results obtained are presented and discussed.

Keywords: *Lightweight concrete masonry, Simple compression, Laboratory tests, Computer simulations, Sensitivity analysis.*

STRENGTH OF MASONRY PRISMS WITH HIGH AMOUNTS OF SUPPLEMENTAL CEMENTITIOUS MATERIALS

Watterson, Scott M.¹; Fonseca, Fernando S.²

¹ Graduate Student, Brigham Young University, Scott.M.Watterson@me.com

² Ph.D., S.E. Associate Professor, Brigham Young University, Department of Civil and Environmental Engineering, ffonseca@et.byu.edu

A masonry prism testing scheme was devised to aid in the determination of whether prisms with grouts possessing high levels of supplemental cementitious materials could meet minimum masonry compressive strength requirements. Class F fly ash and ground granulated blast furnace slag replaced portland cement in large incremental amounts in masonry grout to establish higher use limitations. In conjunction with testing prisms, the variations of grout were tested for their respective compressive strength to determine the correlation between masonry compressive strength and grout compressive strength.

Prisms and grouts underwent standardized testing for maximum compressive strength at age intervals of 14, 28, 42, 56, and 90 days. Seven variations of grout were manufactured in three groups. The first, the control group, contained one grout design with no supplemental cementitious materials and had a portland cement content of 100%. The second group replaced portland cement, by weight, with fly ash in amounts of 45%, 55% and 65%. The third group replaced portland cement with 25% fly ash and 40%, 50% and 60% ground granulated blast furnace slag. The fly ash-slag mixture, thus, replaced portland cement at rates of 65%, 75%, and 85%.

Results indicate that all prisms exceeded minimum compressive strength requirements before the 28 day age period. Not all grout types met the ASTM minimum 13.8 MPa (2000 psi) at 28 days. Neither 55% and 65% fly ash replacements nor the 85% fly ash-slag combination achieved grout strength minimums at the specified age. The grout mixtures manufactured with exceeding addition rates which attained greater than allowed strength at the 28 day age were the 45% fly ash and 75% fly ash-slag combination. All grouts did, eventually, extend their strength gain beyond 13.8 MPa (2000 psi) through the course of testing and all but 65% fly ash achieved this strength within 42 days.

Keywords: *Masonry, Prisms, Grout, Cementitious Materials, Fly Ash, Slag.*

FINITE ELEMENT ANALYSE FOR DAMAGE OF TYPICAL MASONRY SCHOOL BUILDING AND ANTI-SEISMIC STRENGTHENING METHOD

Cui Wei¹; Qu Wenjun²

¹ M.S., Student, Tongji University, Building Engineering Department, 051820@tongji.edu.cn

² Ph.D., Professor, Tongji University, Building Engineering Department, Quwenjun@online.sh.cn

On May 12, 2008, Wenchuan earthquake with Ms 8.0 caused severe damage of school buildings and huge loss of students' lives. Damage investigation indicated that precast holey reinforced concrete (RC) slab is the fatal factor bringing about the collapse of masonry school building. Through the finite element simulation of a typical masonry school building, this paper proves that the inadequate in-plane stiffness of precast holey RC slabs would result in the large deformation longitudinal wall and collapse of whole building afterwards. Then, this paper introduces a new strengthening method-sticking steel strips at bottom of slabs to form truss, and finite element simulation proves that this method is effective to enhance the in-plane stiffness of precast slab.

Keywords: *finite element analyse, masonry school building, in-plane stiffness, strengthening method.*

MASONRY ASSESSMENT FOR THE SEISMIC RISK EVALUATION OF HISTORIC STRUCTURES

**Colla, Camilla¹; Gabrielli, Elena²; Pascale, Giovanni³; Di Tommaso, Angelo⁴;
Ubertini, Francesco⁵**

¹ Research Associated, University of Bologna (Italy), DICAM, camilla.colla@unibo.it

² Ph.D. student, University of Bologna (Italy), DICAM, elena.gabrielli4@unibo.it

³ Professor, University of Bologna (Italy), DICAM, giovanni.pascale@unibo.it

⁴ Professor, University of Bologna (Italy), DICAM, angelo.ditommaso@unibo.it

⁵ Professor, University of Bologna (Italy), DICAM, francesco.ubertini@unibo.it

The preservation of historical and architectural heritage against exceptional events such as earthquakes is one of the most important challenges in Europe. The structural analysis for the seismic risk assessment is generally based on the use of computational methods and requires, as a prerequisite, a good knowledge of the existing structure with regard to the shape, the types of masonry, the mechanical properties, the state conservation and the presence of defects and damage. Semi-destructive methods are available, based on sampling, but their use is to be avoided or minimized on historic structures.

A procedure is proposed in this paper, which is based on the implementation of extensive non-destructive surveys accompanied by limited minimally-destructive testing. As an application, a survey campaign recently carried out on the Ghirlandina Bell Tower in Modena, Italy, is presented. The non-destructive campaign was based on sonic tests. Being aware of the construction phases of the tower and of its various construction materials, the procedure was aimed at identifying uniform areas and portions in which to evaluate the mechanical properties. Furthermore, the tests had the purpose of identifying possible gaps, voids, layering, defects, cracks, detachments and damage. Complete information was obtained concerning the variability of the mechanical properties along the height and the different structural elements. Based on signal velocity values resulting from the non-destructive tests, some locations for semi-destructive testing were chosen. From cores bored on masonry, samples of brick and mortar were obtained. Laboratory tests and data processing were carried out with the aim of obtaining overall information on the mechanical properties of masonry in the tower.

Keywords: *Masonry, assessment, non-destructive testing.*

OBSERVED PERFORMANCE OF RESIDENTIAL MASONRY VENEER CONSTRUCTION IN THE 2010/2011 CANTERBURY EARTHQUAKE SEQUENCE

Dizhur, Dmytro¹; Moon, Lisa M²; Ingham, Jason M³;

¹ PhD Candidate, University of Auckland, Department of Civil and Environmental Engineering,

ddiz001@aucklanduni.ac.nz

² PhD Candidate, University of Adelaide, School of Civil, Environmental and Mining Engineering,

lmoon@civeng.adelaide.edu.au

³ PhD, Associate Professor, University of Auckland, Department of Civil and Environmental Engineering,

j.ingham@auckland.ac.nz

Following the 2010/2011 Canterbury earthquakes a detailed campaign of door to door assessments was conducted in a variety of areas of Christchurch to establish the earthquake performance of residential dwellings having masonry veneer as an external cladding attached to a lightweight timber framing system. Specifically, care was taken to include regions of Christchurch which experienced different levels of earthquake shaking in order to allow comparison between the performance of different systems and different shaking intensities. At the time of the inspections the buildings in the Christchurch region had been repeatedly subjected to large earthquakes, presenting an opportunity for insight into the seismic performance of masonry veneer cladding. In total just under 1100 residential dwellings were inspected throughout the wider Christchurch area, of which 24% were constructed using the older nail-on veneer tie system (prior to 1996) and 76% were constructed using screw fixed ties to comply with the new 1996 standards revision (post-1996), with 30% of all inspected houses being of two storey construction. Of the inspected dwellings 27% had some evidence of liquefaction, ground settlement or lateral spreading. Data such as damage level, damage type, crack widths, level of repair required and other parameters were collected during the survey. A description of the data collection processes and a snapshot of the analysis results are presented within.

Keywords: Residential masonry veneer, Canterbury earthquake, Christchurch earthquake field survey.

PROPOSED TECHNIQUE FOR SEISMIC VULNERABILITY EVALUATION OF SINGLE STOREY UNREINFORCED MASONRY RESIDENTIAL BUILDINGS IN DEVELOPING COUNTRIES

Khalfan, Miqdad¹; Tait, Michael J.²; and El-Dakhakhni, Wael W.³

¹ M.A.Sc. Candidate, Dept. of Civil Engineering, McMaster University, Hamilton, Canada,

miqdad.khalfan@mcmaster.ca

² PhD, Joe NG/JNE Consulting Chair in Design, Construction and Management in Infrastructure Renewal, Dept.

of Civil Engineering, McMaster University, Hamilton, Canada, taitm@mcmaster.ca

³ PhD, Martini, Mascarin and George Chair in Masonry Design, Dept. of Civil Engineering, McMaster

University, Hamilton, Canada, eldak@mcmaster.ca

Developing countries are extremely susceptible to seismic disasters because of their socioeconomic inadequacies and vulnerabilities of prevailing non-engineered structures. Post-earthquake damage data is extremely useful in assessing seismic risk, particularly in developing countries. Fragility curves are derived using empirical, analytical, expert-opinion, or hybrid methods depending on the type of damage data source. A review of existing fragility curves for single storey homes indicates there is a serious lack of data that is needed for empirically deriving fragility curves for residential dwellings in developing countries. A proposed methodology for the derivation of fragility curves of single storey brick masonry homes for seismic risk assessment purposes using post-earthquake damage data is presented herein. As a case study, ShakeMaps in GIS format are used to provide ground motion data together with building damage states from post-earthquake surveys after the May 27th, 2006 earthquake in Indonesia, to construct relevant damage probability matrices and fragility curves.

Keywords: *Developing countries, Empirical, Fragility curves, GIS, Seismic vulnerability, ShakeMap, shapefile.*

SEISMIC SAFETY ASSESSMENT OF THE CHURCH OF MONASTERY OF JERÓNIMOS, PORTUGAL

Lourenço, Paulo B.¹; Roque, João²; Oliveira, Daniel V.³

¹ PhD, Professor, University of Minho, ISISE, pbl@civil.uminho.pt

² PhD, Adjunct Professor, Polytechnic Institute of Bragança, ISISE, jroque@ipb.pt

³ PhD, Assistant Professor, University of Minho, ISISE, danvco@civil.uminho.pt

Preservation of historical constructions with high cultural heritage value is an actual theme in modern societies as these constructions play an important role in the industry of tourism and culture, and consequently in the economy and in the image of countries and self-esteem of people. The seismic hazard of Portugal and, due to its vicinity, of the Mediterranean basin puts under potential risk of damage and collapse a high number of historical constructions, namely most of the old masonry constructions, particularly vulnerable to seismic actions. The seismic behaviour of the Church of Monastery of Jerónimos, Portugal, is discussed here with a numerical simulation, using artificial seismic acceleration time histories in agreement with three seismic hazard scenarios for 475, 975 and 5000 years return periods, allowing to assess its seismic safety.

Keywords: *Historical buildings, in situ investigation, seismic assessment, numerical analysis.*

REINFORCED MASONRY IN EUROPE – STATE OF THE ART: MASONRY UNDER COMPRESSION AND SHEAR

Kubica, Jan¹; Mojsilović, Nebojša²

¹ PhD, DSc, Professor, Silesian University of Technology, Dept of Structural Engineering,
jan.kubica@polsl.pl

² PhD, Senior Scientist, Institute of Structural Engineering, ETH Zurich, mojsilovic@ibk.baug.ethz.ch

The behaviour of reinforced masonry structures, especially where reinforcement is provided to enhance the strength or resistance of the masonry is still not completely investigated. The first task of the recently set Working Group (WG5) – Reinforced and Prestressed Masonry (of CIB W023 Commission) is to produce a State of the Art document covering reinforced masonry applications, mainly in Europe, in order to identify the topics for future research and development. Based on the available test results, the behaviour of reinforced masonry structures is discussed in the present paper. Masonry structures reinforced with bed joint reinforcement only and with both bed joint and vertical reinforcement and subjected to vertical and shear loading are investigated. Finally, the design of reinforced masonry according to Eurocode 6 (EN 1996) and other regulations and national standards is discussed.

Keywords: *Load test, reinforced masonry, standards, state-of-the art, structural behavior.*

SHEAR STRENGTH VARIATION DUE TO MORTAR STRENGTH VARIATION AND THE USE OF A TRIPLET SHEAR TEST SET-UP

Vermeltfoort, A.T¹

¹ PhD, Associated Professor, Eindhoven University of Technology, Department of the Built Environment,
a.t.vermeltfoort@tue.nl

Together with a large masonry wall test program control tests to determine the mortar compressive and the masonry shear strength were conducted. It was shown that even for industrially made mortars the mortar compressive strength varied considerably. However, no clear relationship between mortar compressive and masonry shear strength could be established. Therefore a series of tests was performed to investigate the relationship between mortar compressive and masonry shear strength by varying the mortar properties under laboratory conditions. Mortar tests were performed according to EN 1052-11 and shear triplets were made using one type of soft mud bricks to be tested according to EN 1052-3. Some critical features of the used shear test set-up are discussed and suggestions for improvement are given. Results of the tests in which the mortar properties were deliberately varied are discussed. For comparison, the experiences with more than 400 masonry shear tests, performed earlier, are briefly summarized.

Keywords: *Triplet, shear test, mortar properties, laboratory made mortar, shear strength, fracture surface.*

SHEAR TESTS ON MASONRY ELEMENTS WITH DAMP-PROOF COURSE MEMBRANE

Mojsilović, Nebojša¹; Krucker, Matthias²

¹ PhD, Senior Scientist, ETH Zurich, Institute of Structural Engineering, mojsilovic@ibk.baug.ethz.ch

² Graduate student, ETH Zurich, Institute of Structural Engineering, kruckerm@student.ethz.ch

Within the framework of the research project on the shear behaviour of masonry elements (triplets) with a damp-proof course (DPC) membrane placed in the bed joints, load tests on four series of masonry triplets have been completed. Each series consisted of 12 specimens with dimensions of either 290x250 mm (series A, B, C) or 230x250 mm (series D). Each element's thickness was 120 mm. A DPC elastomer-based membrane was placed in each (10 mm thick) cement mortar bed joint of the specimens of series B, C and D, whilst 12 specimens of series A were built without DPC and served as control specimens. The DPC was placed either in the middle of the bed joint (series B) or between the masonry unit and the bed joint mortar (series C and D). The elements of all series were built using clay bricks, except for series D specimens, for which the outer units were concrete bricks that were used to simulate the concrete slab. Twenty eight days after preparation, the elements were first subjected to a given pre-compression followed by a shear load that was applied in a deformation-controlled manner up to failure of the specimen. Four different levels of pre-compression were considered (0.2 MPa, 0.6 MPa, 1.0 MPa and 1.5 MPa) and for each level three replicates were tested for each series.

This paper presents some preliminary results and discusses their significance in relation to current design practice. A number of conclusions as well as recommendations for practical application and future research are given.

Keywords: *Clay brick, cohesion, damp-proof course (DPC), friction coefficient, load tests, shear.*

EXPERIMENTAL ANALYSIS OF MECHANICAL BEHAVIOR OF LINTELS IN STRUCTURAL MASONRY

Rezende, Fabiana Martins de¹; Rizzatti, Eduardo²; Mohamad, Gihad²; Roman, Humberto Ramos³; Bastos, Marcos Scherer⁴

¹ Ms. Candidate, Federal University of Santa Maria, Civil Engineering, fabianamrezende@yahoo.com.br

² Professor, Federal University of Santa Maria, Civil Engineering Department, edu_rizzatti@yahoo.com.br; gihad@unipampa.edu.br

³ PhD, Professor, Federal University of Santa Catarina, Civil Engineering Department, humberto@ecv.ufsc.br

⁴ Fourth-year undergraduate, Federal University of Santa Maria, Civil Engineering, marcosbts@hotmail.com.br

This study deals with experimental analysis of lintels in structural masonry walls built with hollow clay blocks. The main purpose of this study is to observe their mechanical behavior,

failure mode and deflections, when subjected to concentrated loading. The experimental program was based on reinforced lintels made with structural blocks and horizontal prefabricated bed joint reinforcements, through the use of MURFOR® steel reinforcement. The test results indicate that the failures occurred by the influence of shear stresses, according to compressions on the top of some blocks that could be observed.

Keywords: *Structural Masonry, Clay Block, Lintel, MURFOR® reinforcement masonry.*

THE EFFECT OF MORTAR BEDDING TYPE AND HOLLOW CONCRETE BLOCK GEOMETRY ON THE MECHANICAL BEHAVIOR OF HIGH-STRENGTH STRUCTURAL MASONRY

Casali, Juliana Machado¹; Oliveira, Alexandre Lima²; Sakamoto, Cintya³; Schankoski, Rudiele⁴; Prudêncio Jr., Luiz Roberto⁵

¹ PhD, Professor, Federal Technological University of Paraná, Civil Construction Department, casali@utfpr.edu.br

² PhD, Professor, Federal Technological Institute of Santa Catarina, alexandre@ifsc.edu.br

³ Student, Federal University of Santa Catarina, Civil Engineering Department, cintyakazue@gmail.com

⁴ Master student, Federal University of Santa Catarina, Civil Engineering Department, rudiele_as@yahoo.com.br

⁵ PhD, Professor, Federal University of Santa Catarina, Civil Engineering Department, prudenciouk@hotmail.com

In recent years the use of concrete block structural masonry for construction of tall buildings (above 12 floors) has intensified in Brazil. In this type of masonry, the units used for the first floor are usually “high-strength” blocks (i.e., with compressive strength above 12MPa). To produce such blocks, some plants use a face-shell thickness of 32 mm cause the increase in net area makes it easier to obtain the desired compressive strength. Other plants produce blocks with a face-shell thickness of 25 mm that are lighter and easier to lay. However, in this case, a strong block machine is required. In addition, many construction firms use packaged-dry mortar to increase productivity and quality. This mortar contains cement, dry sand and admixtures. Only water and mixing are required at the jobsite. Another possibility is to use cement-lime mortar, commonly used for structural masonry. The present work aims to study the influence of both concrete block geometry and type of mortar on the prism/unit ratio, deformation and failure behaviour of structural masonry prisms. These were evaluated for two concrete block geometries (face-shell thickness of 25mm and 32mm) and four mortars (two packaged-dry mortars and two cement-lime mortars) with different compressive strengths. The results obtained show that concrete block geometry and type of mortar influenced mechanical behaviour. The highest prism/unit ratio was achieved in prisms with cement-lime mortar. The prisms made with packaged-dry mortar showed elevated deformation and crushing of the mortar joint (with 50% of rupture force). Concrete block geometry also influenced prism compressive strength. Concrete blocks with the smallest thickness resulted lower levels of compressive strength in prisms made with packaged-dry mortar.

However, prisms with this same geometry but built with cement-lime mortar produced the best overall results.

Keywords: concrete blocks, bedding mortar, structural masonry.

MASONRY WALLS WITH BED JOINT REINFORCEMENT – A TRIAL OF DESCRIPTION OF THE PROBLEM WITH FIRST PROPOSITION OF DESIGN METHOD

Kubica, Jan¹

¹ PhD, DSc, Professor, Silesian University of Technology, Dept of Structural Engineering,
jan.kubica@polsl.pl

Nowadays a large number of new types of masonry units, especially many types of vertically perforated hollow bricks and blocks are being in use. Sometimes, it is necessary to enhance the compressive strength of masonry made using such material by reason of preferred smaller thickness of the walls what is connected with building erecting costs reduction. Using of bed joint reinforcement is one of the methods of masonry properties improvement. European Masonry Code EN 1996-1-1:2005 (Eurocode 6) recommends using of steel prefabricated bed joint reinforcement. Requirements for the main four types of such reinforcement are specified in European Standard EN 845-3. In spite of that a lack of calculation methods allowing to take into the account these types of bed joint reinforcement in design practice for load-bearing capacity determination of mainly vertically compressed masonry walls is still observed. In Chapter 8 of Eurocode 6 covers only the general recommendations of bed joint reinforcement using for masonry properties enhancement only based on the minimal reinforcement percentage – without possibility of calculation of the effectiveness of using them.

Author, based on the long tradition and wide experience of using in many countries of Middle-East Europe, Russia and China bed joint reinforcement in case of masonry columns, discusses the problem in relation to masonry walls. The confining effect of using such reinforcement referring to the strain state in bed joints is analysed and discussed.

Additionally, the first proposition of the design method for masonry walls with some types of bed joint reinforcement (orthogonal meshwork and truss type reinforcement) is presented. Proposed analytical calculation method was compared with results of tests of masonry walls made of clay bricks, carried out at the Silesian University of Technology.

Keywords: Compression; bed joint reinforcement; state of stress; state of strain; load-bearing capacity.

THE USE OF PRECAST STAIRS IN MASONRY STRUCTURES

Andrade, Rebecca Cardelli de¹; Mamede, Fabiana Cristina²

¹ Msc, Civil Engineer, Pedreira Engenharia, rebecca@pedreira.eng.br

² Msc, Civil Engineer, Pedreira Engenharia, fabiana@pedreira.eng.br

The great advantage of using masonry structures today is the rationalization of materials and building methods with quality and at low cost. A way of increasing this rationalization level is using masonry structures together with precast elements. They work efficiently together regarding strict quality control, modular coordination, reduction of waste, and high speed of construction. An element that has a lot of advantages in been precast is the staircase. It provides benefits in handling, speed and simplicity of assembly.

Amongst the options of precast staircases, the big challenge is to choose which one fits the project best, targeting savings, compatibility with the streamlined construction process, planning and logistics.

The purpose of this paper is to present a comparative analysis of different types of precast staircases that can be used in masonry structure buildings, and create a database that can help in choosing which staircase is best for a variety of projects.

This analysis is made based on documental and survey researches at construction sites, in which the staircase was implemented and the reasons which led to this particular solution. It describes relevant aspects of the general features of the project, the structural viability of the building for each type of staircase, and the interfaces of the construction process, such as transportation, handling, and designing details of the precast elements.

The results show that there is a great advantage in using precast staircases within masonry structures, eliminating construction stages, minimizing interference between subsystems and raising the quality of the final product.

Keywords: *Precast, staircases, masonry, rationalization.*

DEVELOPMENT OF A RESILIENT POLYURETHANE REINFORCED MASONRY WALL SYSTEM

Forsythe, Carly¹, El-Dakhakhni, Wael²

¹ M.A.Sc., Graduate Student, McMaster University, Civil Engineering Department, forsytc@mcmaster.ca

² PhD, Martini, Mascarin and George Chair in Masonry Design, McMaster Univ., Canada.
eldak@mcmaster.ca

Unreinforced masonry (URM) is one of the most common types of building construction used across the world, and is also one of the most susceptible to large levels of damage during an earthquake. Due to poor construction and lack of adherence to proper engineering design in some developing countries, there is a strong need for a new type of masonry reinforcement that is both easy to use and cost effective. In this preliminary study, masonry reinforced with polyurethane foam was tested to examine how such reinforcement technique could improve URM performance

under compression and out-of-plane bending. Compression assemblages reinforced with polyurethane foams of different densities were tested so as to develop an understanding of how density relates to compressive strength. Those assemblages reinforced with polyurethane foam showed an increase in compressive strength of 42% on average with higher-density polyurethane foam assemblages exhibiting higher compressive strengths than their lower-density counterparts. Of potentially more importance was the ability of the foam to stabilize the face shells of the assemblages after web splitting, which essentially enables the prism to carry more load. This binding effect enables the polyurethane to act as structural integrity reinforcement, thereby preventing catastrophic collapse. In the out-of-plane direction, the masonry walls reinforced with polyurethane foam were able to dissipate large amounts of energy and demonstrate a significantly enhanced strength before the cracking capacity was reached. The reported testing showed great promise and merits further testing and investigation.

Keywords: *Unreinforced masonry, polyurethane foam, compression, out-of-plane.*

RATIONALIZED MASONRY SEALING WITH CONCRETE BLOCKS: PROFESSIONAL QUALIFICATION THROUGH THE CONSTRUCTION COMMUNITY/ABCP

Lordsleem Jr., Alberto Casado¹; Falcão, Emanuelle Pontes²

¹ PhD, Professor, University of Pernambuco, Civil Engineering Department, acasado@poli.br

² Civil Engineering, Brazilian Association of Portland Cement, North/Northeast Department, emanuelle.pontes@abcp.org.br

Professional qualification is an important supplement of engineers' formal education, so as time goes by and the world changes above and beyond experience, it becomes inevitable to acquire and renew knowledge. Furthermore, ongoing professional qualification is responsible for the improvement of skills that contribute to confronting the challenges of the present world. Within this context, the Construction Community of Recife/PE, coordinated by the Brazilian Association of Portland Cement (ABCP) promoted the achievement of the building site monitored program of masonry sealing using concrete blocks. Another purpose of the ABCP program is to increase competitiveness of the cement-based construction systems by implementing the construction technology of rationalized masonry sealing using concrete blocks. The purpose of this paper is to discuss the building site monitored program adopted in the city of Recife/PE, from which it was possible to implement the pilot and monitoring of that technology in multi-floor buildings. The methodology adopted to achieve the program considered different stages ranging from making the work feasible to organizing the activities, to operation and monitoring the results. As a contribution, it stresses the dissemination of knowledge and monitoring the results. As a contribution, it stresses the dissemination of knowledge about the necessary stages to properly implement the rationalized construction technologies not only for bringing together corporate members of the Construction Community of Recife/PE, but also for other professional and builders that may be interested.

Keywords: *Construction community, masonry sealing, concrete blocks.*

PRE-SEALING CONCRETE BLOCKS & PAVERS USING SILICONE NANOTECHNOLOGY

Ren, Kebao¹; Kagi, Douglas²

¹ Ph.D. Technical Manager, Tech-Dry Building Protection Systems Pty. Ltd., Australia,
ren@techdry.com.au

² Ph.D. Managing Director, Tech-Dry Building Protection Systems Pty. Ltd., Australia,
doug@techdry.com.au

The permeability and hydrophilic nature of pressed concrete products leads to easy water penetration. Water penetration is a well-known factor affecting the performance and the durability of pressed concrete masonry.

Efflorescence of concrete blocks is one of the problems associated with water penetration which is particularly important for decorative concrete. Efflorescence is caused by moisture moving through the capillaries and carrying the calcium hydroxide produced from cement hydration to the surface. The carbonation of the calcium hydroxide on the surface results in efflorescence of an insoluble white calcium salt.

Water repellent admixtures can minimise water movement within the concrete and hence reduce water absorption and efflorescence of the concrete.

The performance of conventional admixtures such as stearates and oleates is not completely satisfactory due to the fact that they are not permanently bonded to the substrate. The water repellency is due to hydrophobic deposits of calcium stearate or oleate within the concrete. These admixtures are subject to breakdown due to weathering and biological deterioration.

The current research exhibits an admixture involving silicone nanotechnology using a silicone water repellent admixture. The nano-molecular polysiloxane lines the capillary walls of the concrete via strong siloxane linkages which overcomes the limitations inherent in traditional non-reactive admixtures resulting in long term durability of the hydrophobic treatment. The treated concrete achieves low water permeation and high efflorescence resistance. This innovative technology has achieved market success in creating pre-sealed decorative concrete blocks and pavers in Australia during the past 10 years.

Keywords: *Silicone, nanotechnology, pressed concrete, admixture, pre-sealing concrete.*

WATER PENETRATION TEST ON CONCRETE BLOCK MASONRY

Vilató, Rolando Ramirez¹

¹ PhD, Prof., Mackenzie Presbyterian University, School of Engineering, São Paulo,
rolandovilato@yahoo.com

This paper considers the actual standards in the Brazilian building code related to the performance parameters of external walls resistance to water penetration. It describes a test method to assess the resistance to rain water penetration and leakage of structural masonry walls with concrete block and mortar rendering. Specific equipment was developed in order to measure the effects of abrupt temperature changes on the permeability of the coating. The results of the experiments are discussed and the high performance of structural masonry to water penetration was verified in walls with mortar coatings, even in the cases of unfilled vertical joints. The test method includes the development of a simple test chamber to performance assessment of the resistance to rain water penetration in walls, of structural masonry or other materials.

Keywords: *resistance to water penetration, performance, structural masonry.*

THERMOPHORESIS ON EXTERNAL FACADES: EVALUATION AND ORIGINS

Breitbach, Aécio de Miranda¹; Viotti, Glêdes Cabral de Albuquerque²

¹ Msc, Federal University of Santa Catarina, Civil Engineering Department, aecio.m.b@posgrad.ufsc.br

² PhD, Researcher, Federal University of Santa Catarina, Civil Engineering Department,
gledescabral@gmail.com

The use of an external final coat with low thickness, especially on structural masonry, with final painting latex, has been preferred for its easy execution and low cost. The use of industrially produced blocks under strict quality standards allows a coat with low thickness which enables the appearance of a gradual biodeterioration showing the different porosity of the substrate. This leads to a masking effect by the delimitation of the different constituents of the substrate. As a consequence, the thermophoresis starts giving a discoloration of the superficial facades for different temperatures of the surface which affects the aesthetics of the building. Several proposals in order to counteract this effect are presented and discussed with the aim of raising awareness of the consequences that the reduction of thickness of coatings mortars can bring to the physical appearance of buildings.

Keywords: *thermophoresis, biodeterioration, external coat, coatings mortars, structural masonry.*

QUANTITATIVE ANALYSIS OF CLAY BRICK WASTE GENERATED DURING MASONRY EXECUTION IN RESIDENTIAL BUILDINGS IN THE CITY OF SÃO CARLOS, SÃO PAULO, BRAZIL.

Fumachi, Felipe¹; Parsekian, Marilu Pereira Serafim²;

¹ Civil Engineering Student at UFSCar, felipefumachi@yahoo.com.br

² PhD, Environmental Engineering Professor at UFSCar, mparsekian@gmail.com

For many years, there wasn't an estimate of losses and waste materials during construction processes. In addition, there was no information about the nature of constructive activities, the participation of several agents in the construction of buildings, and origin of waste. Nowadays, the information obtained point out rates of losses in the construction and the waste generated, which have high incidence in the composition of solid waste. The waste can't be considered only as materials not used in the building site, but as any real loss during the construction process. So, currently in the construction process, planning is needed, from design to material control. This study aimed to quantify the waste of clay bricks generated during the masonry execution of three residential buildings in the Residential Damha 1, city of São Carlos, São Paulo, Brazil. The present research employed the method of follow up of the three works with clay bricks used to seal, the organization and analysis of information, in order to solidify the theoretical base of the study. To survey the generation of the amount of clay bricks waste: the initial and final inventory of material (bricks) for construction of the buildings were specified, the receipt of material (bricks) during the work implementation phase was quantified, and the area of masonry performed was measured. For the data analysis it was needed to calculate the amount of bricks used and required for the masonry execution. From these results the amount of waste generated was estimated. After the masonry was done, it was concluded that the generation of clay brick waste was due to several factors such as: an inefficient schedule of the site layout construction, lack of details in design, transportation losses due to management of large piles of bricks, unskilled workers, among others. Regarding the three buildings construction, there was a waste of 4,016 units of clay bricks. The higher percentage of waste was 7.5%. However, this percentage was considered low, for the masonry execution, because the study took in account only the first story, if the second was included, probably the generated waste would be greater.

Keywords: *waste, loss, clay bricks, masonry, fencing.*

THE STRENGTH OF MASONRY WALLS WHEN SUBJECT TO FLOOD LOADING

D.M. Herbert¹; D.R. Gardner²; M. Harbottle³, T.G. Hughes⁴

¹ PhD candidate, Cardiff School of Engineering, Cardiff University, UK, herbertdm@cf.ac.uk

² Lecturer, Cardiff School of Engineering, Cardiff University, UK, gardnerdr@cf.ac.uk

³ Lecturer, Cardiff School of Engineering, Cardiff University, UK, harbottlem@cf.ac.uk

⁴ Professor, Cardiff School of Engineering, Cardiff University, UK, hughestg@cf.ac.uk

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Flooding is increasingly becoming an issue for property owners and they are likely to turn to products designed to waterproof the exterior of the building in a bid to protect their homes. However, very limited research has been completed to assess the effect of the increased hydraulic load upon the structure of the building as a result of such products. This work has been almost exclusively theoretical and has suggested sealing brickwork to a height of between 0.6 m and 1 m. This paper details the initial findings of an experimental research programme that has been initiated to examine the effect of out-of-plane hydrostatic loading on masonry walls typical of domestic or commercial premises. Masonry panels of both brick and block units have been constructed at small scale (1/6th) and hydraulic out-of plane loading has been applied incrementally until failure occurred. The study has been completed using a geotechnical centrifuge to correctly model the effect of self-weight. An important consideration in the theoretical work is the contribution to stability arising from the axial in-plane loading provided by higher floors/roofs and consideration of this is included in the experimental setup. 3D digital image correlation (DIC) was employed to monitor the wall panel during test and allowed in and out-of-plane deflections to be obtained. A series of uniform lateral loading tests, using an air bag, have previously been conducted and have proven the validity of the experimental procedure. The performance of the wall panels tested in this study are presented and the results are compared to the findings from previous research.

Keywords: *Flooding, Small scale, Centrifuge, Lateral, DIC.*

STRUCTURAL EVALUATION OF A NOVEL SOLUTION FOR SUSTAINABLE MASONRY CONSTRUCTION

Ian Molesworth¹; Peter Walker²; Enrico Fodde³

¹ University of Bath, Department of Architecture and Civil Engineering, i.d.molesworth@bath.ac.uk

² PhD, Professor, University of Bath, Department of Architecture and Civil Engineering,
p.walker@bath.ac.uk

³ PhD, University of Bath, Department of Architecture and Civil Engineering, e.fodde@bath.ac.uk

To reduce its environmental impact masonry construction requires novel innovative solutions. The work presented in this paper forms part of a larger PhD project investigating the potential use of fired clay brick masonry with hemp-lime biocomposite insulation. Hemp-lime is a low carbon insulation material, utilising renewably sourced hemp shiv with a lime based binder, that can provide levels of thermal insulation suitable for modern building requirements. Due to its low structural strength and stiffness hemp-lime is generally used in non-loadbearing applications. In the proposed application hemp-lime is cast as an internal insulating layer against an external 102.5 mm thick fired clay brickwork structural facing. This paper presents the results of investigations into the structural interaction between the hemp-lime and brickwork. Although the hemp-lime is considered non-structural, its potential indirect structural restraint to buckling of the brickwork has been explored experimentally. Some enhancement in capacity has been observed, however this benefit has been found to be variable. The experimental results of four large scale wall tests are reported together with discussion and conclusions from the study to date. The contribution of ties between the wall and hemp-lime has been studied. Recommendations for further work are also explored.

Keywords: Sustainability, brick, hemp-lime, structural testing.

MODIFIED COMPRESSION FIELD THEORY (MCFT) FOR SHEAR STRENGTH PREDICTIONS OF REINFORCED MASONRY SHEAR WALLS

Banting, Bennett¹; El-Dakhakhni, Wael²

¹ PhD Candidate, Department of Civil Engineering, McMaster University, Hamilton, Canada.
bantibr@mcmaster.ca

² PhD, Martini, Mascarin and George Chair in Masonry Design, McMaster University, Canada.
eldak@mcmaster.ca

Reinforced masonry (RM) shear walls detailed for use as a Seismic Force Resisting System (SFRS) in Canada are subject to overly conservative methods of determining their shear strength that may result in uneconomic and inefficient designs. In the current study, the results of eight full-scale squat RM walls tested at McMaster University to quantify their shear strength, were used to investigate the application of the Modified Compression Field Theory (MCFT), originally

developed for reinforced concrete (RC) components, to predict their shear strength. The test walls demonstrated shear-strength capacities up to 200% of those predicted by the Canadian Standards Association (CSA) S304.1-04 masonry design code. However, the Simplified Modified Compression Field Theory (SMCFT), adopted directly from the Canadian concrete design code CSA A23.3-04, showed promise for future applications with RM masonry walls as it resulted in more accurate estimate of shear strength compared to the current S304.1-04 masonry design code approach.

Keywords: Reinforced masonry, Seismic performance, Shear failure, Shear walls.

MASONRY DESIGN FOR BLAST LOADING

ElSayed, M.¹, El-Dakhakhni, W.W.²

¹ Ph.D. Candidate, Department of Civil Engineering, McMaster University, Canada,
elsayemm@mcmaster.ca

² Martini Mascarin and George Chair in Masonry Design, Department of Civil Engineering, McMaster University, Canada, eldak@mcmaster.ca

In order to protect the building occupants against accidental or deliberate blast loads, special expertise and knowledge are necessary to ensure adequate performance of the structural system. Although the structure may require an extensive repair following a blast event, the main goal of the protective design is to avoid structural progressive collapse and minimize fragments. Blast loading is very different from other forms of dynamic loading generally analyzed by structural engineers. Peak pressures are several orders of magnitude higher than those associated with other typical dynamic loads, and blast load durations are usually much shorter than the fundamental period of the structure. This paper will focus on the blast loading phenomena as a part of the design requirement implemented in the two recently developed North America's codes, ASCE SEI59-11 (2011) and CAN CSA S850-12 (2012). A description of different level of protections and various masonry loads is presented in this paper, in addition to the general considerations in standards and design guidelines for constructing masonry structures to resist explosive loads.

Keywords: Blast Load, cube root scaling, Masonry, North American Blast Standards.

THE EFFECT OF ONE-WAY ARCHING ON ENHANCING THE PERFORMANCE OF CONCRETE BLOCK WALLS SUBJECTED TO BLAST LOADING

Abou-Zeid, Badr¹; El-Dakhakhni, Wael²; Razaqpur, Ghani³ and Foo, Simon⁴

¹ PhD, Senior Engineer, Structural Department, SNC-Lavalin group, Cairo, Egypt.
badr.abouzeid@snclavalin.com

² PhD, Martini, Mascarin and George Chair in Masonry Design, McMaster University, Canada.
eldak@mcmaster.ca

³ PhD, Professor, McMaster University, Hamilton, L8S 4L7, Ontario, Canada. razaqpu@mcmaster.ca

⁴ PhD, Senior Engineer, Real Property Branch, Public Works & Government Services, Canada.
simon.foo@pwgsc.gc.ca

New standards for blast protection of buildings have been recently developed in the USA and Canada. In this regard, both standards are considering unreinforced masonry (URM) walls as particularly vulnerable to blast events and may not be used in blast resisting structural systems. In this paper, the effectiveness of enforcing arching action to as a cost-effective hardening technique for vertically-spanning one-way URM walls under blast loads is experimentally investigated. A total of eight full-scale concrete-block URM walls were subjected to blast loads generated by high explosives. Enforcing URM walls to arch between rigid supports significantly enhanced their out-of-plane blast resistance compared to similar non-arching (flexural) URM walls. Moreover, no fragments or debris were observed on the leeward side of the arching walls, indicating the potential of the proposed hardening technique in reducing the hazard level for the occupants of buildings with exterior URM walls. A simple bi-linear moment-rotation relationship is developed to model arching URM walls. The model takes into account the masonry material strength, thrust forces, and wall geometry. Nonlinear time-history analyses were performed using a single-degree-of-freedom (SDOF) model. The model takes into account the rocking phenomenon and the second order effects. Responses generated by the SDOF model were verified with available experimental data.

Keywords: *Arching action, Blast loads, Concrete masonry, Dynamic stability, Out-of-plane capacity, Moment-Rotation relationship, rocking phenomenon, SDOF models.*

SYSTEM-LEVEL SEISMIC PERFORMANCE ASSESSMENT OF REINFORCED CONCRETE BLOCK WALL BUILDINGS, PHASE I: COUPLING PREVENTED, TORSION ALLOWED

Heerema, Paul¹ and El-Dakhakhni, Wael²

¹ PhD Candidate, Department of Civil Engineering, McMaster University, Hamilton, Canada.
heeremp@mcmaster.ca

² PhD, Martini, Mascarin and George Chair in Masonry Design, McMaster University, Canada.
eldak@mcmaster.ca

Typically, a building system is understood to perform as the summation of its individual components. Thus, when a masonry building is analysed under seismic loads, the main lateral load resisting walls are identified, their individual resistances are calculated and, assuming adequate ductility capacity of all walls, the building lateral load capacity is typically taken as the summation of the individual wall resistance values. The drawback of this approach is that the effects of the different wall load-displacement characteristics and the wall interaction through the floor diaphragms are not considered. On the other hand, recent research and new directions of international seismic codes are moving towards incorporating system-level behaviour into the seismic analysis and design processes. A floor diaphragm typically provides linkage between various structural walls within a masonry building. This linkage allows for load transfer and facilitates load redistribution between walls particularly when damage or failure occurs in a single wall within the building. In addition, for general (asymmetric) building plans, significant torsional moments in the plane of the diaphragm may develop with seismic loading. These torsional moments affect the load distribution on different walls in a nonlinear manner with wall stiffness reduction and damage evolution. The research presented here aims to study the overall behaviour of reinforced masonry buildings in terms of load distribution between walls, both before and after yielding, torsional deformation, and the effect of the rigid diaphragm coupling of individual walls. To facilitate studying the above parameters, the first of a series of reduced-scale two-story reinforced masonry shear wall buildings was tested under simulated seismic loading. This paper discusses some preliminary results obtained to date in Phase I of these tests where diaphragm coupling is prevented and only torsional moments are allowed to develop.

Keywords: *Concrete Block, Coupling, Diaphragm Action, Reinforced Masonry, Seismic Effects, Shear Walls, Structural Walls.*

UNGROUTED CELL INSPECTION TOOL FOR MASONRY WALLS

A. A. Nassr¹, M.T. Shedid², and W.W. El-Dakhakhni³

¹ PhD Candidate, Department of Civil Engineering, McMaster University, Hamilton, Canada.
nassraa@mcmaster.ca

² PhD, Assistant Professor, Department of Civil Engineering, Ain Shams University, Cairo, Egypt.
shedidmm@mcmaster.ca

³ PhD, Martini, Mascarin and George Chair in Masonry Design, McMaster University, Canada.
eldak@mcmaster.ca

In this study, a new technique for detecting ungrouted cells in concrete block constructions was developed. The concept, based on detecting the local dielectric permittivity variations, was employed to design coplanar capacitance sensors with high sensitivities to detect such construction defects. An analytical model and finite element simulations were used to assess the influence of the sensor geometrical parameters on the sensor signals and to optimize the sensor design. To experimentally verify the model, dielectric properties of various materials involved in concrete masonry walls were measured. In addition, a masonry wall containing predetermined grouted and ungrouted cells was constructed, and inspected using the developed sensors in a laboratory setting. The proposed sensor design, coupled with a commercially available portable capacitance meter would facilitate employing this technique in the field for rapid inspection of masonry structures without the need for sophisticated data analyses usually required by other more expensive and time consuming methods.

Keywords: concrete, block, grout, measurement, non-destructive tests, sensors.

EXPERIMENTAL INVESTIGATION ON THE SEISMIC BEHAVIOUR OF NEW CONCRETE BLOCK MASONRY BUILDINGS

Avila, Leonardo¹; Vasconcelos, Graça²; Lourenço, Paulo. B.³

¹ PhD, Student, ISISE, Department of Civil Engineering, University of Minho, Azurem, Portugal,
leoavila@civil.uminho.pt

² Professor, ISISE, Department of Civil Engineering, University of Minho, Azurem, Portugal,
graca@civil.uminho.pt

³ Professor, ISISE, Department of Civil Engineering, University of Minho, Azurem, Portugal,
pbl@civil.uminho.pt

The present work deals with the experimental validation of a new structural solution for concrete block masonry buildings. Dynamic tests of two identical two-story concrete block masonry models were performed on a shaking table in reduced scale 1:2, with focus on the global behavior. Both models were tested in the two orthogonal horizontal components with uncorrelated artificial

accelerograms compatible with the elastic response spectrum defined by Eurocode 8. The first model was tested in reinforced conditions following the same code, while the second building was tested as an unreinforced solution. The identification of the dynamic properties using modal analysis (based on input-output techniques) as well as the seismic evaluation of both buildings is presented.

In the experimental tests, various input motions with incremental amplitude were implemented. The damage identification through stiffness degradation is studied. Furthermore, the experimental analysis encompasses parameters as the cracking patterns with consequence collapse mechanisms. In-plane and out of plane behavior in terms of displacements and lateral drifts are discussed. Findings related to the global dynamic behavior and comparisons between the results of the two buildings are also presented.

Keywords: *New masonry system, Shaking table test, Dynamic identification, Seismic performance.*

Posters

STRUCTURAL PERFORMANCE OF MASONRY WALLS MADE OF CERAMIC BLOCKS PRODUCED FROM THE MIXTURE OF RED MUD WITH CLAY

Costa, Diogo Henrique Pereira¹; Trindade, Sandro Roberto Santos²; Macêdo, Alcebiades Negrão³; Carneiro, Ronaldson José de F. M.⁴; Oliveira, Dênio Ramam Carvalho⁵

¹ Civil Engineer, M.Sc. student of the Post-Graduate Program in Civil Engineering Federal University of Pará, diogohpc@gmail.com

² Graduate student in Civil Engineering, Federal University of Pará, sroberto@ufpa.br

³ PhD, Professor, Federal University of Pará, anmacedo@ufpa.br

⁴ PhD, Professor, Federal University of Pará, ronaldson.carneiro@gmail.com

⁵ PhD, Professor, Federal University of Pará, denio@ufpa.br

In Brazil the number of buildings grows continuously so that the use of new techniques for waste recovery have become increasingly important in construction, especially when it comes to the use of waste from other industries and reducing consumption of raw natural materials. Thus the objective of this study was to evaluate the use of red mud (RM) waste from alumina production metallurgy, the structural performance of walls made with ceramic blocks with circular cross section and reticulate, and produced from a mixture of 60% RM with 40% clay. The tests were conducted according to technical standards, such as putty on axial compression and simple. Based on the analysis of results showed that the walls made with blocks from the mixture of clay and RM met the normative parameters for resistance to compression, and media were higher than the resistance of the wall ceramic reference blocks.

Keywords: Red mud, masonry structural, ceramic blocks.

LOAD-BEARING PROPERTIES OF MASONRY MADE OF DIFFERENT TYPES OF CERAMIC BLOCKS AND LIME- BASED MORTARS

Santos, Mauro Joel Friederich¹; Santos, Marcus Daniel Friederich²; Rizzatti, Eduardo³

¹ Msc, Professor, University of Santa Cruz, Department of Architecture, mauro@mmcprojetos.com.br

² Msc, Professor, University of Santa Cruz, Department of Architecture, marcusds@unisc.br

³ PhD, Professor, Federal University of Santa Maria, Civil Engineering Department, rizzatti@ct.ufsm.br

This work has as main objective to analyze the influence of the ceramic block geometry in the mechanical performance of the structural masonry, under centered compression, when mortars with resistance varied are used. Two types of ceramic blocks geometries are studied: one with

drained walls (BPV) and the other with solid walls (BPM), possessing approximate resistances of 30MPa, in relation to their net and gross area; also four mortar types with resistances between 4MPa and 17Mpa were used. The experimental program includes the following compression specimens: units, prisms and small walls. Also, the modulus of elasticity, for the mortars, blocks and prisms, and for small walls was obtained. Among the several combinations tested, the variance of the samples submitted to the compression was analysed. Based on the analysis of the results, it may be concluded that the BPM block is more efficient for the use in structural masonry than the BPV one, when an increment in the compressive strength of the masonry is needed, increasing the mortar compressive strength; such efficiency can be defined in the relation of the compression strength of the prisms (two and three blocks) and the small walls in relation to the resistance of the block. The small walls built with BPM blocks present a significant capacity to absorb strains, when high resistance mortar is used (the one used in this work); as for the BPV block, that difference was not so expressive. Therefore, the use of bedding mortar with those compression strengths may potentiate the masonry of ceramic blocks, depending on the geometry (BPV ou BPM) and mechanical properties of the applied blocks.

Keywords: structural masonry, ceramic block, geometry, small walls, modulus of elasticity.

MAT FOUNDATIONS FOR BUILDINGS UP TO FIVE FLOORS IN STRUCTURAL MASONRY

Haack, Melina Baruki¹; Freitas, Augusto Guimarães Pedreira²

¹ Civil Engineer, Pedreira Engenharia Ltda, melina@pedreiradefreitas.com.br

² Civil Engineer, Pedreira Engenharia Ltda, augusto@pedreira.eng.br

With the coming progress in civil constructions, the search for rationalization and alternative methods and are becoming a common theme in the technical sector, especially when dealing with ventures of lower social classes. In these cases, the structure represents a relevant economy on the final cost of construction, therefore generates savings in material, work and time. One of the most used methods in low-budget ventures is the structural masonry. Many studies have been made on how to take advantage in search of good structural performance with low costs and no pathology incidence by optimizing the calculations of the walls and creating a mixture between this method and the foundations used. The purpose of this paper is to analyze the interface of the structural masonry system for buildings of up to five floors, with the variation of the mat foundation, cost analysis and influence of other subsystems, in the solution choice. Mat foundations formed by solid plates of concrete and grids, made with inert elements, were studied by diverse situations of elasticity and conditions of compression with distributed frames, welded screens and steal fibers. The structural designing was simulated by two softwares: TQS for grid analysis and SAP2000 for a finite element analysis, studying possible behaviors of base structures. In the executed constructions, measurements of the displacement were made through the installation of repression pins in diverse points of the mat foundation. The performance of the foundation on the displaced land, cut in many ways, can also be analyzed. With the results obtained it was possible to create recommendations in the use of this type of foundation with structural masonry, to have significant changes in the structure of the mat foundation for other building typologies, and to advance in the rationalization of solutions.

Keywords: mat foundation, masonry, rationalization.

LIMIT PLASTIC ANALYSIS OF A STRUCTURAL CONCRETE BLOCK WALL

Buzar, Márcio Augusto Roma¹; Ritter de Gregorio, Marcos Henrique²

¹ PhD, Professor, University of Brasília, Architecture Department, buzar@unb.br

² M.Sc., Architect, University of Brasília, Architecture Department, marcos@ritteregregorio.com.br

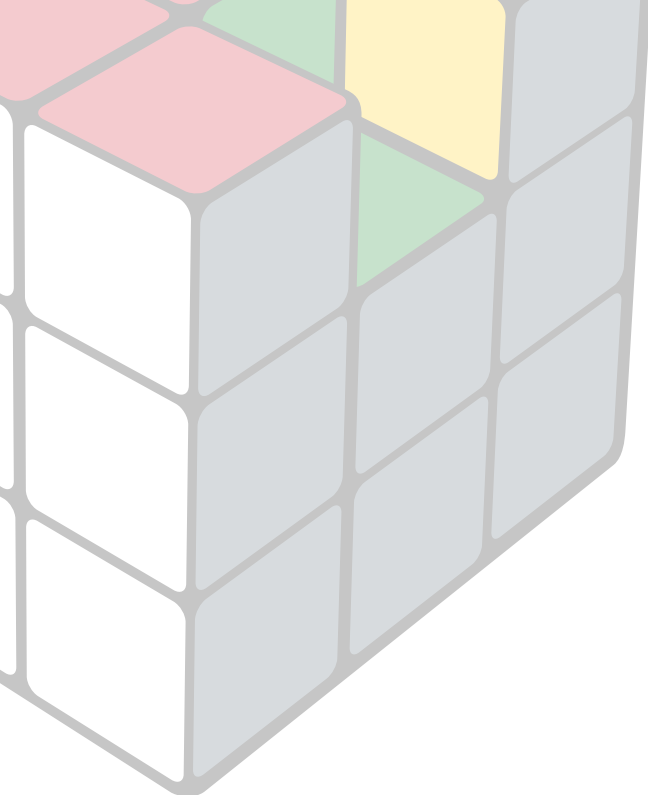
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At this paper, it is searched the maximum collapse load of a structural concrete block wall. Simulations are made considering the removal of resistant material, such as the installation of a door or openings motivated by modifications at the architectural project.

A mathematical programming using the Coulomb and Von Mises criteria is used at the limit plastic analysis assuming the basic hypothesis of associated plasticity. It is used a polyhedral representation of the yielding surface studying the convergence of the results in relation of the chosen number of planes at each representation. It is used the hybrid finite elements formulation.

Numeric examples are shown for the structural concrete block wall case, considering different finite elements meshes and the obtained results are compared with those of the analytical analysis that exists at the criteria adopted by the Brazilian concrete block structure project Standard - NBR 10837.

Keywords: *structural concrete block, hybrid finite elements, limit plastic analysis.*



UFSC

Universidade Federal de Santa Catarina
Campus Universitário
88040-970 - Florianópolis/SC - Brasil
Tel: +55 (48) 3721 5192
e-mail: humberto@ecv.ufsc.br

www.ecv.ufsc.br



Universidade Federal de São Carlos
Rodovia Washington Luís, km 235 - SP-310
13565-905 - São Carlos /SP - Brasil
Tel: +55 (16) 3351 9657
e-mail: parsekian@ufscar.br

www.deciv.ufscar.br