Program and Book of Abstracts

15th CMS
OTTAWA

Organized by:

Canada Masonry Design Centre

Carleton University

June 2-5, 2025

Ottawa, ON

Program and Book of Abstracts

15th Canadian Masonry Symposium

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Foreword

The Fifteenth Canadian Masonry Symposium is jointly hosted by Carleton University, Ottawa, ON and Canada Masonry Design Centre, Mississauga, Ontario. The fourteen previous symposia were hosted by the listed universities at the indicated locations:

1976 First Canadian Masonry Symposium, University of Calgary, Calgary AB
1980 Second Canadian Masonry Symposium, Carleton University, Ottawa, ON
1983 Third Canadian Masonry Symposium, University of Alberta, Edmonton, AB
1986 Fourth Canadian Masonry Symposium, University of New Brunswick, Fredericton, NB
1989 Fifth Canadian Masonry Symposium, University of British Columbia, Vancouver, BC
1992 Sixth Canadian Masonry Symposium, University of Saskatchewan, Saskatoon, SK
1995 Seventh Canadian Masonry Symposium, McMaster University, Hamilton, ON
1998 Eighth Canadian Masonry Symposium, University of Alberta, Jasper, AB
2001 Ninth Canadian Masonry Symposium, University of New Brunswick, Fredericton, NB
2005 Tenth Canadian Masonry Symposium, University of Calgary, Banff, AB
2009 Eleventh Canadian Masonry Symposium, McMaster University, Toronto, ON
2013 Twelfth Canadian Masonry Symposium, BCIT & UBC, Vancouver, BC
2017 Thirteenth Canadian Masonry Symposium, Dalhousie University, Halifax NS
2021 Fourteenth Canadian Masonry Symposium, Concordia University, Montréal QC (Virtual)

Welcome to Ottawa!

Welcome and *Bienvenue* to Canada's beautiful national capital! The successful planning and delivery of the symposium would not have been possible without the significant contributions of staff from the Canada Masonry Design Centre and students from Carleton University. We are also deeply grateful to our industry sponsors, whose generous support makes this event possible. Most importantly, we thank you, the participants, including students, professors, and practicing engineers, for your engagement and contributions. Without you, there would be no symposium.

A total of 112 papers will be presented at the Fifteenth Canadian Masonry Symposium (CMS), held in Ottawa, Ontario, its first return to the city since 1980, when it was previously hosted in partnership with Carleton University. This year's papers have been organized into specific topic areas, with technical sessions running in three parallel streams.

Sincerely,

Symposium Co-Chairs
Bennett Banting
David Stubbs
Ted Sherwood

Organizing Committee

Bennett Banting	Canada Masonry Design Centre
Luisa Carrillo	Canada Masonry Design Centre
David Stubbs	Canada Masonry Centre
Sandra Skivsky	Canadian Masonry Contractors Association
Ted Sherwood	Carleton University
Bora Pulatsu	Carleton University
Ehab Zalok	Carleton University
Andrea McChesney	Canadian Concrete Masonry Producers Association
Scott Jeffries	Clay Brick Association of Canada
Khaled Galal (Past Chair)	Concordia University

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Ali Ahrabi	Canada	Donald Harvey	USA
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Andrew Smith	Canada	Giuliana Cardani	Italy
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Ayan Sadhu	Canada	Guilherme Parsekian	Brazil
Bahman Ghiassi	UK	Gurparam Kang	Canada
Barry Haseltine	UK	Heather Sustersic	USA
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Carlo Citto	USA	John Chrysler	USA
Carlos Cruz Noguez	Canada	John Cooke	Canada
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Dagmar Svecova	Canada	Jordan Dick	UK
Damon Bolhassnai	USA	Katrin Beyer	Switzerland
Daniel Abrams	USA	Kevin Hughes	Canada
Daniele Malomo	Canada	Khaled Galal	Canada

Technical Committee Continued

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Laura Redmond	USA	Philippe Ledent	USA
Lisa Feldman	Canada	Rahil Khoshnazar	Canada
Lydell Wiebe	Canada	Reza Hasanli	Australia
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Patrick Dillon	USA	Yi Liu	Canada
Patrick Kelly	Canada	Yong Li	Canada
Paulo B. Lourenço	Portugal	Yuxiang Chen	Canada

Sponsors

The success of academic conferences such as the Canadian Masonry Symposium depends not only on the dedication of researchers and educators, but also on the invaluable support of our industry partners and sponsors. Their contributions go far beyond financial assistance; they enable the exchange of ideas, foster collaboration, and help bridge the gap between theory and practice. By supporting events like this, the industry plays a direct role in advancing research, driving innovation, and encouraging the development of new technologies and methods that benefit the entire built environment. This collaboration between academia and industry is essential. Moving forward, continued partnership is critical to tackling the evolving challenges of our field. Together, we can shape a more resilient, efficient, and sustainable future for masonry construction in Canada and beyond.

PLATINUM LEVEL

GOLD LEVEL

SILVER LEVEL

BRONZE LEVEL

To the 15th Canadian Masonry Symposium Participants,

On behalf of the Canadian Masonry Contractors Association (CMCA) and the Canada Masonry Design Centre (CMDC), it is with great pleasure that I welcome you to Ottawa, Ontario for the Fifteenth Canadian Masonry Symposium.

For almost five decades, the Canadian Masonry Symposium has brought together international masonry researchers, practitioners, and industry leaders to advance the science, engineering, and application of masonry. This event continues to serve as a platform for sharing knowledge, fostering collaboration, and strengthening the ties between academia and industry. Over the next three days, participants will have the opportunity to engage in technical sessions across a wide range of topics and to connect with colleagues from across Canada and around the world during our networking and social events.

This year marks an exciting return to Ottawa, where the symposium was last held in 1980. We are proud to once again partner with Carleton University and to host this event in Canada's capital—an ideal setting for discussions that shape the future of masonry design and construction.

Founded in 1967, CMCA has long championed the masonry contracting industry in Canada. Its leadership and continuity provide strength and vision for the long-term growth of our sector. This enduring commitment is reflected in CMCA's continued support for innovation, workforce development, and collaboration with our industry partners.

CMDC was established in 2003 by several provincial contractor associations under CMCA, with the goal of promoting the effective use of masonry through research, education, and technical support. Since then, CMDC has expanded to include members from coast to coast. This national network reflects our shared commitment to elevating masonry in Canada through technical excellence and strategic collaboration.

The members of CMCA and CMDC are proud to support the 15th CMS and are deeply grateful to everyone who made this event possible. We also thank the Organizing Committee and Technical Committee for their tireless work. Most importantly, thank you to all participants—students, researchers, engineers, and industry professionals—for your contributions. Your involvement is what makes this symposium a success.

We hope you enjoy your time in Ottawa, and we wish you a productive and inspiring experience at the 15th Canadian Masonry Symposium.

Sincerely,

Tony Masciotra, President CMCA & CMDC
David Stubbs, Executive Director CMCA & CMDC

Dear Participants in the 15th Canadian Masonry Symposium,

On behalf of the Canadian Concrete Masonry Producers Association (CCMPA) and its producer members, I am pleased to welcome you to Ottawa, Ontario for the Fifteenth Canadian Masonry Symposium. This event, now in its 49th year, has grown into one of the four major international conferences focused on masonry research, design, and construction.

The continued success of CMS is a testament to the dedication and collaboration of many individuals who generously volunteer their time to organize the symposium, review technical papers, and contribute through presentations and active participation. We extend our sincere thanks to the Canada Masonry Design Centre (CMDC) and Carleton University for co-hosting this year's event, and we are also grateful for the strong support from our fellow industry sponsors. Most importantly, we recognize and appreciate the contributions of all Canadian and international participants who authored papers, prepared presentations, and made the effort to attend.

At CCMPA, we deeply value the benefits that arise from sustained investment in university research and education. The tangible outcomes, such as improved products, innovative construction methods, and advances in building codes and standards, are vital to the growth and modernization of masonry construction in Canada. Equally important are the less visible but far-reaching benefits: the education and training of the next generation of engineers with hands-on experience in masonry, the development of lasting partnerships with academic researchers, and the collaborative opportunities that drive interdisciplinary innovation.

We are proud of the research ecosystem that has been built in Canada, one that thrives on strong engagement between industry and academia. This ecosystem can only be maintained through ongoing support from both sectors, and through the commitment and enthusiasm of the researchers themselves. Since 2009, CCMPA has provided significant, sustained funding to Canadian universities to help make this possible. The high quality and depth of Canadian research showcased at this symposium is a reflection of that ongoing commitment and collaboration.

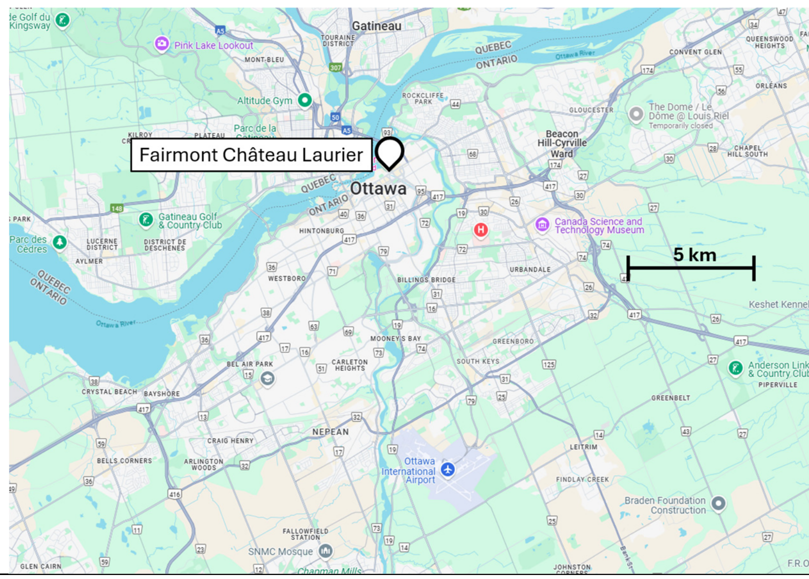
Thank you once again for joining us in Ottawa. We hope this symposium provides you with new knowledge, fresh perspectives, and valuable connections to carry forward into your work.

Sincerely,

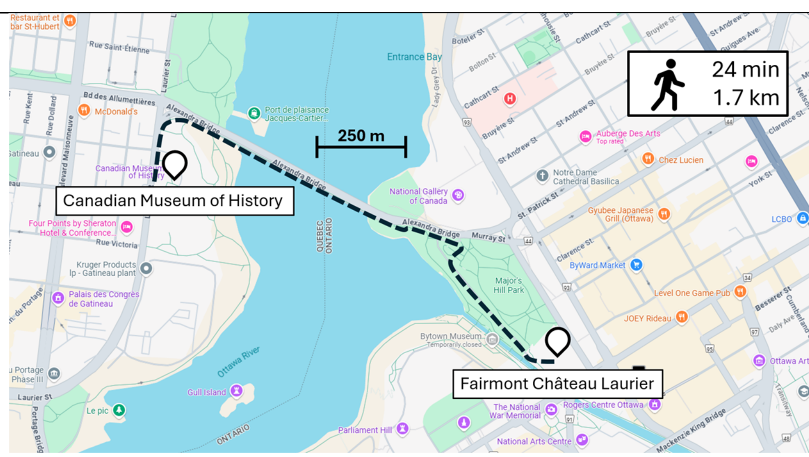
Justin Campbell, President CCMPA
Andrea McChesney, Executive Director, CCMPA

Venue and Offsite Locations

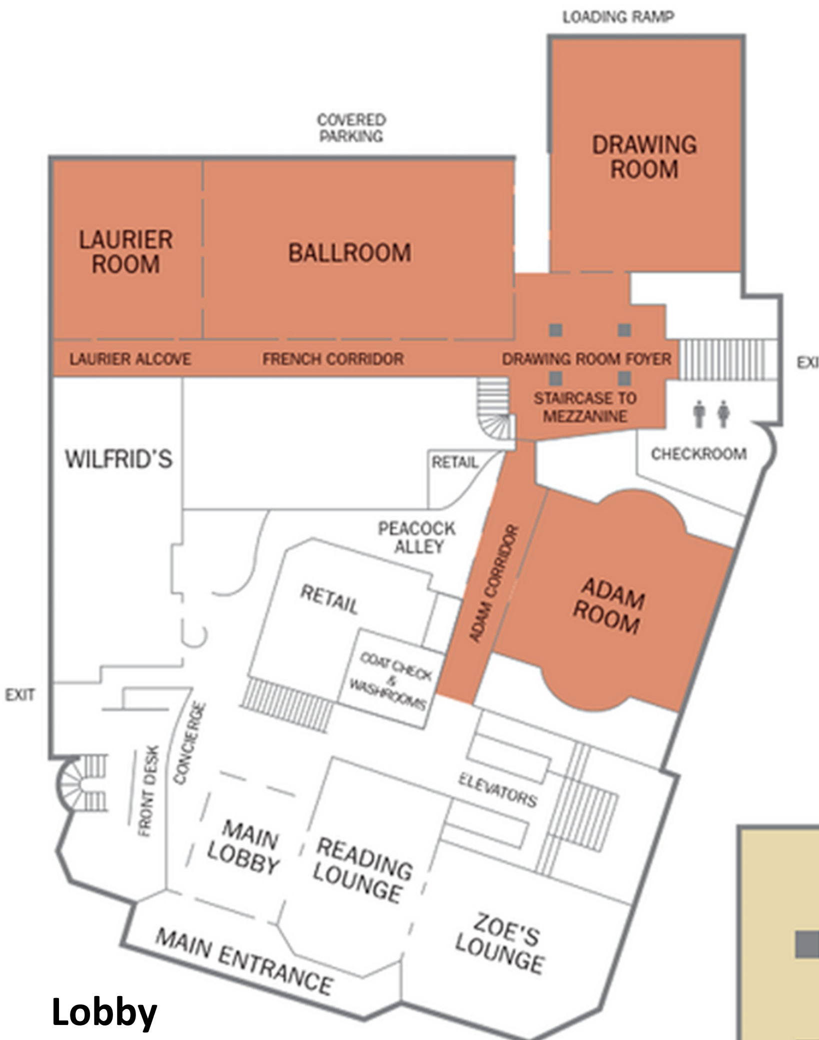
Hotel
Fairmont Château Laurier
1 Rideau St, Ottawa, ON



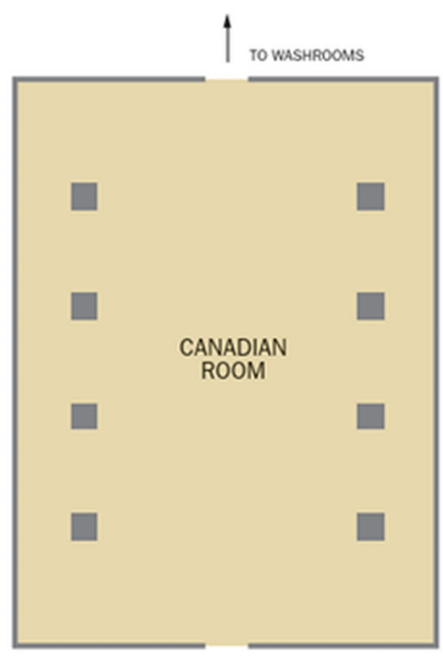
Tuesday Night Dinner
Canadian Museum of History
100 Laurier St, Gatineau, QC



Fairmont Chateau Laurier



Lobby



Lower Level

Conference Schedule and Events

MONDAY JUNE 2, 2025						
TIME		BALLROOM	DRAWING ROOM	ADAM ROOM	LAURIER ROOM	CANADIAN ROOM
15:00	18:00	**Registration Desk Opens** Register and Collect Conference Materials				
18:00	22:00	**Mortar Mixer Reception** Combined Social Event with the Canadian Masonry Contractors Association (CMCA) and the Canadian Masonry Symposium (CMS) to Kick off the Week's Activities *Appetizers & Drinks*				

TUESDAY JUNE 3, 2025						
TIME		BALLROOM	DRAWING ROOM	ADAM ROOM	LAURIER ROOM	CANADIAN ROOM
Registration & Breakfast						
07:45	08:45	**Registration Desk Opens** Register and Collect Conference Materials				**Full Breakfast** All Registered Delegates and Registered Companions
08:45	**09:00**	**Transition Time – Move to Ballroom**				
09:00	10:30	**Conference Welcome and Keynote** Panel Discussion on the Parliament Hill Restoration Project (WSP, DFS, PCL, EllisDon, PSPC)				
10:30	**11:00**	**Coffee & Refreshment Break**				

TUESDAY JUNE 3, 2025

TIME		BALLROOM	DRAWING ROOM	ADAM ROOM	LAURIER ROOM	CANADIAN ROOM
11:00	12:30	**Paper Session 1**				
			Existing Masonry 1	Reinforced Shear Walls 1	Construction and Detailing	
12:30	**13:30**					**Lunch**
13:30	15:00	**Paper Session 2**				
			Existing Masonry 2	Reinforced Shear Walls 2	Climate Change and Masonry	
15:00	**15:30**	**Coffee & Refreshment Break**				
15:30	17:00	**Paper Session 3**				
			Unreinforced Masonry 1	Reinforced Out-of-Plane Walls	Resilient Masonry	
18:00	22:00	**Social Event**				
		Social Night at the Museum of History (***<u>Offsite event</u>*** *for registered delegates and companions*) Joint event with the CMCA Conference				

WEDNESDAY JUNE 4, 2025

TIME		BALLROOM	DRAWING ROOM	ADAM ROOM	LAURIER ROOM	CANADIAN ROOM
07:45	08:45					**Full Breakfast** All Registered Delegates and Registered Companions
08:45	**09:00**	**Transition Time – Move to Ballroom**				
09:00	10:30	**Keynote Address** Paulo B. Lourenço *Standards for seismic assessment of built cultural heritage: European developments and research for the next generation codes*				
10:30	**11:00**	**Coffee & Refreshment Break**				
11:00	12:30	**Paper Session 4**				
			Unreinforced Masonry 2	Assemblage Testing 1	Retrofit and Repair	

WEDNESDAY JUNE 4, 2025						
TIME		**BALLROOM**	**DRAWING ROOM**	**ADAM ROOM**	**LAURIER ROOM**	**CANADIAN ROOM**
12:30	**13:30**					**Lunch**
13:30	15:00	**Paper Session 5**				
			Existing Masonry 3	Assemblage Testing 2	Veneers 1	
15:00	**15:30**	**Coffee & Refreshment Break**				
15:30	17:00	**Paper Session 6**				
			Reinforced Out-of-Plane Walls	Infill Walls	Assemblage Behaviour	
18:00	22:00	**Awards Banquet**				
		Awards Banquet Dinner for all registered delegates and companions and presentation of awards				

THURSDAY JUNE 5, 2025						
TIME		**BALLROOM**	**DRAWING ROOM**	**ADAM ROOM**	**LAURIER ROOM**	**CANADIAN ROOM**
07:45	08:45					**Full Breakfast** All Registered Delegates and Registered Companions
08:45	**09:00**	**Transition Time – Move to Ballroom**				
09:00	10:30	**Keynote Address** Khaled Galal *Two decades of research on the structural performance of reinforced concrete masonry at Concordia University*				
10:30	**11:00**	**Coffee & Refreshment Break**				
11:00	12:30	**Paper Session 7**				
			Innovations in Masonry	Unreinforced Masonry 3	Veneers 2	
End of Symposium						

Tuesday June 3rd, 2025

Panel Presentation, Discussion, and Q&A on the Parliament Hill Rehabilitation Project

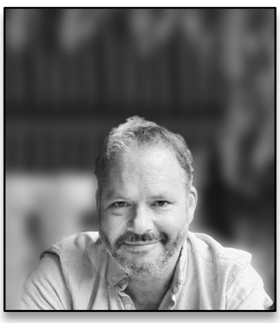
Centre Block and selected sections of Parliament Hill are undergoing a comprehensive rehabilitation to meet the contemporary and operational requirements of the Parliament of Canada. The rehabilitation is a complex blend of heritage conservation with appropriate and sensitive contemporary interventions, including upgrades to address its seismic integrity, physical security, accessibility, and sustainability, and the renewal of all base building systems, accommodations and building finishes. Join us for a presentations and a moderated Q&A session from representatives involved in the project.

Panel Participants

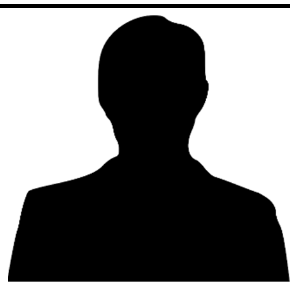
Brian Langenberg is a Senior Building Science Consultant and Project Manager with over 25+ years' of experience and is part of the Façade Engineering team at WSP Canada. Brian has also been supporting CENTRUS, a joint venture of WSP and HOK, the architects and engineers of record for the Centre Block Rehabilitation Project as a Building Science Discipline Lead. Over his career, Brian has been involved in a wide variety of projects that includes; Building condition assessments, diagnostic investigations and exploratory work, component monitoring and performance testing. Brian also has extensive experience in building envelope design and consulting support services, commissioning, and envelope performance verification/ testing for a variety of new construction projects.

David Edgar is a British conservator, stone carver and restoration stonemason with over 20 years' experience working on heritage buildings and monuments in Canada and in the UK, including The West Block of Parliament Hill, Ottawa; The Saskatchewan Legislative Building; Brownsea Castle; Kingston Lacy; Thomas Hardy's Cottage; Liverpool Central Library; Cartmel Priory and the Cathedrals of Salisbury, Winchester, Manchester and Sheffield. David is the co-owner of David Edgar Conservation Ltd; and is currently working as the consulting stone conservator for various projects across Canada, including The North Park Armoury, Halifax, and The Block 2 Rehabilitation Project, Ottawa. David is also the Lead Conservation Manager for the Centre Block Rehabilitation Project, Ottawa, where he represents the PCL / Ellis Don Joint Venture. David has lectured on the subject of stone conservation for the Ontario Association of Architects, The Canadian Association for Conservation, and the Association for Preservation Technology, as well as the Universities of Carleton and McGill.

Matthew Chase earned a Bachelor of Science (Civil Engineering) degree from Queen's University in 2006, specializing in environmental engineering. He then went on to obtain a Master of Science degree in 2009 from the University of Manitoba where he focused on the infiltration of wind-driven rainfall into plastered straw bale buildings. In his career as a consulting engineer with Crosier Kilgour in Winnipeg and WSP in Ottawa/Gatineau, he has worked on the investigation and restoration of existing and new building envelopes and structural systems, as well as the design of new concrete, masonry, steel, and wood structures. Matt has been instrumental in leading structural investigations and restoration of historic structures, including buildings on the University of Manitoba campus and the Global Centre for Pluralism (formerly the Dominion Archives and the Canadian War Museum) and Centre Block in Ottawa. His curiosity about historic construction methods and materials, attention to detail, and insatiable thirst for knowledge have led to developing an expertise in the investigation, in situ testing, and restoration of historic masonry structures. He is currently responsible for the structural rehabilitation of Centre Block's stone masonry façade, as well as the structural specifications for the Centre Block Rehabilitation project. Matt is registered as a professional engineer in Ontario and Québec.



Pascal Létourneau has been leading the heritage team at DFS Inc. since 2015. With an impressive group of conservation architects, technologists, and conservators, they have worked on the most significant conservation projects in the province of Quebec, Ontario, and the Maritimes. He is highly esteemed within the conservation community, not only for his extensive expertise but also for his natural, all-encompassing, and compassionate leadership style. Pascal's portfolio boasts the preservation of some of Canada's most iconic heritage buildings, cleverly employing a harmonious blend of traditional methods and cutting-edge technologies. Currently, Pascal is heavily in the rehabilitation of the Parliament of Canada Centre Block, where he leads a large group of conservation architects and heritage planners for CENTRUS.



Jeff Meek is a Project Manager of the Centre Block Rehabilitation Program and works for Public Services and Procurement Canada. Biography and photo unavailable at the time of publication.

Wednesday June 4th, 2025

Paulo B. Lourenço Presents:

Standards for seismic assessment of built cultural heritage: European developments and research for the next generation codes

Dr. Lourenço is a Professor at the Department of Civil Engineering, University of Minho, Portugal. Experienced in non-destructive testing, advanced experimental and numerical techniques, innovative repair and strengthening techniques, and earthquake engineering. President of ICOMOS ISCARSAH – International Scientific Committee on the Analysis and Restoration of Structures of Architectural Heritage. Specialist in structural conservation and forensic engineering, with work on 200 monuments, including 20 UNESCO World Heritage Sites. Revision leader of the European masonry code (EN 1996-1-1). Coordinator of the MSc on Structural Analysis of Monuments and Historical Constructions, with alumni from 75 countries and European Heritage / Europa Nostra Award. Editor of the International Journal of Architectural Heritage, Taylor & Francis. Author of "Historic Construction and Conservation" and "Finite Element Analysis for Building Assessment", Routledge (2019 and 2022). Supervised 80 PhD theses and coordinated multiple national and international research projects. Awarded a European Research Council Grant to develop an integrated seismic assessment approach for heritage buildings. Coordinator of a European Doctoral Network with 15 PhD students on sustainable building lime applications.

Thursday June 5th, 2025

Khaled Galal Presents

Two decades of research on the structural performance of reinforced concrete masonry at Concordia University

Dr. Khaled Galal is a Professor in the Department of Building, Civil, and Environmental Engineering at Concordia University in Montréal, Québec, Canada. With over two decades of research excellence, Dr. Galal has established a distinguished track record in the field of reinforced masonry and concrete structures. His primary research objectives focus on developing innovative and efficient methods for designing structures to withstand dynamic loads, including seismic events, high winds, and progressive collapse, with the overarching goal of promoting sustainable and resilient buildings and infrastructure.

Dr. Galal's scholarly contributions span a broad range of Structural Engineering disciplines, including reinforced concrete and masonry structures, earthquake engineering, structural dynamics, structural rehabilitation, and the application of fiber-reinforced polymer (FRP) composite materials.

Since joining Concordia University, Dr. Galal has secured over $15 million in research funding. He is a Gina Cody Research and Innovation Fellow, Director of Concordia's Structures Lab, and Director of the GCS Research Centre for Structural Safety and Resilience (CSSR). He is also an active member of the Centre d'études interuniversitaire des structures sous charges extrêmes (CEISCE) and serves as a voting member of the CSA S304 Committee on the Design of Masonry Structures

Dr. Galal has supervised or co-supervised 41 graduate students at the Ph.D. and Master's levels, co-authoring over 250 peer-reviewed research publications in collaboration with his students and colleagues. He is a licensed professional engineer in Quebec and Ontario, Canada.

Awards to be Presented at the 15th CMS

Award winners will be announced at the Banquet Dinner on Wednesday June 4th, 2025. A description of the awards which will be handed out this year is provided below:

Paper & Presentation Awards

The H. W. H. West Award

The Best Overall Paper with a Graduate Student as the Lead Author

The M. A. Hatzinikolas Award

The Best Paper Related to Innovative and New Masonry Materials, Systems or Structures.

The C. T. Grimm Award

The Best Overall Paper Related to Building Envelope, Sustainability, Durability and Resilience of Masonry Materials and Structures.

The R. G. Drysdale Award

The Best Paper Related to Design, Behaviour and/or Analysis of Masonry Structures.

Exceptional Reviewer Award

Awarded to a member of the technical committee for their commitment, diligence and detail in providing authors with valuable feedback in a timely manner.

15th CMS Awards Selection Committee

Nominations for paper awards were made by members of the technical committee. Noteworthy papers were then reviewed by the awards committee for the selection of finalists. The paper awards committee is comprised of the following:

Bora Pulatsu, Carleton University, Co-Chair Technical Committee 15th CMS
Ehab Zalok, Carleton University, Co-Chair Technical Committee 15th CMS
Khaled Galal, Concordia University, Co-Chair Technical Committee 14th CMS
Yi Liu, Dalhousie University, Co-Chair Technical Committee 13th CMS
Nigel Shrive, University of Calgary, Chair CSA S304 Design of Masonry Structures

"Mortar Mixer" Welcome Reception

Monday June 2nd, 18:00 – 22:00

CHATEAU LAURIER BALLROOM

Start the conference with a warm welcome at the iconic Fairmont Château Laurier. Enjoy refreshments, meet fellow attendees, and get ready for an exciting week ahead in the heart of downtown Ottawa. This reception, held in collaboration with the Canadian Masonry Contractors Association (CMCA), provides a unique opportunity for CMS and CMCA attendees to connect and network, fostering meaningful connections across both organizations. It's also a fantastic chance for students to engage with their peers, share ideas, and build valuable relationships within the industry.

Canadian Museum of History Event

Tuesday June 3rd, 18:00 – 22:00

CANADIAN MUSEUM OF HISTORY

Enjoy an unforgettable evening at the Canadian Museum of History, one of Canada's most renowned cultural landmarks. This joint event with the Canadian Masonry Contractors Association (CMCA) offers a unique opportunity for CMS and CMCA attendees to come together, explore fascinating exhibitions, take in breathtaking views of Parliament Hill, and network with industry professionals in an inspiring setting.

CMS Awards Banquet

Wednesday June 4th, 18:00 – 22:00

CHATEAU LAURIER BALLROOM

To close out the symposium, we will host our awards banquet in the Ballroom. Come celebrate industry achievements in an elegant setting befitting the occasion. Enjoy a gourmet dining experience, inspiring speeches, and a memorable evening with colleagues and friends.

Companion Program

Please note: *There is no dedicated companion program*. However, companion registration includes access to all social events, so bring a guest and enjoy these unforgettable experiences together.

Those who are not attending the symposium's technical program are encouraged to discover all that Ottawa has to offer. Consider exploring nearby locations including:

PARLIAMENT HILL

Parliament Hill remains a must-see destination in Ottawa, even as it undergoes a historic restoration. While the Centre Block is temporarily closed for renovations, visitors can still admire the iconic architecture from the outside, enjoy stunning views of the Ottawa River, and experience the vibrant atmosphere that defines Canada's capital. Free guided tours of the Senate and House of Commons are available nearby, offering a rare chance to see the country's democracy in action from unique temporary locations.

BYWARD MARKET

Step into the lively heart of Ottawa at the historic ByWard Market, one of Canada's oldest and most vibrant public markets. Just steps from the Chateau Laurier Hotel, this bustling district is a hub of local culture, offering everything from fresh produce and handcrafted goods to international cuisine and Canadian specialties like the famous BeaverTails pastry. Wander through charming streets lined with artisan boutiques, cafes, and galleries, or soak in the lively atmosphere with street performers and seasonal events. Whether you're shopping, dining, or simply exploring, ByWard Market offers an authentic and unforgettable Canadian experience.

RIDEAU CANAL

Experience the charm of Ottawa with a visit to the Rideau Canal, a UNESCO World Heritage Site that comes to life as the city blooms. Stroll along its scenic pathways lined with tulips and fresh greenery and see the historic locks that date back to the 19th century. The warmer months are perfect for picnicking along the water's edge, exploring nearby parks, or relaxing at outdoor cafés with canal views. It's the ideal time to enjoy the fresh air and vibrant atmosphere of one of Canada's most iconic landmarks.

Conference App

We are pleased to offer a mobile app for the 15th Canadian Masonry Symposium, powered by *Eventify*. Through the app, you can browse the Symposium schedule and view the full text and author information for all papers expected to be presented directly on your personal smartphone or tablet. You can also use the app to learn more about our sponsors and connect with conference attendees and grow your professional network.

Scan the QR code below (Apple or Google Play, according to your device) to download the app and search for the Canadian Masonry Symposium (CMS). Enter *the email address that you used to register for the conference* and you will receive a passcode to log into the conference app. If you do not have access to the email address that was used to register you to the conference, or if you experience any difficulties getting the app, please reach out to the conference staff and we will gladly assist you.

Apple Appstore **Google Play**

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Abstracts of Papers Published in the 15th CMS and Detailed Presentation Schedule

TUESDAY JUNE 3RD, 2025 — Paper Session 1

Existing Masonry 1			**Drawing Room**
Time	**Authors**	**Title [paper#]**	**Page**
11:00 – 11:15	Madalena Ponte; Gabriele Guerrini; Andrea Penna and Rita Bento	Assessing Interactions Between the Structural Units of a Rubble Stone Monumental Aggregate using Equivalent Frame Models **[086]**	2
11:15 – 11:30	Lucy Davis; Paolo Petroni and Daniele Malomo	A visual programming-aided discontinuum approach for an efficient macro-scale seismic analysis of unreinforced masonry structures **[160]**	3
11:30 – 11:45	Qianqing Wang and Katrin Beyer	3D Microstructure Generation of Rubble Stone Masonry Walls from 2D Images **[089]**	4
11:45 – 12:00	Anushka Mukherjee; Andrei Farcasiu; Douglas La Prairie; Tom Morrison and Bora Pulatsu	Multi-Level Framework for Structural Analysis of an Old Masonry Building **[080]**	5
12:00 – 12:15	David Arnold; Arash Sahraei and Timir Baran Roy	Case Study of the Canadian Parliament Building's Unreinforced Masonry Tolerance to Excavation-Induced Vertical Movement **[123]**	6
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Paper Session 1

Existing Masonry 1

Drawing Room

Assessing Interactions Between the Structural Units of a Rubble Stone Monumental Aggregate using Equivalent Frame Models

Madalena Ponte[i], Gabriele Guerrini[ii], Andrea Penna[iii], and Rita Bento[iv]

ABSTRACT

Rubble stone monuments, common in Mediterranean countries, are particularly vulnerable to seismic activity due to their construction techniques and materials. These structures typically consist of irregular, uncut stones, loosely bound with weak mortar, resulting in low tensile strength and poor cohesion. In addition, these historical structures are usually built as irregular aggregates, contributing to their earthquake vulnerability. Due to their cultural importance, in addition to safety and economic reasons, it is of utmost importance to perform accurate seismic assessments of historical masonry structures to preserve them. Most of the time, however, it is not easy for engineers to consider the interactions between different structural units in the aggregate, especially when it is difficult to define these units themselves.

The National Palace of Sintra, located in Sintra, Portugal, is a representative example of irregular, large-scale rubble stone monuments built in aggregate without previous planning. This paper presents an overview of the study conducted on the Palace, including the historical research and experimental campaign carried out to perform its seismic assessment. The equivalent frame numerical modeling of such a complex case study is also discussed, focusing on the interaction between the structural units. This modeling strategy was chosen due to the limited number of parameters required, which makes it one of the preferred methods within the practitioners' community.

KEYWORDS

historical aggregates, interactions between buildings, equivalent frame modeling, nonlinear static analyses.

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A Visual Programming-Aided Discontinuum Approach for an Efficient Macro-Scale Seismic Analysis of Unreinforced Masonry Structures

Lucy Davis[i], Paolo Petroni[ii] and Daniele Malomo[iii]

Abstract

Accurate 3D geometric models are a critical step in the documentation and evaluation of old unreinforced masonry (URM) structures, where complex and irregular geometries are often present. However, detailed geometric documentation strategies such as close-range photogrammetry or 3D terrestrial laser scans often result in large, difficult to navigate digital files. Transitioning from these detailed, high-resolution models to functional 3D CAD models presents several challenges, including high computational cost and significant time investment. Traditional workflows often struggle to efficiently create workable models suitable for structural/seismic analysis, which can be overcome using novel strategies. This paper presents a visual programming approach to discontinuum analysis in a case study of a typical URM industrial building in Eastern Canada. This approach leverages a previously developed simplified modelling strategy, the Distinct-Element macro-crack-network, informed by the Equivalent Frame Method (EFM) as a discretization method implemented into a distinct element software for subsequent seismic analysis. The proposed workflow enables the rapid conversion of dense data into discretized models by automating repetitive tasks and integrating rule-based algorithms for model refinement. The case study analysis investigates the seismic response of a typical old URM industrial building constructed using clay brick masonry and located in Montréal, QC. Results from this study display the use of algorithms paired with a simplified modelling strategy to enhance understanding of the structural behaviour of old URM buildings.

Keywords

Equivalent frame method, discrete element method, unreinforced masonry, visual programming, Eastern Canada

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3D Microstructure Generation of Rubble Stone Masonry Walls from 2D Images

Qianqing Wang[i], Katrin Beyer[ii]

Abstract

Microscale modeling of rubble stone masonry structures is hindered by the lack of geometric data on the microstructure, including units' shapes and arrangement in 3D. This paper introduces an automated method for generating synthetic 3D models of rubble stone masonry walls using photos of real walls. The process involves identifying geometric parameters from 2D stone shapes in the segmented wall photos, and generating 3D stones with these parameters based on spherical harmonics. A geometric planning algorithm, mimicking the construction process of masons, is then used to assemble the generated stones, creating multi-leaf masonry walls. We use the method for a case study, where a wall of size 1600 mm × 1600 mm × 400 mm is created from the photo of the façade of a real wall. The generated wall is compared to the real wall using indices that quantify the geometric features of units, including size, aspect ratio and sphericity. The arrangement of stones is also compared in terms of vertical interlocking and course horizontality, demonstrating similarity between the synthetic and real structures.

Keywords

Rubble stone masonry, microstructure, spherical harmonics, typology generator

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Multi-Level Framework for Structural Analysis of an Old Masonry Building

Anushka Mukherjee[i], Andrei Farcasiu[ii], Douglas La Prairie[iii], Tom Morrison[iv], and Bora Pulatsu[v]

ABSTRACT

This research presents computational investigations to predict the overall macro-behaviour of a historic masonry building located in St. John's, NL, Canada, subjected to wind loading. The process begins with the documentation of the building, where principal geometrical features, construction morphology of the masonry walls, and the sizes and locations of the openings (e.g., doors and windows) are obtained using documentation methods. Continuum-based simulations (also denoted as macro-modelling) are performed following the standard non-linear finite element analysis (FEA) in which the geometrical properties are taken from the adopted documentation approach and automatically transferred into the solid shapes. The non-linear structural behaviour of the large-scale 3D macro-model is evaluated using the Mohr-Coulomb material model with different mesh sizes. The global structural behaviour as well as the most vulnerable sections of the building are identified, taking advantage of the computational efficiency of macro-modelling. Subsequently, a detailed structural analysis based on the discrete element method (DEM) is performed. The DEM-based approach represents brickwork assemblages as a system of discrete blocks in a fully discontinuous setting and simulates the interaction of masonry units at the contact points. Further insights are gained regarding the detrimental effects of existing cracks, which can be explicitly represented in the discontinuum-based analysis. The outcomes of this research highlight the integrated use of continuum and discontinuum-based modelling strategies in conservation engineering.

KEYWORDS

Historic masonry, computational modelling, continuum analysis, discontinuum analysis, structural assessment, structural analysis, collapse mechanisms

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Case Study of the Canadian Parliament Building's Unreinforced Masonry Tolerance to Excavation-Induced Vertical Movement

David Arnold[i], Arash Sahraei [ii], and Timir Baran Roy[iii]

ABSTRACT

Centre Block, Canada's iconic Parliament building, is currently undergoing a significant rehabilitation. Part of the planned work includes excavation of three additional partial basement levels. Throughout the excavation, the building will be partially supported on temporary steel shoring. This will be a system of drilled steel piles that will be exhumed and braced as the excavation proceeds. Vertical movements of the temporary steel shoring as well as the adjacent rock mass are expected. These vertical movements have the potential to damage Centre Block's heritage unreinforced masonry walls. A project specific vertical movement limit has been established to define an acceptable level of control. Development of the movement limit has accounted for the specific geometry and materials of Centre Block's masonry walls as well as the building's structural interaction with the shoring system. This paper discusses the non-linear analysis performed to establish the vertical movement limit. It is observed that many of Centre Block's walls have significant capacity to tolerate localized vertical movements. However, the associated load redistribution caused by the vertical movements needs to be considered in the shoring design. A summary of the vertical movement limits and corresponding shoring specification requirements is provided.

KEYWORDS

Canadian Parliament, Centre Block, unreinforced masonry, excavation induced movements, non-linear analysis

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Application and Evaluation of the New Standard for Existing Masonry Structures: Case Studies and Proposed Refinements

Heather Sustersic[i], Arezu Feizolahbeigi[ii], Patrick Dillon[iii], and Teagan Allen-Raffetto[iv]

ABSTRACT

In March, 2024, the Existing Masonry Guidelines (EMG) task group of The Masonry Society (TMS) convened a design summit to advance the creation of a new consensus standard for the assessment and rehabilitation of existing masonry structures, TMS 405. The summit brought together a diverse group of technical experts from the United States and Canada, encompassing academia, industry, and professional engineering practice. The initial draft provisions developed during this summit have been entrusted to the newly formed Existing Masonry Standards Committee (EMSC) of TMS, which will oversee their further refinement, review, and balloting.

A key objective of the EMSC is the development of detailed worked examples that apply the new standards to representative case study projects. These examples are essential in demonstrating the practical application of the proposed standards while also serving as an important tool for identifying areas that may require further modification prior to codification. Specifically, the examples highlight potential gaps, ambiguities, and instances where the provisions may result in overly conservative or insufficiently rigorous outcomes. This paper presents these case studies, offering an analysis of the draft standards in action, and providing a roadmap for refining the guidelines to ensure their robustness, practicality, and effectiveness for use in professional practice.

KEYWORDS

Codes and standards, evaluation standards, existing masonry, historical constructions, repair design, The Masonry Society

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TUESDAY JUNE 3RD, 2025

Paper Session 1

Reinforced Shear Walls 1

Adam Room

Numerical Investigation of In-Plane Response of Un-grouted Reinforced Masonry Walls

Muhammad Umer Farooq[i], Bowen Zeng[ii], and Yong Li[iii]

ABSTRACT

In conventional masonry construction, the use of grout significantly increases construction costs and time due to the additional material, labour, and curing processes required. This numerical study aims to identify alternatives to conventional fully grouted reinforced masonry (FGRM) walls that use less or no grouting, without bonding the vertical reinforcement. To demonstrate this, the effect of grout and bonding, on the in-plane (IP) behaviour of masonry walls was studied. A total of 20 walls were analysed which were categorized into five groups. In addition, to capture different failure modes (e.g., flexural, shear), four different aspect ratios i.e., 2, 1.44, 1 and 0.86 were considered. The numerical simulations were conducted in the general-purpose finite element software ABAQUS using the simplified micro modelling strategy, in which the individual components (e.g., concrete block, grout, reinforcements) were explicitly represented. The results indicated that when compared with URM masonry, un-grouted RM walls have higher strength and ductility. However, the un-grouted walls with unbonded reinforcement exhibit complex failure patterns and relatively lower in-plane capacities than conventional FGRM walls due to the absence of grout. It was also observed that the grouted unbonded masonry walls with a smaller aspect ratio are inherently stable with maximum loads comparable to those of conventional bonded RM walls. Based on the above numerical modelling and analyses, it is concluded that the use of unbonded reinforcement would save construction time and labour costs, particularly when constructing non-slender masonry walls.

KEYWORDS

Masonry Construction, Un-grouted Masonry, Unbonded Reinforcement, In-Plane Behaviour, Numerical Modelling

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Crack Tracking in Reinforced Masonry Walls: A Pilot Study to Find the Best Predictor of the Drift Experienced by Damaged Walls

Gonzalo Lema[i], Sebastián Calderón[ii], Antonio Suazo[iii], and Cristián Sandoval[iv]

ABSTRACT

Evidence suggests that shear walls might be more damaged than they appear after a seismic event. Many cracks become undetectable once the load is removed, representing a real challenge for post-earthquake structural assessments. Accordingly, this research proposes a methodology to assess and quantify the development of visible damage in BJR-PG-RM walls subjected to in-plane cyclic loads. The study aims to quantify cracks observed at peak deformation and the residual cracks remaining after load removal. This allows the assessment and quantification of the effective damage incurred by the wall following a simulated earthquake.

A detailed damage characterization was conducted on three test walls, extracting surface damage indicators such as crack width, crack length, internal crack area, and bounding box area of cracks. These damage parameter indices were obtained at different load stages of the in-plane cyclic load test. Observations revealed that walls can conceal up to 35% of the visible damage upon unloading. This capacity to conceal visible damage diminishes after the wall reaches its peak shear resistance. This study also highlights that relying solely on maximum crack width is ineffective in accurately characterizing the damage state of a wall. It is not capable of reliably predicting whether a wall has reached its peak shear resistance. In contrast, crack length and internal crack area emerge as suitable candidates for damage characterization, exhibiting a consistent progression that enables clear differentiation between damage states before and after reaching peak shear resistance. This study presents a novel methodology for assessing and evaluating damage in masonry walls under in-plane cyclic loading. It contributes to a deeper understanding of the damage progression in masonry shear walls, providing valuable damage characterization.

KEYWORDS

damage assessment, damage progression, in-plane cyclic loads, crack development, closing cracks

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A Penta-Linear Load-Displacement Backbone Model for Unbonded Post-Tensioned Masonry Shear Walls

Mohamed Ismail[i], Ahmed Yassin[ii], and Wael El-Dakhakhni[iii]

Abstract

Unbonded post-tensioned masonry walls (UPTMWs) have been introduced by several researchers in recent years as efficient seismic force-resisting systems due to their high in-plane strength, low damage, and self-centering capabilities. Few design procedures, exist in the literature, have been proposed to predict the in-plane flexural response of UPTMWs under cyclic loading. However, the simplified assumptions and the limited datasets used in developing and validating these procedures may lead to low accuracy problems and uncertain generalizability. To address these issues, genetic programming (GP), a form of artificial intelligence techniques, in parallel with mechanics, were utilized in this study to uncover underlying complex relationships controlling the seismic response of UPTMWs and developed simplified procedures for predicting the corresponding load-displacement backbone curve. Due to the limited experimental data in the current literature, a validated nonlinear numerical model was used to generate a matrix of 50 UPTMWs developed with various design parameters including the wall aspect ratio, the number and arrangement of post-tensioning tendons, the axial compressive stress level, and the compressive strength of masonry. Based on the generated dataset, a penta-linear backbone model was developed to predict the load-displacement response of cyclically loaded UPTMWs up to 20% strength degradation. The results showed that integrating mechanics and GP could yield simple and robust predictive procedures that can be adopted by masonry design standards for predicting the seismic response of UPTMWs.

Keywords

Artificial intelligence, backbone model, concrete block wall, genetic programming, mechanics, unbonded post-tensioned masonry shear walls.

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Evaluation and Quantification of Seismic Performance of Reinforced Masonry Core Walls with Boundary Elements

Amgad Mahrous[i], Belal AbdelRahman[ii], Khaled Galal[iii], Najib Bouaanani[iv], and Pierre Léger[v]

Abstract

Reinforced masonry (RM) structures have recently gained popularity as they are considered a cost-effective and fast construction technique. However, the seismic design of mid- to high-rise RM structures is still a challenge because it requires a reliable seismic force-resisting system (SFRS) capable of providing the required ductility and capacity. Reinforced concrete (RC) core walls are commonly used as the primary lateral force-resisting system in modern building construction as it accommodates the elevators and staircases. Therefore, this study examines the adequacy of using reinforced masonry core walls with boundary elements (RMCW+BEs) as a potential SFRS alternative to rectangular reinforced masonry shear walls (RMSWs) with and without boundary elements, given their enhanced structural and architectural characteristics in typical RM buildings. Furthermore, this study introduces a new modeling technique utilizing the applied element method (AEM) implemented in the Extreme Loading for Structures software (ELS), that can capture the seismic performance of RMSWs having different cross-sectional configurations and design parameters. Moreover, the developed models are used to evaluate the seismic performance of RM buildings located in North American moderate seismic zones that employ the RMCW+BEs as the main SFRS. The performance of the proposed system is evaluated using nonlinear time history analysis (NLTHA) utilizing typical ground motion records for North America. The system ductility and overstrength are quantified using nonlinear pseudo-static pushover following the FEMA P695 procedure. The results showed that utilizing the RMCW+BEs as the main SFRS can adequately control the seismic demand results from typical North American ground motions. Nonetheless, the system provides the required ductility, overstrength and deformation capacity for a ductile SFRS for typical mid- and high-rise buildings. The findings of this study contribute toward implementing the RMCW+BEs as an effective SFRS for typical RM buildings in the next generation of North American design standards for masonry structures.

Keywords

Core walls; Boundary elements; Nonlinear analysis; FEMA P695; Applied element method; Seismic response.

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Structural Vulnerability Assessment of a CMU-PG Reinforced Masonry Building

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ABSTRACT

In Chile, a great part of residential buildings are made of masonry, many of them reinforced or confined, partially grouted, and typically up to four stories high. In general, these buildings are structured in walls, making them very stiff and prone to fail in shear when subjected to lateral loads. This type of failure is of particular interest in the country due to its high seismic activity, implying that evaluating the seismic vulnerability of this type of building has always been a concern. Despite this, performing vulnerability evaluations of this type of building is uncommon in the country.

Different approaches have been proposed to perform vulnerability analyses and evaluate the response of a building under different earthquake scenarios and its most damage-susceptible structural elements. Recent studies have implemented numerical models to assess the seismic vulnerability of multi-story buildings, although these studies only focus on the performance of fully grouted masonry structures. The grouting type in masonry significantly impacts the material's behavior and performance, meaning that appropriate models must be developed for assessing partially grouted masonry.

In response to this gap, a case study four-story concrete masonry unit reinforced masonry building is numerically modeled to evaluate its structural vulnerability. The model is implemented in OpenSees. The shear wall elements were simulated employing a non-linear macro model, which was validated against experimental results of walls available in the literature. Once the suitability of the modeling approach for each structural element was validated, their assembly representing the whole case study structure was employed to run nonlinear incremental dynamic analysis. The obtained results at the shear wall element level show the suitability of the approach, and the results at the whole structure model are coherent with failures reported in post-earthquake field inspections.

KEYWORDS

Nonlinear modeling, incremental dynamic analysis, concrete masonry unit, structural vulnerability

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Ductility of Special Reinforced Partially Grouted Reinforced Masonry Shear Walls Under High Axial Loads

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ABSTRACT
The flexural performance of three full-scale special reinforced partially grouted masonry shear walls (PG-RMSWs) has been examined, with two of these walls exceeding the axial load limits and maximum reinforcement criteria outlined in TMS 402-22 (Building Code Requirements and Specification for Masonry Structures). This research seeks to assess how high axial loads affect the inelastic behavior, displacement characteristics, and ductility of PG-RMSWs, as the existing TMS 402-22 guidelines, primarily based on fully grouted walls, may not truly reflect the distinct behavior of partially grouted systems. The non-conforming walls were subjected to axial loads exceeding the TMS 402-22 allowable limits, presenting practical design challenges where the maximum flexural reinforcement ratio, as prescribed by the code, becomes lower than the provided reinforcement. The walls were designed as special reinforced walls and were tested under fully reversed cyclic loading to failure. The influence of increasing axial compression was assessed, revealing reductions in ductility, with displacement ductility values decreasing from 2.39 at 10% axial stress to 2.07 at 20% axial stress. The results indicate that while higher axial loads improved strength and stiffness, the PG walls maintained significant inelastic displacement capacity, with clear formation of plastic hinges and yielding of the reinforcement. However, failure was characterized by toe crushing and spalling of face shells at elevated axial loads. These findings highlight the need for updates to current design standards to more accurately reflect the unique inelastic behavior of PG-RMSWs, ensuring sufficient ductility and energy dissipation for seismic applications.

KEYWORDS
Partially grouted, axial compression, displacement ductility, reinforced masonry shear walls, reinforcement limits, seismic performance.

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TUESDAY JUNE 3RD, 2025 **Paper Session 1**

Construction and Detailing

Laurier Room

From Reality to Virtual Reality: Comparing Motion Patterns of Masons in Real and Simulated Environments

Noreen Gao[1], Emmanouil Katsimpalis[1], JuHyeong Ryu[2], Chul Min Yeum[1], Eihab Abdel-Rahman[3], and Carl Haas[1]

ABSTRACT

The construction industry plays a significant role in Canada's economy but faces challenges associated with health and safety, particularly ergonomic hazards involved in manual materials handling. These hazards, such as frequent heavy lifting, often lead to musculoskeletal disorders (MSDs), with masonry and plastering among the highest-ranking occupations for MSD claims. Recent technological advancements have made Virtual Reality (VR) applications increasingly adopted in construction training, demonstrating improvements in engagement, skill development, and safety, offering potential benefits over conventional in-person training. However, its effectiveness in teaching proper ergonomic posture and reducing injury risks has not been thoroughly explored. A key question is whether users adopt different movements when handling a weightless block in a virtual masonry environment. This study conducted experiments to compare real lifts (lifting physical blocks in a real-world setting) and VR lifts (lifting virtual weightless blocks in a VR-simulated environment), assessing motion behaviour in both contexts. In both experiments, while performing the same tasks of lifting blocks, participants were asked to wear a motion capture suit to record the motion data. The collected data were processed for analysis using the Rapid Upper Limb Assessment (a standard test for ergonomic risk), followed by a detailed analysis of the scores for body sections, including upper arm, lower arm, neck, and trunk. Experimental results demonstrate a significant statistical difference in motion behaviour between VR and real-life tasks, particularly in the trunk and neck. We conclude that VR training developments for the trades must recognize this limitation.

KEYWORDS

motion capture, virtual reality, ergonomics, masonry

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Masonry Beam Design and Construction in the U.S.: Findings from a Survey on Current Practices

Ece Erdogmus[i], Laura Redmond[ii], Aakash Basu[iii], and Shreedhar KC[iv]

ABSTRACT

This paper aims to identify and discuss the current practices of masonry beam design and construction in the United States. An online survey was administered to identify professionals' design and construction choices for masonry beams, with particular interest in identifying structural design practices. The survey was distributed through social media (LinkedIn), the masonry society (TMS), Masonry Contractors Association of America (MCAA), and several other masonry-related organizations and groups in the U.S. The survey also aims to understand why designers might select materials other than masonry beams/lintels to span openings in masonry walls. 106 unique and complete responses are received including 7 architects, 72 structural engineers, and 27 contractors. After the analysis of the data, the results show that practices and opinions related to masonry beams vary between architects, engineers, contractors (A-E-C), and many of these relate to two fundamental issues: 1) lack of communication and coordination between A-E-C professionals, and 2) lack of consistent education specific to masonry design and construction at U.S. universities. Engineers' primary barriers to designing masonry beams are complex loading conditions and contractor preference. Contractors noted that architects and engineers often specify other materials for spanning openings in masonry walls, or they provide too few details and too much reinforcement, making them difficult to build. Architects noted their top concern was cost, even though contractors were not as concerned about cost of construction. It should be noted that the response rate from architects is too small to draw strong conclusions regarding any topic. Other key themes that emerged from the study included: a general lack of trust in masonry beams for large spans, limited use and awareness of structural clay masonry, and the lack of clear code guidance on complex design issues such as torsion, deflection limits, and biaxial bending specific to beam design in the United States. The survey results are valuable to shape future research and code development related to masonry beams.

KEYWORDS

Beam Design, Deflections, Masonry Beams, Masonry Design, Masonry Lintels

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Stability Assessment of Early-Age Masonry Walls Without a Temporary Bracing

Ali Abasi[i], Bennett Banting[ii], and Ayan Sadhu[iii]

ABSTRACT

Masonry construction is widely used in the building industry due to its cost-effectiveness and durability. However, the structural properties of early-age masonry are not well-documented, making it difficult to establish reliable design parameters during the initial curing stages. Current Canadian codes primarily address fully-cured masonry structures, with limited guidance on temporary bracing requirements for early-age masonry walls under wind loads. This paper presents an assessment of early-age masonry properties and proposes a methodology for designing masonry walls without temporary bracing. A comprehensive literature review highlights existing research on masonry behavior, focusing on out-of-plane loading conditions and the role of wind-induced pressures during construction. The study employs experimental data of masonry wall tests and numerical modeling result from the recent literature to assess flexural tensile strength development at different curing times. Using a wind velocity-based approach, this research evaluates the stability of masonry walls under varying wind speeds without applying reliability-based load factors. The study introduces a sawtooth model to conservatively estimate masonry tensile strength over key construction stages, ensuring safe design assumptions. The results demonstrate that early-age masonry gains significant strength within the first seven days, allowing for the possibility of eliminating temporary bracing in specific conditions. By establishing thresholds for lateral stability and structural integrity, this research provides practical design guidelines for engineers and contractors, enhancing construction efficiency and safety.

KEYWORDS

Early-age mortar, early-age masonry, out-of-plane strength, monitoring of masonry walls, curing time, wind load, temporary bracing.

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Experimental Analysis of Freezing Effects on Masonry Elements

Rui Zhong[i] and Graziano Fiorillo[ii]

ABSTRACT

Cold temperatures challenge masonry structures in terms of long-term durability problems and short-term construction difficulties. Low temperatures reduce the heat of hydration required for both mortar and grout, slowing or even entirely pausing the hydration reaction until temperatures return to suitable levels; then, the structure can fully withstand the expected strength and serve as designed. The water content in the mortar and grout starts freezing below -2.8 ℃ (26.96 °F). Frozen water increases porosity, prolongs curing, reduces strength, and may shorten the masonry's lifespan. Research has emerged on the effects of the freeze-thaw cycles on masonry structures, the inner microstructure damage caused by the frost influence, the insulation applied on structures to reduce freezing temperatures effects, the long-term freeze-thaw damage observation, and the frost effect on structure seismic strength effects. While many studies have investigated the long-term durability of mature masonry under freeze-thaw cycles, there is limited research on how low temperatures and for how long the strength of newly constructed masonry exposed to cold temperatures could be affected. This work aims to study the effects of freezing temperatures on the strength development of masonry structures during the first 0 to 48 hours after construction. Thus, to further understand the phenomenon and the actual behaviour of masonry components curing under cold weather conditions, multiple groups of concrete masonry specimens were assembled and moved into an environmental chamber with temperatures equal to -6 ℃ (21.2 °F), -12 ℃ (10.4 °F), and -24 ℃ (-11.2 °F), and the exposure time of 6, 24, and 48 hours. The specimens were tested for compressive strength after 7, 28, and 90 days of maturity to elucidate the effects of cold weather on newly constructed masonry elements. As a result, even though some specimens showed a delay in strength growth, eventually, all specimens' compressive strength reached a value higher than the compressive strength required by CSA S304 for ungrouted and grouted hollow concrete masonry assemblages.

KEYWORDS

Masonry Prism Compressive Strength, Concrete Blocks, Extreme Cold Temperature, Exposure Time, Curing Time, Strength Delay.

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Early Reinforcing Lap Strength and Internal Wall Bracing of Masonry Walls

W. Mark McGinley[i] and Jacob B. Latham[ii]

ABSTRACT

The Committee for Masonry Wall Bracing was formed and developed the Standard Practice for Bracing Masonry Walls (Practice). In its provisions, a restricted zone is defined until the wall is supported laterally. Typical masonry wall construction is broken down into two periods: the initial period (<=24 hours) and the intermediate period. In the initial period, areas around the wall must be evacuated for winds more than 20 MPH. In the intermediate period, the areas around the wall must be evacuated for winds above 35 MPH, and the masonry wall and braces must be able to resist forces from a 40 MPH wind load.

The use of internal bracing through reinforcing and grouting the base of the wall to form a fixed support often provides a less cluttered and thus a safer work environment and has grown more popular. Internally bracing masonry walls using the Bracing Practice is a simple and effective way to improve masons (and others) safety on the job site. Although the guidelines and provisions described in the Bracing Practice have been well established, it was based on research conducted in the late 1990's. Recent improvements in grout mixes and increases in masonry unit strengths are likely resulting in conservative internal bracing designs.

Thus, an investigation was performed. The goals of this investigation were to determine if there is a change in masonry assembly performance with an out-of-plane cantilevered bending strain gradients in a typical CMU wall configuration, especially with contemporary units, mortars, different aged grouts, and rebar. The study also evaluated the use of high early strength cement/admixtures to see if they can be used to improve early age performance of the internally braced masonry wall.

The report will provide a summary of the results of this investigation.

KEYWORDS

Lap splices, early grout age, internal bracing.

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Reinforcement Learning Assisted Robotic Construction for Masonry Block Dry-Stacking in Simulation Environments

Bowen Zeng[i], Yuxiang Chen[ii], and Yong Li[iii]

ABSTRACT

Traditional masonry construction methods face significant challenges in tasks such as masonry block stacking, including labor intensity, quality variability, and the demand for high precision. These challenges often result in inefficiencies and inconsistent outcomes. Robotic construction technology presents a promising alternative by automating repetitive and complex tasks, which can improve efficiency, consistency, and accuracy. However, conventional industrial robots heavily rely on the pre-programming and human insights. Moreover, they are limited by the need for precise control and struggle to adapt to varied construction environments. To overcome these limitations, this study introduces a reinforcement learning (RL) strategy to optimize robotic masonry block dry-stacking. In this approach, the robotic arm autonomously learns and refines its stacking techniques through iterative interactions within a simulated environment that replicates the construction conditions. Performance evaluations indicate that the RL is capable of facilitating the block stacking process during the dry masonry construction, marking a step forward in automated masonry process.

KEYWORDS

Reinforcement Learning, Robotics, Block Dry Stacking, Masonry Construction

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TUESDAY JUNE 3RD, 2025 **Paper Session 2**

Existing Masonry 2

Drawing Room

Structural Analysis of a Historic Masonry Rib Vault: A Case Study from Canada's Centre Block

Isis Bennet[i], Relja Lukic[ii], Carl Mohammadi[iii]

ABSTRACT

Preserving our built heritage necessitates the analysis of historic structures under new loading conditions to bring structural performance up to modern codes and to accommodate changes to the building use or configuration. This case study looks at the performance of a masonry gothic rib vault ceiling under seismic loading and alteration to the existing load path.

The rib vault within Canada's central parliament building, Centre Block, was designed with traditional analysis methods, and has supported its self-weight for over a century. The rehabilitation of Centre Block involves the introduction of a movement joint that will seismically separate the attached Library of Parliament. This joint would disrupt the existing gravity load path of the historic rib vault ceiling requiring restraint of the thrust crossing the joint as well as a reassessment of the vault's stability.

Traditional analysis methods are adequate for assessing capacity and stability under gravity and seismic loads. However, these methods become insufficient when the gravity load path is altered, and finite element analysis (FEA) can provide useful insight into structural behaviour. This case study presents a methodology for validating an FEA model through traditional thrust line and kinematic methods. Modern standards are discussed and are applied to the results. This approach allows for the evaluation of the vaulted ceiling stability and informs the design of future interventions to ensure its preservation under new support conditions and seismic demands.

KEYWORDS

Thrust line analysis, unreinforced masonry, finite element analysis, masonry arches, vaulted stone ceilings, seismic.

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A Design-Assist Approach to Laser Cleaning of Stonework at the Centre Block, Parliament Hill, Ottawa.

David Edgar[i] and Kate Westbury[ii]

Abstract
The Centre Block (CB) is a Classified Federal Heritage Building housing Canada's Parliament. Nearly a century after opening, it closed in 2019 for rehabilitation. The requirements of the Centre Block Rehabilitation Project (CBRP) include major structural, seismic and security upgrades, while prioritizing the preservation of the building's heritage character and materials. Lessons learned during the rehabilitation of other buildings in the Parliamentary Precinct led to the adoption of an integrated approach to conservation, using "Design Assist" to bring conservation specialists – under contract to the Construction Manager (CM) - directly into a role that combines design and construction activities. The conservation of the exterior stonework forms a major part of the project scope and the chosen "level of clean" must address multiple challenging factors: technical and regulatory conservation requirements; Client/Stakeholder expectations; public perception; construction budget and schedule. The CM team reviewed existing masonry materials reference documentation and testing results, including the nature of the soiling to be removed by laser cleaning. A gap analysis exercise then identified any additional testing requirements. A program of trials was developed whereby every contractor/supplier with previous laser cleaning experience on Parliament Hill carried out three small trials in discreet locations on the CB building. Each contractor supplied three different levels of clean. The processes and outcomes were carefully managed by the Heritage Leads from the Client (Public Service and Procurement Canada), the Consultant (CENTRUS) and the CM (PCL/ED). The Client engaged various project stakeholders and representatives of applicable regulatory bodies to review the results of the trials on site. Testing was carried out to determine changes in surface morphology, colour, and moisture movement properties. Every stage in the process and every decision was evaluated by the collaborative team and rigorously documented. The trials, analysis and reporting fed into the development of specifications and tender documents. The suppliers who carried out trials on site were evaluated and pre-qualified to bid on the larger scope of work. The CBRP's innovative "Design-Assist" project approach encouraged input from craftspeople, equipment suppliers, designers, client(s), the CM, conservators and material scientists, resulting in a genuinely holistic approach to architectural conservation. The design-assist led cleaning trials have contributed to a successful construction phase, with minimal need for variations to scope, budget or schedule.

Keywords
Laser ablation, masonry conservation, stone cleaning, sandstone, gothic architecture, analysis.

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Assessment of Structural Systems of Residential Buildings with Unreinforced Masonry Walls in Montreal

Maryam Montazeri[i], and Ahmad Abo El Ezz[ii]

ABSTRACT

Buildings with unreinforced masonry bearing walls (URM buildings) are seismically vulnerable, providing insufficient resistance to lateral forces, as demonstrated by major earthquakes worldwide. Evaluating the seismic vulnerability and performance of these buildings is crucial in earthquake-prone regions with a high concentration of URM buildings. In Montreal, which experiences moderate to high seismicity, a considerable proportion of residential buildings include URM bearing walls, most constructed between 1850 and 1950. These buildings were typically made using a variety of materials, including natural stone, concrete, and clay, or were built with mixed structural systems combining masonry and wood elements. The popularity of these construction methods varied over time, making it important to assess the structural capacity and fragility performance of these buildings to understand regional-scale seismic risk in Montreal. Seismic risk assessment involves integrating regional hazard data, building inventories, and vulnerability analyses. This paper reviews the existing literature to define the characteristics of mixed structural systems in Montreal, focusing on trends in URM building construction over time. It examines how past studies have addressed these buildings in inventories, response analyses, or fragility functions, identifies gaps in current research, and outlines key resources to simplify and enhance the regional-scale seismic risk assessments of the city.

KEYWORDS

Unreinforced masonry bearing wall buildings, Plexes, mixed structural systems, regional seismic risk assessment, residential buildings.

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From Monitoring to Modeling: 3D-DEM Application to Masonry Arch Bridge Case Studies

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ABSTRACT

Thousands of masonry arch bridges are still in operation today, forming a vital part of the railway and road networks in Italy and Europe. As most of these bridges were built over a century ago, issues such as material deterioration, lack of maintenance, as well as increased axle loads and traffic volumes have raised concerns about their long-term structural integrity. In earthquake-prone regions, the integrity of these structures is also challenged by loads induced by seismic activity. Within this context, an increasing number of existing masonry bridges in Italy have been incorporated into the national Seismic Observatory of Structures. This initiative aims to monitor oscillations caused by earthquakes, providing the technical and scientific community with fundamental data to understand the seismic response of these structures. This paper presents three-dimensional models of two existing masonry arch bridges, developed using an advanced modeling strategy based on the discrete element method. Located in Northern and Southern Italy, these bridges are constructed from regular stone masonry and are characterized by multiple consecutive arch vaults. The complete bridge structures are modeled as assemblies of discrete blocks, incorporating all structural and non-structural components, such as piers, abutments, arch vaults, spandrel walls, and backfill material. The geometric characteristics of the bridges and mechanical properties of the materials were assigned based on available in-situ surveys. The numerical dynamic behavior of the generated models is compared and validated against monitoring data collected from these structures, also investigating the effects of alternative boundary conditions at the bridge extremities. Nonlinear time-history simulations with different seismic inputs are then conducted to assess the bridge vulnerability and identify critical structural areas, guiding the design of potential retrofit interventions to enhance their seismic performance.

KEYWORDS

Boundary conditions, Distinct element method, Masonry arch bridge, Structural monitoring, Nonlinear dynamic analysis

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Model Updating of a Masonry Arch Bridge: Evaluating the Effectiveness of Structural Intervention

Andrea Gennaro[i], Matteo Salvalaggio[ii], Filippo Lorenzoni[iii], Luca Tosolini[iv] and Francesca da Porto[v]

ABSTRACT

The seismic performance of masonry arch bridges is of paramount importance, given their historical significance and structural vulnerability to seismic events. A comprehensive understanding of the dynamic behavior of these structures is essential to ensure structural safety and to evaluate possible effective intervention strategies. In addition, evaluating the effectiveness of the executed interventions is also crucial to confirm that the implemented measures provide the expected improvements.

This study assesses the efficacy of a structural intervention on a masonry arch bridge through the application of model updating techniques based on post-intervention data. The bridge was restored in order to improve its resistance to seismic events. After the restoration work, Ambient Vibration Tests (AVTs) were conducted in order to capture the bridge's modal characteristics, including natural frequencies and mode shapes. The model updating process involved calibrating the Finite Element (FE) model to align with the measured dynamic responses, adjusting parameters such as material properties, boundary conditions, and structural details. Despite the absence of pre-intervention dynamic data, the updated FE model provides an accurate representation of the bridge's current state, allowing for an indirect assessment of the intervention's effectiveness in enhancing seismic performance.

KEYWORDS

Masonry arch bridge, Finite Element Modelling, Experimental test, Model updating, Ambient Vibration Tests

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Moving the Impenetrable

Jamie Marrs[i], and Chris Vopni[ii]

ABSTRACT

The Ottawa City Registry Office was constructed in 1874 following specifications prepared by Kivas Tully, The Provincial Architect and Engineer for Ontario. It is one of several similar structures across the province, used to store the land registers and to provide search and copy services to the public. To serve these important public services, the Offices were built as secure vaults, impenetrable to would-be thieves and neighbourhood fires, which were a common occurrence throughout major cities at the time. In Ottawa, the stone foundation walls extended to bedrock (> 10' deep) with 6" thick stone floor slabs (that protected the Office from potential tunnelling), and the six-wythe brick walls with brick vaulted ceilings protecting the contents from outside fires.

The building eventually became obsolete when the official registry was relocated and the structure cycled through many tenants before it was vacated in 1982. The area around the Office has been developed, leaving the building to stand alone adjacent to the loading docks of a shopping mall. The project aims to redevelop the area with a new residential high-rise, and to accommodate all services and needs of the site, the Heritage Designated building needed to be relocated.

Moving a building that was built as a fortress comes with significant difficulties. Discussion will focus on the process of the relocation, including the unique experience of observing cracking develop as the move progressed over different bearing conditions and the difference between how cracking appeared in restored and unrestored masonry. Also, engineering design related to the installation of the support structure, and the multiple support scenarios before, during and after the move. Further complications due to ongoing work on site will be explored, such as blasting during the move and after while in its temporarily supported scenario.

KEYWORDS

Masonry Conservation, Preservation Engineering, Adaptive Reuse, Building Move, Case Study

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TUESDAY JUNE 3RD, 2025

Paper Session 2

Reinforced Shear Walls 2

Adam Room

Finite Element Micro-Modelling of North American Partially Grouted Masonry Shear Walls

Dina Helmy[i], Carlos Cruz-Noguez[ii], and Clayton Pettit [iii]

ABSTRACT

Partially-grouted concrete block masonry walls are an attractive gravity and lateral load resisting system due to their low seismic mass, thermal efficiency, and constructability. Contrary to fully-grouted walls where all cells within the masonry wall are filled with grout, partially-grouted walls only feature grout in cells containing steel reinforcement. While resulting in a more economical solution compared to fully-grouted walls, the presence of voids in partially grouted walls creates difficulties in analyzing the wall system using conventional mechanics-based methods. This, compounded with the complexities associated with the block-mortar and block-grout interfaces, has resulted in a noticeable lack of understanding towards the behaviour of partially-grouted walls under in-plane lateral loads. In this study, a finite element (FE) methodology for micro-modelling partially-grouted concrete block masonry walls subjected to in-plane loading is developed. Within the FE framework, all cementitious components (masonry units, mortar, and grout) are separately modeled as two-dimensional solid continuum elements while reinforcing bars as beam elements. Interfaces existing between the masonry units, mortar, and grout are accounted for and defined through contact-based cohesion models. Several experimental studies were selected to validate the model and ensure the robustness of the modelling methodology under different loading scenarios and wall configurations. Examples of parameters investigated include wall openings, incorporation of bond beam and/or bed-joint reinforcement, cyclic loading, and wall aspect ratio. Results of the micro-model simulation for each experimental study are presented and followed by a detailed discussion of the performance, limitations, and applications of the micro-model.

KEYWORDS

Masonry, Shear Walls, Partially-Grouted, Finite Element, Micro-Modelling

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Lateral Cyclic Behaviour of High-Aspect-Ratio Partially Grouted Reinforced Masonry Shear Walls with Bed Joint Reinforcement

AbdelRahman AbdAllah[i], Belal AbdelRahman[ii], and Khaled Galal[iii]

ABSTRACT

Partially grouted reinforced masonry shear walls (PG-RMSWs) offer a cost-effective construction system widely used in North America. Unlike fully grouted walls, PG-RMSWs only require grouting in masonry cells that contain reinforcement, potentially reducing material and labor costs. However, limited research on the seismic performance of flexural-dominated PG-RMSWs has raised concerns about their suitability for mid- and high-rise reinforced masonry buildings. This study focuses on evaluating the lateral cyclic response of high-aspect-ratio PG-RMSWs with bed joint reinforcement (BJR) as the primary shear reinforcement. BJR not only accelerates construction but also enhances crack control. Two half-scale PG-RMSWs with an aspect ratio of 5.90 were tested under in-plane quasistatic cyclic loading, greater than the value 2.0, which is the upper limit specified for PG-RMSWs in CSA S304-14. Both walls had the same axial stress and flexural moment capacity but differed in cross-sectional design: one had a rectangular section (REC RMSW) while the other incorporated boundary elements (RMSW+BEs). The results showed that both walls exhibited flexural-dominated behavior, achieving high displacement ductility. The REC RMSW and RMSW+BEs reached ductility levels of $6.0\Delta_y$ and $12\Delta_y$, respectively, with corresponding force modification factors of 4.76 and 9.63. These findings suggest that the current design restrictions in CSA S304 should be revised to allow partial grouting in the plastic hinge region for high-aspect-ratio RMSWs, improving their applicability in seismic regions.

KEYWORDS

Partially grouted; Reinforced masonry, Boundary elements, Rectangular shear walls, Quasistatic cyclic test, Bed-joint reinforcement, Displacement Ductility.

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Effect of Vertical Reinforcement on the In-Plane Shear Strength of Concrete Masonry Walls

Mahmoud Zaki Abdelrahman[i], Belal AbdelRahman[ii], and Khaled Galal[iii],

ABSTRACT

In-plane shear strength is one of the key parameters in the design of concrete masonry shear walls. According to the North American masonry standards (i.e. CSA S304-14 and TMS 402/602-22), the shear forces are primarily resisted by masonry and horizontal shear reinforcement, whereas the New Zealand standards (NZS 4230) consider the contribution of vertical reinforcement in the calculation of shear strength. This study experimentally investigates the in-plane shear (diagonal tensile) strength of full-scale masonry assemblages (i.e., wallets). Nine full-scale wallets with dimensions of 1.2 ×1.2 m in accordance with ASTM E519 were constructed to yield three groups of specimens, namely, fully grouted wallets with a reinforcement ratio of 0.42%, partially grouted wallets with a reinforcement ratio of 0.17%, and ungrouted wallets. The results showed that the vertical reinforcement reached its yield capacity, significantly contributing to the shear strength of the tested wallets. Using these results, along with data from 44 previously studied masonry walls with different vertical and horizontal reinforcement ratios, the shear strength expressions proposed by the North American and New Zealand masonry standards were evaluated. The results demonstrated that CSA S304-24 produced the most conservative predictions compared to other standards, while NZS 4230 had the closest shear strength values to those observed by the experimental data. This can be attributed to the contribution of vertical reinforcement in resisting the shear stress in the NZS 4230. An adjustment to the shear strength equation of CSA S304-14 is proposed to incorporate vertical reinforcement, which has resulted in more precise and reliable predictions of masonry shear strength.

KEYWORDS

Vertical reinforcement, Shear strength, Concrete masonry walls, Diagonal tension, Horizontal reinforcement.

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Experimental Testing of Controlled Rocking Masonry Walls Incorporating Rubber Pads for Enhanced Seismic Performance

Yara Soliman[i], Mohamed Ezzeldin[ii], and Lydell Wiebe[iii]

ABSTRACT

Most controlled rocking masonry walls (CRMWs) that have been studied previously depend on unbonded post-tensioning (PT) tendons for self-centering but often suffer from high prestressing losses and challenging repairs after damage. The current study examines an innovative CRMW design that eliminates unbonded PT tendons, instead relying on vertical gravity loads for self-centering. By integrating rubber pads to mitigate toe crushing, this new design not only minimizes structural damage but also significantly enhances lateral displacement capacity, offering a more resilient and efficient alternative to conventional masonry systems. The test wall, constructed from half-scale fully-grouted concrete masonry blocks and equipped with steel flexural yielding arms as externally-mounted energy dissipation devices, was subjected to dynamic snap-back testing and quasi-static cyclic loading. The experimental results are presented, including free vibration response, equivalent viscous damping, and force-displacement characteristics. The findings highlight the system's effectiveness in reducing damage and enhancing lateral displacement capacity compared to conventional masonry systems. The results also highlight the potential of rubber pads in mitigating compression toe issues and further improving the seismic resilience of CRMWs.

KEYWORDS

self-centering, controlled rocking, experimental testing, dynamic, rubber pads, reinforced masonry walls

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In-plane Cyclic Response of a Flexural Reinforced Masonry Core Wall with Boundary Elements

Amgad Mahrous[i], Belal AbdelRahman[ii], and Khaled Galal[iii]

ABSTRACT

Designing seismic-resistant mid- to high-rise reinforced masonry (RM) buildings requires an effective seismic force-resisting system (SFRS) that provides sufficient lateral strength and deformation capacity. Core walls are often chosen as the SFRS for reinforced concrete (RC) structures because they efficiently incorporate elevators, staircases, and utility shafts within the building core, maximizing floor space. These walls also offer flexibility in architectural layouts while maintaining structural integrity and seismic performance. Although much research has focused on RC core walls, little is known about the behavior of reinforced masonry core walls. This study experimentally evaluated the structural performance of a reinforced masonry core wall with boundary elements (RMCW+BEs) under lateral cyclic loading. The C-shaped RMCW+BEs was tested as a potential alternative to rectangular RM shear walls, offering improved structural and architectural benefits for typical RM buildings. The wall, representing the first story of a core wall in a 12-story building, demonstrated high ductility ($14\Delta_y$) without losing lateral strength. The core wall exhibited a flexural-dominant ductile response, with a well-distributed crack pattern and significant energy dissipation. The findings suggest that RMCW+BEs could serve as an effective SFRS in RM buildings, contributing to the advancement of seismic-resistant construction and improving the resilience of RM buildings in North American seismic zones.

KEYWORDS

Core walls, Reinforced Masonry, Cyclic response, Quasi static, Lateral capacity, Ductility, Boundary Elements.

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Practical Application of Two New Diagonal Shear Load Capacity Equations for Partially Grouted Masonry Walls

Klaus Medeiros[i], Jianyixian Zhu[ii], Rodolfo Palhares [iii], Guilherme Parsekian[iv], and Nigel Shrive[v]

ABSTRACT

The paper aims to demonstrate the practical application of two new equations to predict the diagonal shear load capacity (DSLC) of partially grouted masonry walls (PGMW). The first equation, validated through numerical and experimental analysis, has shown significant improvements in predicting the DSLC for walls with different geometric configurations, considering factors such as masonry material properties, applied axial load, vertical and horizontal reinforcement, and vertical and horizontal grouting. The second equation, validated through existing experimental testing of small-scale material testing and full-scale wall testing, considers factors of only the masonry, the axial load, and the horizontal reinforcement: the masonry contribution is based on experimental testing for cohesion and the coefficient of friction rather than creating a function of the compressive strength. This study focuses on applying the equations to various practical scenarios and exploring their limitations and capabilities. Examples of calculations are provided, examining the impact of wall aspect ratios, the minimum and maximum allowable lengths of ungrouted panels between grouted cores, and the necessary conditions for a wall to be classified as partially grouted. These examples seek to illustrate the equations' flexibility and accuracy in predicting wall shear behavior under different design conditions. This practical approach will give engineers a clearer understanding of the equations' real-world applicability and provide guidelines for their use in structural design. The study emphasizes the equations' potential to improve knowledge of the behaviour of masonry subject to shear and to replace or complement existing code provisions, improving the safety and efficiency of masonry design. Further refinement may be in order to provide a consistently accurate method of predicting the DSLC of PGMW.

KEYWORDS

Masonry, Shear wall, Partially grouted, Diagonal shear load capacity, Aspect ratio, Grouting limits.

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TUESDAY JUNE 3RD, 2025 | **Paper Session 2**

Climate Change and Masonry | **Laurier Room**

Modeling Natural Carbon Sequestration Rates of Dry-Cast Manufactured Concrete Products

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ABSTRACT

Accurate quantification of the natural carbon sequestration of dry-cast manufactured concrete products is crucial for assessing their long-term environmental impact. Previously, test protocols for measuring carbon sequestration in manufactured dry-cast concrete products were developed, and the results on the amount and rate of sequestration of nine sets of concrete masonry units (CMU) from 1 to 6 months of age were reported. This paper presents a follow-up study that extends the analysis on the same nine sets of units to a 3-year period. Furthermore, experimental tests using crushed samples of the nine sets, exposed to the atmospheric conditions, provide an estimate of the maximum carbonation potential for dry-cast concrete. The results demonstrate that initial drying conditions during sample preparation play a crucial role in carbon uptake for dry-cast CMUs, with specimens dried at 45°C showing higher uptake at 28 days due to residual moisture enabling additional carbonation. However, this effect was not observed at 91 and 182 days, indicating that residual moisture's influence decreases over time. Additionally, crushed CMU samples reached a practical upper limit of 52%-55% of the maximum calcination carbon emission potential after four months of exposure. A proposed logarithmic model effectively captures the observed carbon uptake trends, aligning with the deceleration of carbonation over time due to pore blocking and the limited availability of reactive phases.

KEYWORDS

carbon uptake modeling, carbonation potential, CO_2 uptake modeling, concrete masonry unit (CMU), dry-cast, sequestration

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Cradle to Gate Embodied Carbon LCA Comparison

Heidi Jandris[i]

Abstract

The primary goal of this investigation is to provide a comparative embodied carbon cradle-to-gate (A1-A3) LCA (Life Cycle Analysis). Three different prototype buildings are compared: a CMU (Concrete Masonry Unit) structure with architectural CMU veneer, a wood and steel light frame podium-style building with metal panel rainscreen, and an insulated precast panel concrete building with a thin brick veneer. This study incorporates recent carbon sequestration research for the CMU.

Due to the unique structure of dry-cast concrete products, a relatively large amount of carbon dioxide is sequestered at significantly faster rates within the first 28 days of manufacture when compared with other types of wet-cast concretes. This timeframe is considered to be within A1-A3 for concrete masonry unit manufacturing. Building elements included in this LCA are the foundation, beams and columns, exterior walls, and stairwells/shafts.

The secondary goal of this study is to serve as a frame of reference to use when evaluating the embodied carbon of CMU structures and making comparisons. It can also serve as a roadmap for LCA practitioners, providing guidance for how to evaluate the embodied carbon of masonry components such as mortar, grout, and how to calculate the volume of units used.

The tertiary goal of this study is to serve as a starting point for future embodied carbon Whole Building LCA studies incorporating use stage scenarios. Examples of this are demonstrating how masonry structures can lower use phase embodied carbon with low maintenance requirements, less replacement due to durability and inherent resiliency, and incorporating carbon sequestration that occurs during the building's use stage and beyond. Such analysis can also be used in conjunction with energy modeling to demonstrate how operational carbon can be lowered by accounting for concrete masonry's inherent thermal mass.

The findings of this study show that conventional concrete masonry construction has only 6% more embodied carbon compared to the wood and steel light frame prototype, whereas the precast prototype contained 51% more embodied carbon than the wood and light frame building. These comparative values do not take into consideration the additional carbon sequestration that would be realized during the use phase of the concrete structures.

Keywords

Concrete masonry, embodied carbon, dry-cast concrete, sequestration, LCA, Life Cycle Analysis, A1-A3, Global Warming Potential

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Solar Reflectance and Energy Usage – Impact of Thermal Mass on Cool Walls

Nate Huygen[i], and John Sanders[ii]

ABSTRACT

Cool walls are designed to reduce energy consumption by having a high solar reflectance which minimizes the heat energy absorbed from solar radiation. This strategy is more effective for light-weight wall systems than for more thermally massive walls due to the ability of the mass to act as a buffer against heat transfer. In this study, three different wall systems were analyzed – fiber cement cladding, brick veneer cladding, and brick veneer over typical concrete masonry unit (CMU) – to cover a spectrum of thermal masses typical in residential and commercial buildings. Using a 2D finite element program, along with typical metrological year (TMY) climate data, these walls' performance was simulated. The influence of climate zone, wall orientation, and solar reflectance was studied. It was found that the thermal performance of the light-weight wall had the highest sensitivity to changes in solar reflectance due to its minimal capacity to store and buffer solar energy. Conversely, increasing the wall's thermal mass not only made the thermal performance less sensitive to solar reflectance, but also significantly reduced the energy usage of dark-colored walls. A brick veneer wall was found to have a 22% decrease in cooling energy and 44% decrease in peak cooling load as compared to a fiber cement wall in climate zone 1. A brick veneer wall over CMU was found to have a 28% decrease in cooling energy and a 66% reduction in peak cooling load as compared to a fiber cement wall in climate zone 1. If a wall has enough thermal mass and is in a favorable climate, there are conditions where a darker colored wall has a lower total energy usage. These results emphasize the need for holistic design of the building envelope when trying to optimize energy efficiency.

KEYWORDS

Thermal Mass, Solar Reflectance, Energy Modeling, Wall Envelope

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Sustainable and Cost-Efficient Cement Clinker Reduction: Retaining Strength and Lowering Carbon Emissions

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ABSTRACT

The Portland cement (PC) industry significantly contributes to global CO2 emissions, accounting for 5% to 8% of annual anthropogenic emissions. Supplementary cementitious materials (SCMs) offer sustainable alternatives that reduce the environmental impact of PC concrete. Still, the increased cost of conventional SCMs due to industry changes has created a need for more cost-effective solutions. Pulverised limestone (PL) has emerged as a promising alternative due to its abundance and cost-efficiency. While PL can reduce clinker by up to 15% in North America and 35% in Europe, it often leads to a significant decrease in compressive strength. Recent studies suggest that the ideal clinker replacement is around 12% by weight, beyond which strength is compromised. To produce eco-friendly concrete block, in this study, a new proprietary mineral admixture called Duraflex was assessed for its potential to maintain strength in cementitious pastes with higher PL content. Duraflex has previously shown promise in improving soil stabilization by enhancing strength and reducing porosity. The findings indicate that small amounts of Duraflex (2%) can effectively retain strength in cement mixes containing up to 30% PL, surpassing the performance of conventional SCMs. While PL replacement beyond 12-15% generally reduces strength, Duraflex mitigates this effect, allowing for greater clinker reduction without sacrificing performance. The study shows that using 30% PL with 2% Duraflex could reduce greenhouse gas (GHG) emissions by up to 20% compared to current Portland Limestone Cement formulations, which achieve a 10% GHG reduction with lower strength. This research highlights the potential of combining PL with Duraflex as a sustainable and cost-efficient approach to reducing clinker content while maintaining concrete strength and workability and lowering carbon emissions. In addition, an alternative approach to the problem is shown to be almost ready to be transferred to industry.

KEYWORDS

compressive strength, concrete masonry units, duraflex, granulated blast furnace slag (GBFS), portland cement, pulverised limestone

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Life Cycle Assessment of Masonry Structures: Towards a Systematic, Standardized, and Transparent Calculation Approach

Abdalla Talaat[i], Mohamed Ezzeldin[ii], and Wael El-Dakhakhni[iii]

ABSTRACT

Reducing the environmental impacts of the construction industry is becoming increasingly urgent for Canada to meet its committed climate change mitigation targets. As the masonry industry explores new decarbonization pathways, current life cycle assessment (LCA) efforts remain inconsistent and not standardized. In this respect, the current study evaluates the environmental performance of masonry construction using a comprehensive LCA methodology. The study first appraises the underlying principles behind life cycle-based environmental assessment. Subsequently, focusing on embodied impacts, the study outlines how different calculation tools and data sources can offer a clear, systematic, and transparent approach to assessing masonry products. Rather than solely emphasizing operational efficiency, the analysis highlights the importance of quantifying material-related impacts for energy-efficient buildings. Finally, a case study is presented herein, where the environmental impact of a masonry wall assembly is calculated using different LCA approaches. The analysis results show that black-box LCA calculations showed lower environmental impacts compared to the manual step-by-step calculation alternative. The latter offered a higher level of detail and transparency, allowing for the identification of material hotspots. For example, grout was the dominant contributor across all impact categories, suggesting that optimizing its quantity or using alternative mix designs could enhance the eco-efficiency. Evidently, employing robust calculations strengthens the credibility of the environmental assessment and moves us a step further towards standardizing the assessment of embodied impacts – similar to operational efficiency. This research area is expected to steer the masonry industry toward more sustainable practices and supports the achievement of its decarbonization targets.

KEYWORDS

Life Cycle Assessment (LCA), Environmental Assessment, Decarbonization, Building Sector, Masonry Structures.

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Experimental Quantification of Thermal Effects in Heritage Masonry Buildings

Graziano Fiorillo[i], Alireza Kaboorani[ii], Hamza Mustapha[iii], Parash Khand[iv], and Bennett Banting[v]

ABSTRACT

Although for centuries, the vast majority of residential buildings have been built using massive wall technologies, information regarding the effects of thermal mass on building performance including thermal comfort, resiliency, durability and energy consumption are not well known and the information is all over spread. While it is generally accepted that buildings in warmer climates benefit most from using more thermally massive constructions, there are conflicting statements on whether it also provides significant benefits in colder climates like Canada. In this paper, the experimental investigation of a research group in Manitoba to assess the thermal effects of heritage buildings is discussed. The investigation consists in the construction and the monitoring of three huts built at the Notre Dame Campus of RRC Polytech. Manitoba Masonry Institute (MMI) with the collaboration of the Building Efficiency Technology Access Centre (BETAC) at RRC Polytech and the University of Manitoba. The huts were constructed with different building envelope systems.

KEYWORDS

Thermal efficiency, Thermal mass, Heritage masonry, Building envelope.

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TUESDAY JUNE 3RD, 2025

Paper Session 3

Unreinforced Masonry 1

Drawing Room

AI-Assisted Seismic Debris Distribution Prediction for Unreinforced Masonry Structures

Jiadaren Liu[i], Ersilia Giordano[ii], and Daniele Malomo[iii]

ABSTRACT

Unreinforced masonry (URM) buildings are widely prevalent across North America due to their durability, cost-effectiveness, and construction simplicity. However, older and sub-standard URM structures are particularly vulnerable to seismic loads, often experiencing severe damage and catastrophic collapse. The resulting debris from such collapses poses a significant threat to the functionality of transportation systems, severely hindering critical post-disaster operations such as medical rescue and personnel evacuation. Discontinuous modeling is the most effective approach for simulating URM failure mechanisms, as it accurately captures block detachment and damage evolution. However, traditional structural analysis tools require numerous input parameters and involve high computational costs. To address these limitations, this study employs Blender, a software primarily designed for video game development, to simulate URM collapse using its integrated physics engine. While physics engines share similarities with structural analysis tools, they prioritize computational efficiency over absolute accuracy, enabling significantly faster simulations. Following an initial validation against experimental data, the Blender physics engine was used to generate a virtual experimental database, incorporating variations in key parameters such as ground motion intensity and building height. Based on the generated database, the gradient boosted decision trees (GBDT) algorithm was employed to develop debris distribution prediction models, with hyperparameter tuning performed through ten-fold cross-validation. The resulting GBDT-based model is demonstrated to reliably predict the debris distribution of URM buildings and generate debris distribution heatmaps, which can intelligently inform decision-making in post-earthquake functional recovery efforts by proving insights into potential obstruction zones, optimizing resource allocation, and enhancing the efficiency of emergency response operations.

KEYWORDS

seismic debris, unreinforced masonry, physic engines, gradient boosted decision trees

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Seismic Vulnerability Analysis of Non-Engineered (Without Engineering) Houses in the Punta Negra District, Lima – Peru

Luis Moran[i], Cesar Rojas[ii]

ABSTRACT

At present, the percentage of self-constructed homes (without engineering guidance) is higher than those built respecting all the established construction processes. It is known that 70% of homes have been built informally and are probably highly vulnerable to earthquakes. Punta Negra is a district where there is a lot of evidence of self-construction, the main causes being the low economic possibilities of the inhabitants and lack of knowledge of construction processes. The objective of this research is to apply the Benedetti-Petrini method to determine the degree of seismic vulnerability in the houses of the district of Punta Negra. For this purpose, the district was distributed in 10 sectors, which allowed the evaluation of structural, constructive and geometric aspects of the houses in an orderly manner. For each house, data was collected for the 11 parameters of the Benedetti-Petrini method, which will determine the vulnerability index of the homes.

Obtaining a seismic vulnerability map of the district will be another objective of the research. The vulnerability map obtained will serve to make the authorities aware of the situation and to be able to improve the territory occupancy and a better seismic delimitation of Punta Negra district. Thus, preventive measures can be taken in the event of a high magnitude earthquake.

Finally, it is concluded with the values found for the vulnerability index that the district of Punta Negra is moderately vulnerable to earthquakes. Most of houses reach the highly vulnerable level because they did not receive advice from a specialist during construction.

KEYWORDS

non-engineered masonry structures, self-constructed homes, Benedetti Petrini method, seismic vulnerability, masonry housing, confined masonry

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Shake table tests on the out-of-plane two-way response of a U-shape masonry structure

Dario Vecchio[i], Babar Ilyas[ii], Nuno Mendes[iii], and Paulo B. Lourenço[iv]

ABSTRACT

Unreinforced masonry (URM) structures are vulnerable to strong earthquakes, due to their limited resistance to dynamic actions. These vulnerabilities often lead to failure or collapse, with out-of-plane mechanisms posing a major threat for existing structures not possessing integral (or box-like) behaviour. Despite the number of uncertainties within structural components, the response is usually governed by macro-elements, such as the main façade and orthogonal walls. Based on the degree of connection, URM structures may experience two types of out-of-plane mechanisms, namely one-way and two-way bending. The former involves a macro-element connected only at its top and bottom, leading to a vertical bending axis. In contrast, the latter occurs with two axes of bending, vertical and horizontal, given the additional connection with the orthogonal walls. Moreover, if the façade is insufficiently restrained at the top and lacks adequate connections with the return walls, overturning of the façade and cracking in the orthogonal walls may occur. Such a complex scenario challenges the understanding of the typical two-way bending behavior of URM structures. Predicting the total capacity of these mechanisms is challenging, and currently, the literature lacks adequate analytical and numerical models. This paper presents an extensive shake-table campaign conducted at the University of Minho to evaluate the two-way bending behaviour of URM structures. A specimen was constructed in a U-shape configuration consisting of a façade and two return walls, made of dry-stack granite blocks, to simulate the behaviour of historical URM structures, and to allow for testing repeatability at large displacements near collapse. The response of the specimen, with fixed geometry and boundary conditions, was observed under different recorded ground motions. The changes in the targeted hybrid mechanisms were observed and conclusions were drawn. Data collected is essential to update existing analytical formulations and to calibrate refined numerical models.

KEYWORDS

Shake table testing, U-shape, Out-of-plane, Overturning, Two-way, Collapse.

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Optimizing Numerical Modelling for In-Plane Response of Clay and Calcium Silicate Masonry through Data-Informed Semi-Automation

Abide Aşıkoğlu[i], Paul Korswagen[ii], and Jan Rots[iii]

ABSTRACT

This study presents a semi-automated, data-informed framework for selecting parameter-consistent numerical models to approximate the in-plane behaviour of clay and calcium silicate masonry walls. A comprehensive experimental campaign has been executed on full-scale unreinforced calcium silicate and clay masonry walls at Delft University of Technology. The in-plane response of these walls was evaluated based on stiffness, strength, damage intensity at equivalent drift levels, and the overall impact of the damage. The findings indicate that unreinforced calcium silicate masonry walls are more prone to damage through the brick units, while cracks in unreinforced clay masonry walls predominantly align with mortar joints. Calcium silicate walls tend to develop larger and more prominent cracks, often requiring the replacement of individual bricks for a complete repair. In contrast, the damage in clay walls is typically easier to address through repointing of mortar joints. A parametric finite element analysis was performed to investigate these failure mechanisms, systematically varying input parameters to generate 3,456 numerical simulations. Each model permutation was evaluated to select models that closely approximate observed experimental responses. Unlike conventional calibration methods, this framework systematically explores possible combinations of input and output parameters to identify numerical models that replicate key structural behaviours. The preliminary results demonstrate that multiple parameter combinations can yield numerical responses closely matching experimental observations, providing a structured approach for improving masonry modelling practices.

KEYWORDS

Data-informed numerical model selection, semi-automation, parametric analysis, unreinforced calcium silicate and clay masonry, in-plane behaviour, and numerical-experimental agreement.

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Seismic Analysis of Structure 86 at the Archaeological Site of Shivta in Israel

Michol Rampado[i], Yotam Tepper[ii], Michael Cohen[iii], and Francesca da Portoi[v]

ABSTRACT

In Israel, most of the historical buildings dating back to the 5th - 8th century CE consist of masonry constructions that present numerous vulnerabilities related to the construction techniques of the time. To preserve the state of these buildings of high historical, artistic and architectural value, specific analysis and evaluations are necessary. This is of great importance in sites which have been declared as world heritage site, like the Shivta National Park, Israel. However, the analysis of existing masonry structures presents many difficulties mainly related to the knowledge of the original construction technique, the mechanical characteristics of the material, and the intensity of the actions that affected the structures during time. This research aims to provide an overview of the seismic vulnerability of some structures in Shivta, focusing on a specific building (Building 86), dating back to the Roman period, which presents typical earthquake damage. Starting from a historical, archaeological and geometric analysis of the archaeological site of Shivta, also supported by Building Information Modeling of the existing structures, a detailed seismic analysis of building n.86 is carried out.

KEYWORDS

Masonry buildings, Seismic Vulnerability, Numerical Analysis, Earthquake, Late antiquity archaeology, Shivta abandonment.

INTRODUCTION

Defining the historical seismicity of an archaeological site is an articulated process that combines different approaches and methods [1]. Generally, the Archeoseismic and historical analysis of a site allow relating

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Bedding Mortar Selection for the Rehabilitation of the Canadian Parliament Building's Historic Masonry

Mathew Chase[i]

ABSTRACT

Centre Block, Canada's heritage-designated federal Parliament building, was constructed in 1916 after fire destroyed an earlier building of the same name that occupied the site. The building was reconstructed using techniques considered state-of-the art at the time. This included hybrid walls consisting of an exterior sandstone wythe built integrally with clay brick backing and using a cement-based mortar.

Currently, Centre Block is undergoing a major rehabilitation, including extensive rehabilitation of the exterior, load-bearing masonry walls. This includes repointing, reconstructing deteriorated masonry, installing reinforcement at critical locations, and exposing, cleaning, repairing, and protecting structural steel members embedded in the exterior walls. The selection of a compatible restoration mortar is critical to the long-term success of these interventions.

Initially, an extensive investigation program was conducted to establish the material properties of the existing mortar, masonry units, and historic performance of the overall masonry assembly. Centre Block's mortar was found to have exceptionally high compressive strength, attributed to the large proportion of early-generation Portland cement used in the mortar mix. This often results in poor long-term performance of masonry; however, this has not been observed with Centre Block's sandstone masonry.

Subsequently, target material properties were established to guide the selection of a replacement mortar that is compatible with the existing mortar and balances structural and hygrothermal requirements. Various mortar types and mixes were investigated and an extensive testing program performed. A replacement mortar with cement content that is significantly higher than typically used for historic masonry repair work was selected. The approach taken, results obtained, and lessons learned are presented.

KEYWORDS

Centre Block (Canadian Parliament Buildings), mortar selection, historic masonry rehabilitation, cement mortar, Nepean sandstone, clay brick.

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TUESDAY JUNE 3RD, 2025

Paper Session 3

Reinforced Out-of-Plane Walls

Adam Room

Optimizing Tall Masonry Walls with Partially Unbonded Guided Post-Tensioning

Mahmoud Elsayed[i], Rafael Gonzalez[ii], Alan Alonso[iii], Clayton Pettit[iv], Douglas Tomlinson[v], and Carlos Cruz-Noguez[vi]

ABSTRACT

Tall masonry walls are widely used in single-story structures such as warehouses, schools, and industrial facilities. However, their high slenderness ratios (height/thickness) make them susceptible to second-order moments, often necessitating thicker walls and limiting their viability. While post-tensioning (PT) techniques have proven effective in reducing tensile stresses and member thickness in high-span reinforced concrete structures, their application in tall masonry walls remains relatively unexplored. In this study, the use of partially unbonded guided PT techniques to enhance the performance of tall masonry walls is investigated. A full-scale concrete masonry wall with a height of 8.75 metres and a slenderness ratio of 46 was experimentally tested under realistic loading and different boundary conditions. The wall was subjected to eccentric vertical loads and uniform out-of-plane pressures using an airbag, simulating conditions typical of one-story structures. The test objective was to investigate the effect of the applied PT stress, the presence of eccentric vertical load, and the effect of the base condition on the out-of-plane response of the PT masonry wall. The results indicate that using a fixed base and/or increasing the applied PT stress improves the response of the wall up to the serviceability limits. Additionally, the findings reveal that even with low levels of applied PT force, PT masonry walls can outperform or exhibit behaviour comparable to walls reinforced with conventional mild steel.

KEYWORDS

Tall masonry walls, unbonded post-tensioning bars, Out-of-plane response, Full-scale experimental testing

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Analysis Model for Slender Masonry Walls: The Effect of Wall-Foundation-Soil Interaction on the Out-Of-Plane Response

Alan Alonso[i], Mahmoud Elsayed[ii], Rafael Gonzalez[iii], Clayton Pettit[iv], Douglas Tomlinson[v], and Carlos Cruz-Noguez[vi]

Abstract

Load-bearing masonry walls are an effective structural system for single-storey buildings such as warehouses, theatres, community centres, and school gymnasiums. Usually, these types of walls reach a height-to-thickness ratio greater than 30 and are subjected to combined gravity and lateral loads. Due to their perceived vulnerability to second-order effects, North American masonry design standards (CSA S304 and TMS 402/602) set additional design criteria for these walls. In the previous version of CSA S304-14, one of those design requirements was to assume a pinned base condition, neglecting the inherent stiffness provided by the wall-foundation-soil interaction, which affects the strength and stiffness of slender masonry walls. Current versions of CSA S304-24 and TMS 402/602-22 permit using a base support different of a pin for any height-to-thickness ratio by using a more comprehensive analysis. This study aims to determine the out-of-plane flexural response of masonry walls subjected to combined gravity and lateral loads under various height-to-thickness ratios, types of soils, footing geometry, and foundation depth. The parametric analysis showed increased flexural capacity and decreased deflections when the analysis included wall-foundation-soil interaction. The foundation depth and soil capacity were the aspects that most affected the base stiffness. Elastic effective height factors were proposed to account for base stiffness during the design of slender masonry walls for different values of rotational base stiffness. These findings imply that accounting for base stiffness in the analysis and design of slender masonry walls could be an untapped source of strength and stiffness, which may lead to more cost-effective masonry wall designs.

Keywords

Base stiffness, foundation, masonry wall, out-of-plane, slender, soil-structure interaction

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Out-of-plane Seismic Behavior of Partially Grouted Reinforced Masonry Walls Under High Axial Loads

Tousif Mahmood[i], Ahmed A. Gheni[ii] and Mohamed ElGawady[iii]

ABSTRACT

This research explores the out-of-plane seismic behavior of partially grouted reinforced masonry (PG-RM) walls when subjected to high axial loads. The study involved testing three full-scale PG-RM walls under out-of-plane cyclic loading at axial load levels of 10%, 15%, and 20%. The focus was on analyzing their load-displacement characteristics, damage evolution, and deformation profiles. Findings reveal that higher axial compression significantly influences the structural response, leading to increased lateral load capacity but reduced ductility. Specifically, the wall with the maximum axial load demonstrated a 43% increase in peak lateral force, while its lateral drift capacity decreased by 30%. This suggests a critical balance between strength and deformation capabilities. To ensure realistic assessments, a state-of-the-art testing setup was created to apply continuous axial loads while simulating out-of-plane seismic demands, providing appropriate boundary conditions to evaluate the walls' flexural performance. In light of the recent removal of the maximum reinforcement ratio specified for out-of-plane loading in TMS 402-22, this study aimed to assess the performance of PG-RM walls under significant axial load. The results confirmed that the walls preserved their structural integrity without experiencing sudden crushing or excessive bed joint openings at their ultimate capacity, even at an axial load of 20%. The wall sustained strength degradation up to a lateral drift of nearly 5%. These outcomes underscore the necessity to reassess current design guidelines, as PG-RM walls exhibited better seismic performance than what is currently anticipated by existing code provisions. The walls displayed inelastic behavior and clearly defined plastic hinge formation, even under substantial axial loading, maintaining structural integrity beyond expected limits. This suggests that current design methodologies may be overly cautious and should be updated to reflect the true capacity of PG-RM walls more accurately, thus achieving a better balance between strength and ductility in seismic scenarios.

KEYWORDS

Partially grouted, reinforced masonry (PG-RM), out-of-plane seismic behavior, axial load, seismic design.

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Evaluation of Splice Length for Reinforcement in Masonry Walls

Rafael Gonzalez[i], Mahmoud Elsayed[ii], Alan Alonso[iii], Carlos Cruz-Noguez[iv], and Douglas Tomlinson[v]

ABSTRACT

Slender masonry walls are widely used in single-story commercial structures due to their efficiency and cost-effectiveness. However, increasing architectural demands for taller and thinner walls have amplified the vulnerability of these structures to buckling and second-order effects. Current design practices often rely on conservative approaches, such as increasing wall thickness, which raises material costs and compromises productivity. An alternative strategy—placing vertical reinforcement closer to the edge of the grouted cell—offers the potential to enhance out-of-plane performance but raises concerns about bond strength and durability. This paper presents the first phase of an experimental program aimed at evaluating the bond behaviour of vertical reinforcement placed at varying positions within masonry block cells. A total of ten pullout tests were conducted using a novel setup designed to replicate realistic conditions while eliminating compressive stresses on the surrounding masonry. Results demonstrated that current splice length provisions in CSA S304:24 are overly conservative, particularly for reinforcement located near the cell edge. Most tests resulted in steel yielding before bond failure, which indicates the need for reduced splice lengths in future specimens to ensure bond-dominated failure mechanisms. These findings show that more efficient design expressions that consider innovative reinforcement configurations without compromising the safety or structural integrity of walls are needed. By addressing key gaps in current standards and leveraging a scalable test setup, this work sets up for the next phase of research, which will expand the experimental database. These insights contribute to the development of more competitive and sustainable masonry construction practices.

KEYWORDS

bond, experimental test, lap splice, pullout test, reinforced masonry

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Experimental Study of Reinforced Masonry Columns

Yi Liu[i]

ABSTRACT

This paper presents the results of an experimental study on masonry columns subjected to concentric and eccentric axial loads until failure. A review of available literature revealed limited experimental studies and data on masonry columns over the past four decades. The current Canadian masonry design standard applies the same provisions for masonry columns as for masonry walls. This study aimed to investigate the behaviour and strength of reinforced masonry columns, providing new physical data using current masonry products and building techniques. Additionally, the results were used to verify the efficacy of design provisions for masonry columns in both the Canadian and American masonry design standards, with a focus on the moment magnifier method.

Six masonry columns with slenderness ratios (kh/t) ranging from 6.3 to 15.8 were tested. For each slenderness ratio, two cross-section configurations—constructed with either stretcher blocks or C-shaped blocks—were studied. The experimental results revealed that the failure modes of the specimens depended on their slenderness and loading conditions. At low slenderness and under concentric axial load, failure was characterized by splitting longitudinal cracks and localized crushing, leading to the buckling of longitudinal reinforcement. At higher slenderness and under eccentric axial load, failure was characterized by flexural tensile cracking and compressive crushing, primarily around the midspan of the specimens. As slenderness increased, the capacity of the specimens decreased, with pronounced nonlinearity at the outset of loading.

The comparison with design values highlighted the design difference in Canadian and American design provisions. The possible causes for this difference were discussed in the paper.

KEYWORDS

Masonry columns, slenderness effect, eccentric compression loading, moment magnifier method, experimental study

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TUESDAY JUNE 3RD, 2025

Paper Session 3

Resilient Masonry

Laurier Room

Experimental Investigation on Unreinforced and Waste Fibre-Reinforced Masonry Under Impact Loading

Joel Junias[i], Nikhil Ranjan[ii], Sanket Nayak[iii], and Sreekanta Das[iv]

ABSTRACT

Most of the population in developing countries like India live in masonry houses. These structures are common because the materials are readily available and affordable. However, masonry houses located alongside roads or in hilly areas are vulnerable to natural calamities, such as rockfalls and debris flows due to landslides. While these structures perform well under gravity loads but are inadequate in withstanding lateral loads. Therefore, it is essential to mitigate these structures against lateral forces. In this study, an experimental investigation was conducted in which unreinforced and reinforced single brick walls measuring 1.5 m in length and 1.5 m in height were constructed. The coir fibre (agro waste) and nylon fibre (textile waste) were added to the mortar mix to test their effectiveness in strengthening unreinforced masonry walls (URM) against impact loading. A pendulum impact test setup was fabricated, consisting of a pendulum arm and external weight disks to introduce impact loads on the specimens. A 70 kg weight was attached to the pendulum arm, and the specimens were subjected to impact loading at the centre of the wall using a hemispherical-shaped impactor released at a 30° angle. The reinforced masonry specimens exhibited significantly better performance than the URM in terms of impact resistance, load-carrying capacity, and energy absorption. This improvement may be attributed to the increase in tensile strength of the URM due to the addition of fibres, which initiates a fibre-bridging mechanism that restricts further crack propagation. This keeps the masonry intact and prevents the impactor from penetrating the wall, enabling the reinforced structures to endure more hits than the unreinforced specimen

KEYWORDS

Masonry, impact, pendulum, strengthening, fibre

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Evaluating the Impact Resistance Performance of Masonry Wallets Internally Reinforced With Waste Fibres

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ABSTRACT

The internal mortar reinforcement technique is gradually picking up the pace in the construction industry due to its proven performance in recent years. Nylon and coir fibres are becoming popular reinforcement materials for their favourable mechanical properties. Most of the previous studies have focused on concrete structures subjected to seismic loading. However, there is a rise in vehicle impacts on roadside structures and rockfall and debris flow impacts in hilly regions. A significant portion of the population still resides in masonry structures, which are more affordable to the common man than reinforced concrete structures. In the current study, a simple and cost-effective drop-weight impact testing machine was developed to evaluate the impact resistance of masonry wallets measuring 500 mm in length, 500 mm in breadth, and 120 mm in depth. Nylon (textile waste) and coir fibres (agro waste) were used for mortar reinforcement to strengthen the wallets, and a comparative analysis was carried out between the impact resistance of unreinforced and reinforced masonry. Coir fibres of 15 mm in length were added to the mortar at concentrations of 0.25%, 0.3%, and 0.4% by weight. Similarly, the nylon fibre's length was fixed at 18 mm and was added at concentrations of 0.15%, 0.2%, and 0.25%. The results showed that regardless of the type and concentration of fibres used, the flexural strength of all fibre-reinforced mortar prisms and the impact resistance of the masonry wallets were significantly enhanced. Therefore, it can be concluded that nylon and coir fibres effectively strengthen masonry structures against impact loading by internally reinforcing the mortar with fibres.

KEYWORDS

Masonry, impact, nylon, coir, fibre, strengthening

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Optimum Design of Masonry Passive Houses

W. Mark McGinley[i] and Briana Kozlowski[ii]

ABSTRACT

Studies by the U.S. Department of Energy (DOE) indicates that about 30% of the energy used in the US is being used by the housing sector. Thus, energy efficiency in residential structures is a significant focus of energy efficiency and environmental impact efforts.

Passive home design has grown in popularity as a good approach to reduce energy demand for heating and cooling. Passive design principles (superinsulation, airtight envelopes, elimination of thermal bridges, etc.) were pioneered in North America in the 1970s and 1980s and refined in Europe. These principles are thought to be universally effective in significantly reducing heating and cooling loads.

Due to the high thermal mass of concrete masonry walled homes, traditional passive house design methods were felt to underestimate the impact of these high mass walls have on the heating and cooling demand of the homes. Thus, an investigation was conducted to evaluate the energy performance of a typical residence that uses exterior concrete masonry wall systems using holistic energy analyses. Within this study, a typical home placed in the seven climate zones of the US was assessed using holistic energy modeling software and analyzed for their energy efficiency and costs. This paper presets the key findings of this investigation.

The study showed that prototype home could be modified to reach passive home performance with wood stud walls with high levels of insulation, in all climate zones. The analysis also showed that in most climates increasing wall insulation was needed to achieve the fixed 53.95 $kJ/^2$ (4.75$kbtu/ft^2$) cooling and heating energy limits for passive house performance but more insulation had a decreasing impact on energy use, especially in warmer climates.

The study also showed that passive home designs can be achieved with CMU exterior walls and increasing wall insulation was needed to achieve the fixed cooling and heating energy limits for passive house performance but increasing values of insulation had a much lower impact on energy use than with the wood stud wall systems, especially in warmer climates.

KEYWORDS

Masonry walls, energy use, passive house, optimum design

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Masonry Structure Vulnerability and Strengthening Needs for Extreme Storm Surge and Sea Level Rise

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ABSTRACT

This research investigates the vulnerability and strengthening of masonry structures against storm surge and sea level rise. In hurricane-prone regions, many existing masonry structures were built decades ago and lack contemporary design measures. Recent hurricanes have highlighted the weak response of masonry to storm surge, revealing poor design details and reinforcement corrosion. Despite the increasing use of masonry as a preferable alternative to wood foundations in flood-prone areas, there is a lack of experimental data to assess the condition of these structures. This study, initiated recently at the University of Houston, aims to bridge this knowledge gap by providing insights and solutions for the masonry design community. The research involves fabricating 1:6-scale loadbearing masonry walls using various design schemes (ungrouted and partially grouted) and testing them under simulated storm surge conditions in the wave flume facility at the University of Houston. The project's goal is to develop an understanding of the vulnerability of masonry structures and study mitigation strategies, thereby enhancing masonry resistance in hurricane-prone regions. This research contributes to safer masonry design practices against extreme storm events.

KEYWORDS
Flood risk, storm surge, wave flume, wave-structure interaction, structural masonry, hurricanes.

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Dry-Mix Concrete Incorporating Ultrafine Slag and Medium-Grade Metakaolin for Potential Application in Concrete Block Masonry Unit Production

Saeid Ghasemalizadeh[i] and Rahil Khoshnazar [ii]

ABSTRACT

Concrete block masonry units (CMUs) are widely used around the world in construction practices. CMUs mainly rely on Portland cement (PC) to develop compressive strength. Production of PC, however, is a significant source of greenhouse gas (GHG) emissions, emphasizing the need for methods to reduce the carbon footprint of CMUs. A practical and effective approach to reduce the carbon footprint of concrete products is partially substituting PC with supplementary cementitious materials (SCMs). However, the extent of PC substitution with SCMs in CMUs has remained limited as it adversely affects the strength development of the CMUs, where achieving a high early-strength is crucial. It is therefore necessary to develop methods to benefit from higher quantities of SCMs in CMUs without compromising their strength development. This study focuses on the utilization of ultrafine slag (UFS), instead of ordinary slag, in combination with a locally available medium-grade metakaolin (MK) to replace up to 40 wt% of PC in cementitious mixtures. Combinations of MK-UFS, and MK-slag were used to substitute 40 wt% of type GU and HE cement in mortar samples. The superplasticizer demand of the mortars and their compressive strength for up to 7 d were recorded. The results were then compared with those obtained for mortars prepared with only GU or HE cement. Selected blends were then used in preparing dry concrete mixtures which were tested for the compressive strength at the ages of 3 and 7 d. The results of mortar samples showed that replacing 40 wt% of GU cement with MK-UFS blend resulted in mortar samples with a higher compressive strength compared to that made with 100 wt% GU cement starting from 1 d, however, such an enhancing effect was not observed when the UFS-MK blend was used to replace the same content of HE cement. The dry concrete mixture made with 60 wt% GU cement and 40 wt% UFS-MK blend achieved a 7-d compressive strength of higher than 50 MPa, showing promising results for application in high-strength CMU production.

Keywords: Supplementary cementitious materials, Slag, Metakaolin, Compressive strength, Concrete block masonry Unit.

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Comparative Analysis of Alternative Supplementary Cementitious Materials for Potential Application in Concrete Masonry Units

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ABSTRACT

Portland cement plays a major role in concrete masonry units (CMUs) as a binding agent; however, cement production contributes to high amounts of greenhouse gas emissions. A widely adopted strategy for reducing such emissions is the use of supplementary cementitious materials (SCMs) as partial replacements for cement. However, the increasing scarcity of conventional SCMs, such as fly ash and slag, has necessitated the need to explore alternative SCMs (ASCMs). Therefore, this research aims to compare the effects of two ASCMs, namely reclaimed fly ash (RFA) and recycled glass powder (RGP), on the properties of cementitious mixtures. Cement paste and mortar samples with 20 wt% cement replacement by these ASCMs were prepared, and tested for rheology, heat of reactions, flow table, and compressive strength development. The results were compared to a reference sample containing 100 wt% cement and a sample with 20 wt% cement replacement with Class F fly ash (FA). The results showed that the RFA did not considerably affect the flowability of cementitious mixtures as determined by the apparent viscosity of the pastes and flow table measurements of the mortars. Incorporating RGP slightly increased these parameters compared to the reference samples made with only cement. The total heat evolution of the pastes incorporating these ASCMs over the 7-day testing period was lower than that of the reference, with the heat of the paste with RGP being marginally higher than that of RFA and FA. The mortars with RFA and RGP had reduced compressive strength at early ages, however, this diminished by 91 days, when compared to the reference mortar and that with FA. These findings provide a basis for implementation of these ASCMs into CMUs to reduce their cement content while maintaining or improving their mechanical properties, contributing to the development of low-carbon CMUs.

KEYWORDS

alternative supplementary cementitious materials, cement mortar, compressive strength, heat of reaction, rheology

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Paper Session 4

Unreinforced Masonry 2

Drawing Room

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Analysing Damage from Quasi-static and Dynamic Ground Movements on Dutch Masonry Buildings via Numerical Models

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Abstract

Masonry buildings in the Netherlands are especially prone to damage in the form of small cracks. This is because the masonry is unreinforced, the foundations are shallow and often also unreinforced, the bedding is composed of soft soils like peat or clay, dilation joints are missing in older or historical structures, and current loading conditions, such as earthquake vibrations, were never considered in the design of the buildings. The latter includes mining operations for salt and gas that have led to subsidence and induced seismicity. Moreover, farming policy and water management, in combination with regional subsidence, have led to varying groundwater table levels which, in turn, cause wetting and drying of sensitive soils. This process is exacerbated by more extreme seasons of precipitation and drought because of climate change, leading to swelling and compaction of the ground underneath buildings.

To understand building damage in this context, it is necessary to evaluate the combined effects of these various hazards. Their actions can be decomposed into vibrations caused by earthquakes and ground deformations. The former can be characterized by the PGV or PGA of the vibrations, and the latter by the induced curvature of the soil surface and/or by the horizontal strains at the surface because of deformations deep in the underground. Moreover, repeated earthquake events and seasonal soil subsidence or heave lead to cyclic actions.

The contribution and interaction of these loads causing progressive damage to masonry buildings have been the focus of an extensive modelling study with detailed non-linear models of the buildings and the soil. The slow soil deformations were analyzed first and served as the starting point for subsequent, repeated vibrations. For example, a horizontal strain of 0.1 mm/m caused by mining, in combination with an angular distortion of 1/2000 due to local soil compaction, can produce cracks of about 1 to 2 mm wide in a particular masonry façade. The damage is then aggravated by an earthquake vibration in the order of 5 mm/s, which is further increased by about 10% with a repeated event. The expected final damage may include multiple cracks of up to 3 mm. In this manner, the combination of all actions can lead to the establishment of conservative thresholds to prevent or limit damage to existing structures.

Keywords

Deep-subsidence, Settlements, Vibrations, Numerical Modelling, Crack Damage

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Out-of-Plane Shake-Table Tests on Unreinforced Masonry Gables

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ABSTRACT

Typical low-rise masonry buildings worldwide commonly feature unreinforced masonry (URM) walls, often paired with various pitched roof configurations supported or finished by masonry gables. These buildings constitute a significant portion of the building stock in several seismic-prone regions, including areas vulnerable to both natural and induced seismicity. Masonry gables in such buildings are frequently associated with high seismic vulnerability, as evidenced by damage observed after past earthquakes. This paper presents key results from an experimental campaign aimed at enhancing the understanding of the seismic out-of-plane response of masonry gables. Incremental full-scale shake-table tests were performed on three densely instrumented URM gables until the complete collapse. Within this context, the study systematically investigated the effects of motions applied at the top of the gable, both being linearly amplified as well as amplified and out-of-phase, with respect to the motion applied at the base of the gable. Such differential motions simulate the effect of the gable interaction with three different roof configurations, each exerting a different filtering effect on the seismic motion. The response of the gables to both induced and tectonic earthquakes was considered. The experimental findings are presented in terms of failure mechanisms, force-displacement hysteresis behaviour, and acceleration and displacement capacities. All generated experimental data, along with the associated instrumentation schemes, are openly available for download at https://doi.org/10.60756/euc-1avy7q49.

KEYWORDS

Collapse, Gable walls, Roof stiffness, Shake-table tests with differential input motions, Out of plane, Unreinforced Masonry.

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Influence of the Horizontal-to-Vertical Compressive Strength Ratio of Hollow Clay Bricks on the In-Plane Lateral Loading Behaviour of Unreinforced Masonry Walls

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ABSTRACT

Masonry walls are critical structural elements in buildings subjected to seismic actions. Their seismic performance is strongly influenced by the mechanical properties of the masonry units, particularly the vertical and horizontal compressive strengths of the bricks. During an earthquake, damage in unreinforced masonry (URM) walls initiates with cracking at the head and bed joints and can propagate through the bricks, affecting the overall drift capacity. Although current design recommendations recognize the possible impact of horizontal compressive strength, its effect on deformation capacity has not been extensively investigated. A previous experimental study explored the seismic response of URM shear walls, primarily analyzing shear strength, ultimate drift, effective stiffness, and failure mechanisms. The work presented here expands on previous research by incorporating additional experimental data and providing a more detailed evaluation of deformation capacity at multiple limit states, from initial cracking to axial load collapse. Six shear-compression tests were conducted on URM walls built with vertically perforated clay bricks and standard cement mortar, using three types of bricks with similar vertical strength but varying compressive strength ratios (0.09, 0.20, and 0.29). The walls (1.5 m long, 2.0 m high, 0.25 m thick) were tested under two levels of compression load with double-bending boundary conditions to promote shear-controlled failure. Beyond the assessment of ultimate drift, this study also examines the maximum crack widths at different limit states and their implications for deformation capacity. The experimental results highlight variations in failure mechanisms and provide new insights into the relationship between the horizontal-to-vertical compressive strength ratio and the seismic performance of masonry walls. These findings contribute to a better understanding of local damage progression and its correlation with global structural behavior, offering valuable data for refining design approaches for modern URM structures.

KEYWORDS

Unreinforced masonry, drift capacity, hollow clay bricks, experimental testing, seismic performance

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Seismic Assessment of Clustered Masonry Buildings: A Case Study in Castelsantangelo Sul Nera (Italy)

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ABSTRACT

Historical centres often consist of clusters of masonry buildings, commonly arranged as urban blocks or terraced houses. Their strong irregularity and the effects of interaction among adjacent structural units often lead to an increase in seismic vulnerability. The complexity of this building type makes the assessment of the seismic response a challenging undertaking. It is therefore of great interest to identify a methodology for the seismic assessment of clusters of buildings, encompassing all stages from the knowledge process to modelling and analysis. In this context, adopted modelling strategies play a crucial role, and thus a comprehensive acknowledgement of their advantages and limitations is necessary. In this work, two modelling approaches are adopted, i.e., equivalent frame model (EFM) using 3Muri and finite element model (FEM) using Diana FEA. First, a simplified prototype case was developed. This step was essential to establish modelling strategies that ensure compatibility of the two approaches. These strategies were then extended to a real case study of terraced houses, located in Castelsantangelo sul Nera (Central Italy). The structure was affected by the 2016 Central Italy earthquake. The on-site structural, material and damage surveys carried out allow for the calibration of the implemented numerical models. The global behaviour was examined by performing nonlinear static analysis. Various configurations were simulated considering single structural units, as well as the entire cluster. The results obtained by the two modelling strategies are compared and discussed.

KEYWORDS

masonry, seismic vulnerability, historical buildings, aggregate, cluster buildings, pushover analysis.

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Videogame-Inspired Out-of-Plane Collapse Analysis of Dry-Joint Masonry Structures

Anna Wang[i], Bora Pulatsu[ii], Sheldon Andrews[iii], and Daniele Malomo[iv]

ABSTRACT

Numerical modelling is a critical part of structural and seismic evaluations, particularly for existing unreinforced masonry (URM) structures built without mortar or exhibiting mortar-loss (i.e., dry-joint). Discontinuum methods are typically used for simulating the failure and collapse behaviours of dry-joint URM; however, such refined computational solutions often require excessive analysis times. An underexplored alternative for structural analysis of dry-joint URM is the use of physics engines, computational tools that present surprising conceptual similarities with DEM but are primarily used in animation and videogame industries for visually credible simulations. While these techniques feature exceptional computational speed when simulating rigid body collisions (i.e., contact, separation, and re-contact), they have yet to be rigorously scrutinized for URM structural analysis. This study explores the capabilities of PyBullet, a Python-based module operating the well-known, open-source Bullet Physics engine, in replicating the out-of-plane (OOP) collapse behaviour of dry-joint URM assemblies and full-scale constructions. Preliminary results indicate that PyBullet models can accurately predict the typical failure and collapse modes observed during experimental testing. However, the implicit Coulomb friction cone model utilized for simulating joint slip underestimates the angle of collapse during OOP tilting. Response predictions obtained using PyBullet are overall in agreement with previous experimental and traditional discontinuum results, but require significantly less time to complete, making them a promising alternative for complex URM discontinuum analysis.

KEYWORDS

Discontinuum analysis, unreinforced masonry, physics engines, PyBullet, dry-joint, collapse

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The Davenport Hotel: The Pulsing Heart of Spokane

Sara Ganzerli[i], Alli Willmarth[ii], and Ally Delaney[iii]

ABSTRACT

Spokane: a small town nestled in the pacific northwest, revolutionized by economic prosperity into a jewel of Washington State, US. Spokane holds unique architectural features, specifically in masonry, shaped by environmental and economic factors at the end of the eighteenth century. After a devastating fire in 1889, rapid reconstruction efforts focused on masonry buildings with steel reinforcements due to their fire-resistant qualities. At the same time Spokane experienced significant growth as it became a stop on the railroads that connected the US Coasts. This allowed the new buildings to be constructed taller than ever before. One of these buildings is the historical Davenport hotel. The luxury Inn provided a place of rest for weary travelers. The hotel still stands tall along the Spokane skyline and provides a major masonry landmark.

In the mid 1980's economic challenges where felt harshly throughout downtown Spokane as growth declined. After a series of hardships in 1985 the Davenport filed for bankruptcy and its doors were closed. However, the hotel's legacy would not end there. Walt and Karen Worthy purchased the hotel and restored it to its former glory. In 2002 the Davenport was reopened, maintaining the original luxury as its grand opening in 1914. The revitalization of the Davenport marked another period of growth in Spokane, and allowed restaurants, entertainment venues, and shops to flourish.

The Davenport is an excellent example of a masonry building that has been pivotal for the economic well-being of its city. The effects of its revitalizion show how preservation of historic buildings can provide fundamental change for the economy and prosperity of their context. This paper will focus on the challenges and solutions which arose during the renovation of this historic landmark.

KEYWORDS

Clay bricks, existing buildings, renovation, historical preservation, fire resistance.

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Paper Session 4

Assemblage Testing 1

Adam Room

Behaviour of Stack Bonded Masonry Under Concentrated Compression Loading

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ABSTRACT

Stack bonded (or stack pattern) masonry is a form of construction in which the masonry units in successive courses are aligned vertically above one another. This bonding pattern leads to continuous vertical joints resulting in a weak form of construction, which is vulnerable to cracking along the continuous vertical joints. Despite its inferior structural performance compared to more traditional bonding patterns, it has a history of being used in architectural feature applications. Furthermore, its popularity has increased again in recent years as architects push the boundaries of what is possible in masonry facades. In response, new code provisions which require the use of bed joint reinforcement were introduced to AS3700 - Masonry Structures in 2018 [1] to help inform the structural design of stack bonded masonry subjected to out-of-plane bending. However, its performance under concentrated compression loading is yet to be studied. The current paper presents an experimental study designed to investigate the relative performance of stack bonded masonry, with and without bed joint reinforcement, compared to traditional running (stretcher) bonded masonry, when subjected to concentrated compression loads. For running bonded masonry, AS3700 [1] allows strength enhancement immediately beneath a concentrated load due to the confinement provided by the surrounding masonry and assumes concentrated loads will disperse through the masonry at 45° to the horizontal. However, due to the presence of the continuous vertical joints in stack bonded masonry, it remains unclear whether these assumptions still apply. The current study investigates these aspects with a view to assessing the suitability of the current code provisions for applications involving stack bonded masonry. While it was found that unreinforced stack bonded masonry has limited ability to disperse concentrated loads, the use of the AS3700 [1] prescribed quantities and distribution of bed joint reinforcement is effective in achieving a performance similar to that of unreinforced running bonded masonry.

KEYWORDS

concentrated compression load, masonry, stack bond, stack pattern

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Experimental Study on the Parameters Influencing Modulus of Rupture (MOR) for Masonry Beams and Comparison with Bond Wrench Testing

Shreedhar KC[i], Aakash Basu[ii], Laura Redmond[iii], and Ece Erdogmus[iv]

ABSTRACT

Currently, the experimental database for Modulus of Rupture (MOR) of masonry beams is limited and current provisions in TMS 402/602-22 use the MOR values from wallette tests. The primary goal of this research is to experimentally determine the parameters that influence MOR for masonry beams. In addition, there are two primary methods for determining MOR in the literature, beam testing and bond wrench testing. As such, the secondary goal is to compare the MOR values from beam- and bond wrench- tests obtained in this study versus those published in literature. The standard ASTM E518 test was used for determining MOR values for beams and a modified approach to ASTM C1072 that nullifies the eccentricity in loading was used in the bond wrench testing. In total, 16 beams and 20 bond wrench prisms were tested with varying grout type, mortar type and masonry units. The results of the testing show that the MOR values significantly increase with the increase in grout strength and are not as influenced by the mortar type. Also, it is worth noting that there was significant variation between MOR values obtained from the two test methods, while the trends remained consistent with respect to the studied parameters among the tests. The obtained data set indicates between a 30% and 59%increase in MOR values obtained from bond wrench as compared to beam tests, and literature confirms a lack of consensus on this topic. Future work will utilize this data and those in the literature to create discrete element method (DEM) models and examine if fundamental differences in stress distributions can be identified to explain these differences.

KEYWORDS

bond wrench, flexural bond strength, grout, masonry beam, modulus of rupture

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Impact of Grout on Axial Compression Behaviour of Interlocking Dry-Stack Concrete Masonry Wallettes

Mathavanayakam Sathurshan[i]; Hossein Derakhshan[ii]; Julian Thamboo[iii]; Jack Gill[iv]; Cathy Inglis[v]; Tatheer Zahra[vi]

ABSTRACT
Interlocking dry-stack masonry has shown to accelerate the wall construction compared to conventional mortared masonry, however the widespread adaptation of interlocking dry-stack masonry is hindered due to the lack of design provisions. The compressive strength and stress-strain behaviour of dry-stack masonry should be known to appropriately design such walling systems. In this study, an experimental campaign was conducted to understand the compressive behaviour of dry-stack concrete masonry. To this end, five different interlocking dry-stack concrete blocks were acquired from across Australia. These blocks were used to construct either four- or five-course high, dry-stack concrete masonry wallettes with and without core fill grouting. In total, 80 wallettes were tested with strength of core-filled grout being varied from 20 MPa to 40 MPa. The results have been analysed in terms of failure patterns, compressive strength, and deformation characteristics. The results showed that the grouted dry-stack concrete masonry wallettes exhibited similar failure patterns as those of conventional grouted concrete masonry, which has mortar joints. The average axial compression strengths of tested grouted dry-stack wallettes ranged between 9.6 and 18.6 MPa, whereas the ungrouted wallettes varied from 4.8 to 11.8 MPa. The grouted dry-stack concrete masonry demonstrated better performance than the ungrouted dry-stack concrete masonry in terms of stiffness and load carrying capacity. The grouted wallettes exhibited higher strength, deformation capacity, and elastic moduli with increasing grout strength.

KEYWORDS
Dry-stack masonry, Concrete blocks, Axial compression behaviour, Grout, Stress-strain behaviour

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Evaluation of Flexural Bond Strength in a Masonry Lab with a Statistical Comparison of Beam versus Bond Wrench Test Methods

Cesar Gerardo Freyre-Pinto[i] and Jennifer E. Tanner[ii]

ABSTRACT

The University of Wyoming masonry design class has a robust laboratory component. Groups of students construct 6-unit stack brick masonry prisms A suite of three specimens were subjected to a 4-point beam test as described in ASTM E518. These tests fail in the center with two 3-unit brick prisms remaining. Both prisms are placed within a bond wrench apparatus in accordance with ASTM C1072. Each prism provides another four measurements of bond strength (two per prism half). Test data indicates that the beam test (ASTM E518) is higher than the average measured by the bond wrench test (ASTM C1072). A statistical analysis was performed to verify the significance of this difference. Although the p-value was higher than the significance level (T(2)=2.05, p-value=0.088), the statistical effect size was found to be of practical importance (d=1.19).

KEYWORDS

Tensile bond strength, brick prism, beam test, bond wrench test, statistical evaluation

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WEDNESDAY JUNE 4TH, 2025

Paper Session 4

Retrofit and Repair

Laurier Room

Seismic Performance Enhancement of Masonry Arch Bridges with ECC Reinforcement

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ABSTRACT

Masonry arch bridges are among the earliest bridge forms worldwide. These structures are often old and typically not designed to withstand seismic loads. To improve their resilience, it is crucial to thoroughly assess their performance and identify vulnerable areas under seismic excitations. Post-earthquake surveys of masonry arches have shown various types of damage, including arch ring failures, in-plane and out-of-plane damage to spandrel walls, and ring separations. While many shake table studies have been conducted on bare masonry arch vaults, there is a lack of tests on complete masonry arches with all structural components. In this study, shake table experiments were performed on small-scale masonry arch bridges. The results indicate various possible modes of structural damage when seismic loads are applied in the span direction. The major vulnerabilities were found in the spandrel walls, which ultimately collapsed in the out-of-plane direction after being damaged in the in-plane mode. In the second phase of the study, Engineering Cementitious Composites (ECC) were applied to the extrados of the arch ring and the inner surface of the spandrel walls. This significantly improved the performance of the arch bridge. The finite element (FE) model of the arch bridge was created in Abaqus and calibrated with the experimental model. Once calibrated, both the unreinforced and ECC-reinforced FE models of the arch bridge were analyzed using time history in Abaqus. The results showed a similar type of behaviour in the FE model as in the shake table study. In the final part of the study, the calibrated FE models were analyzed by providing the realistic boundary conditions in which the backfill soil was made continuous with the surrounding soil. The typical behaviour of the arch remained the same, and ECC was able to prevent the collapse of the spandrel walls, which is a major failure mode under seismic loads.

KEYWORDS

Masonry arch bridges, Shake table tests, Engineering Cementitious Composite, FE modelling,

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Designing Stone Dutchman Repairs in Slender Stones

Ellen M. Laase[i]

Abstract

Designing stone dutchman repairs requires a nuanced approach to ensure long-term durability and stability. A successful stone dutchman repair must consider many factors, including material compatibility, precise workmanship, and effective reinforcement. Dutchman repairs in stones within the field of the wall are typically not structurally challenging to design or implement, in that the gravity loads within the load-bearing walls have alternative load paths both around the repair and behind the partial depth. However, through-depth dutchman repairs in slender linear elements such as window mullions and columns present additional challenges that are discussed herein.

This paper will explore stone dutchman repair considerations, including additional considerations when the dutchman repairs are located within slender linear elements such as vertical mullions between windows and must resist gravity loads and magnified wind loads imparted from the adjacent windows. The paper will present how to design an effective repair when the dutchman repair is full-depth with no alternative load path around or behind the repair. By exploring the multiple considerations for dutchman repairs, particularly at slender elements, the paper will explain the complexities of dutchman repairs in historic masonry and offer insights into designing repairs that are capable of resisting both gravity and lateral loading to ensure repairs that are durable, stable, and respectful to the building's history.

Keywords

Restoration, stone, dutchman

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Experimental Study of Remedial Actions for Non-Structural Masonry Walls in Earthquake Prone Areas

Vlatko Z. Bosiljkov[i], Martin Klun[ii] and David Antolinc[iii]

ABSTRACT

Masonry non-structural walls serve as physical barriers between two spaces, fully span the storey height, and provide sound isolation. They are usually built from either clay solid and hollow blocks or autoclaved aerated concrete units (AAC). There are no special requirements for non-structural walls in the current seismic codes, however recent earthquakes revealed high vulnerability of these secondary elements even in the case of moderate seismic events. This problem is particularly evident for public buildings (e.g. schools, hospitals), where due to high stories, the slenderness of these elements could be a crucial parameter that may significantly amplify design parameters derived from storey response spectra of primary structure. The main aim of this experimental study was to increase resistance of these elements due to out-of-plane seismic actions in the process of regular refurbishment works.

A series of 18 large URM panels (316 x 195 x 12 cm) built from brickwork with lime mortar (representing old masonry - NF) and new AAC masonry panels (303 x 188 x 10 cm) were out-of-plane tested with four point bending cyclically displacement-controlled load. Each type of masonry was also strengthened with introduction of glass fibre mesh or fabric attached on both sides. For each configuration of masonry and reinforcement, three specimens were tested. In the strengthened state, both types of masonry had their maximum resistance increased by four times, while their ductility was doubled. A minimally invasive and cost-effective solution can be recommended for remedial actions on partition walls during regular refurbishment works.

KEYWORDS

out-of-plane test, non-structural walls, strengthening, glass mesh, brickwork masonry, autoclaved aerated concrete

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Experimental Testing of Seismically Retrofitted URM Parapets using Vertical Screw Reinforcing

Jerry Y. Zhai[i], Francisco Galvez[ii], Eyitayo A. Opabola[iii], Robert Hudson[iv], David Sommer[v], Dmytro Dizhur[vi]

Abstract

Seismic retrofit of unreinforced masonry (URM) parapets can provide enhanced seismic performance and collapse prevention. While widely adopted retrofit methods (e.g. braced systems) have been shown to be effective, they often require tradeoffs in the form of high installation and fabrication costs, risk of water ingress due to roof penetration, and disturbance of historical aesthetic. This paper presents a simple and cost-effective retrofit system consisting of high-strength mechanical fasteners that are drilled and mechanically anchored through the top of the parapet to an effective embedment below the diaphragm-to-wall connection. To demonstrate the effectiveness of this retrofit system, a series of monotonic and cyclic tests were undertaken on as-built and retrofitted URM double-wythe parapet specimens. The results showed that retrofitted parapets had an up to 25x increase in out-of-plane strength. The ultimate strength and failure mode of retrofitted specimens was influenced by wall aspect ratio, diaphragm connection strength, anchor spacing, and effective anchor embedment.

Keywords

Unreinforced masonry (URM) parapet, mechanical anchors, out-of-plane strength, seismic strengthening, retrofit.

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Overview of NDE Methods for Masonry Structures

Micah Heide[i] and Donald Harvey[ii]

ABSTRACT

Nondestructive evaluation (NDE) can be used to provide valuable information about the current state of existing masonry structures. NDE is often chosen as an alternative to more destructive methods to preserve as much of an existing structure as is reasonably possible and to minimize damage and disruption. This is especially beneficial when assessing historic structures where the preservation of original construction is often paramount. The appropriate use of NDE typically results in better economy for building assessments without compromising the retrieval of information necessary to inform any structural interventions.

An overview of the NDE methods that can be applied to existing masonry structures as commonly conducted by Atkinson-Noland & Associates (ANA) and found in the literature are described in the associated paper. Such methods include, but are not limited to, ground penetrating radar, ultrasonic pulse echo, infrared thermography, and flatjack testing. The general procedures for each method are described and the applications to masonry investigation are presented. Additionally, field examples are included to illustrate the use and combination of NDE methods when applied to masonry structures.

KEYWORDS

NDE, investigation, brick, CMU, stone, nondestructive

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Numerical Seismic Assessment of Strengthened Masonry Piers through a Novel 3D Nonlinear Macroelement

Christian Salvatori[i], Gabriele Guerrini[ii], Alessandro Galasco[iii], and Andrea Penna[iv]

ABSTRACT

The seismic vulnerability of unreinforced masonry (URM) structures and their extensive presence worldwide has driven significant efforts in the assessment and retrofit of existing buildings and in the design and detailing of new construction. The seismic performance of existing URM buildings is often compromised by local overturning mechanisms, as these constructions were predominantly conceived without consideration of horizontal forces. However, even if local failure is prevented through structural interventions or adequate construction details, the building might still result inadequate to withstand the in-plane seismic demand. To improve the performance of URM structures, retrofitted solutions involving material with significant tensile strength, such as Fabric-Reinforced Cementitious Matrices (FRCM), Composite-Reinforced Mortars (CRM), Near-Surface-Mounted (NSM) bars, steel or timber exoskeletons, applied to one or both sides of the masonry walls, are commonly employed.

This paper presents a novel three-dimensional equivalent-frame macroelement that extends a previous two-dimensional formulation and resorts to a computationally efficient axial-flexural integration to simulate the nonlinear static and dynamic behavior of URM panels with a limited number of degrees of freedom. In particular, the versatility of the proposed formulation allows incorporating additional lumped and distributed reinforcement into the macroelement, and explicitly modeling several reinforcing and strengthening layouts. The capability of the resulting macroelement formulation in reproducing lateral strength and stiffness, hysteretic cycles, and displacement capacity of masonry panels, is finally validated against experimental outcomes.

KEYWORDS

Equivalent-frame modeling, masonry structures, nonlinear three-dimensional macroelement, seismic analysis, strengthening interventions.

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WEDNESDAY JUNE 4TH, 2025

Paper Session 5

Existing Masonry 3

Drawing Room

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Addressing Erosion and Preservation Strategies for Historic Stone Stairs

Andrea M. La Greca[i], Rachel M. Lynde[ii], and Peter M. Babaian[iii]

Abstract

Sandstone and limestone are cherished as iconic building blocks of historic architecture and face critical preservation challenges that jeopardize both the structural integrity and aesthetic value of the stone. Both sandstone and limestone are common materials for historic building construction and are often found in buildings on collegiate campuses in North America. Some college campuses were strategically founded adjacent to nearby quarries to economically source the stone used to construct the academic buildings. These venerable stone edifices continue to grace campuses, but their endurance is largely attributable to meticulous conservation efforts. Without ongoing and diligent masonry preservation, the legacy of these historic buildings remains at risk.

While the buildings themselves are the focus of the architecture and preservation efforts, one critical element that often goes unnoticed until too late is the humble stone stair. Multi-tiered, built-into-grade, and simple single-flight stairs face common threats that expedite stone erosion relative to the stone used at other building locations. It is, for all practical reasons, impossible to limit continuous foot traffic, exposure to elements, and the abundant use of de-icing salts on the stairs that expedites deterioration. However, strategic multifaceted repair strategies such as providing a waterproofed concrete substructure, a dedicated drainage plane between the stone and concrete, and transforming the multi-wythe stone to a rainscreen veneer can help to mitigate erosion while maintaining the historical aesthetic. From a historical preservation standpoint, salvaging and repurposing existing stone remains paramount but can be challenging given the level of erosion. This paper examines the author's experience with stone stair deterioration across college campuses in North America, alongside repair techniques aimed at preserving these historic structures. While the focus of this paper is stone stairs on college campuses, the principles and findings apply to stone stairs similarly constructed on other buildings.

Keywords

sandstone, limestone, collegiate architecture, historic preservation

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Much Ado about Sandstone: Technical Guidelines for Selecting New Sandstone for Localized Use in Preservation Projects to Balance Long-Term Durability and Compatibility with the Existing Stone

Matthew Bronski[i] and Jordan Dick[ii]

ABSTRACT

North America and the British Isles both have a rich architectural heritage of buildings with sandstone facades. Lewis Mumford famously termed 1865-95 "The Brown Decades," but the widespread use of sandstone extended well beyond these decades, and well beyond "brownstone" (brown sandstone), to encompass a broader range of sandstones spanning several centuries.

Preservation professionals often face two profound dilemmas:

1) Many historic sandstone quarries are now closed, thus obtaining stones from the original quarry for use in preservation is often not possible.

2) Some sandstones were notoriously non-durable in the climate in which the building was constructed, and have been failing badly for decades. How do we avoid repeating this durability problem, while respecting the original historic fabric, and while not creating new problems by introducing localized "harder" sandstone in contact with a "softer," less durable weathered original stone?

Both dilemmas evoke the same difficult question: "Where the original stone has proven non-durable, and is failing badly, how should localized replacement stone be selected to balance compatibility and historic appropriateness with improved durability?"

The authors present a broadly applicable guideline of principles and approaches for preservation professionals to consider in selecting suitably durable sandstone for localized use in preservation projects where the original stone is no longer available, and the original stone is deteriorating.

KEYWORDS

Sandstone, brownstone, selection, specification

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An Overview of Structural Health Monitoring of the Centre Block in Ottawa During Ongoing Structural Rehabilitation

Timir Baran Roy[i], Alexander Timoshenko[ii], and David Eiblmeier[iii]

ABSTRACT

Structural health monitoring plays a crucial role in the success of a project. This is particularly the case in a project as complex as the Centre Block Rehabilitation (CBR) project, a major rehabilitation of one of Canada's most prominent heritage masonry buildings. The monitoring specifications, layouts of monitors, monitoring thresholds, data processing interfaces and other relevant information gathered from projects previously undertaken across North America, Europe and Australasia were studied to inform the design of CBR's structural health monitoring program. The CBR project includes a deep excavation under the existing CB building, a significantly large masonry structure, in close proximity to the Peace Tower (PT), a 92-metre-tall concrete/masonry structure. Ongoing construction activities such as blasting for rock removal, piling, drilling and others can lead to ground movement, and local and global displacement and rotation of the building. Monitoring of the CB building and the PT through the use of sensitive equipment, strategically placed, is critical to help understand the effects of vibration & settlement on the masonry building structures. Stringent threshold values for movement and vibration were established due to the heritage value of the buildings, which in turn required innovative monitoring equipment such as liquid level systems, robotic total stations, vibration monitors and others. This paper highlights key lessons learned from monitoring strategies of a heritage masonry structure, types of equipment used, the different challenges encountered, and the mitigation techniques adopted for local and global monitoring for the CBR project.

KEYWORDS

Structural health monitoring, data processing, masonry structure, construction activities, threshold values, innovative monitoring equipment, lessons learned.

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Combining Reinforced Concrete with Masonry: Case-Study on the North Towers of Centre Block

Carl Mohammadi[i], **James J. Maddigan**[ii]

Abstract

Centre Block, the centrepiece of the Canadian Parliamentary Precinct in Ottawa and a Classified Federal heritage building, is undergoing a multi-year rehabilitation to bring the building up to current code standards and contemporary requirements. The building will undergo seismic upgrades to enable it to resist the 2020 NBC seismic demands with minimal damage. The building has four north towers, all approx. 40 m high, built in mass masonry stone and brick, which will primarily be repurposed to house new mechanical systems, and will remain unconditioned above the roof of Centre Block. The towers are also particularly vulnerable to seismic loading. Multiple structural options for strengthening the towers were considered, with a new reinforced concrete liner selected as the preferred structural option for its stiffness compatibility and ease of connecting the towers to the surrounding floor diaphragms. The towers have experienced significant deterioration over the last hundred years due to their exposure and vulnerabilities in the original design. The preferred structural option raised concerns related to combining reinforced concrete construction with mass masonry construction and that changing the historic conditions could promote further deterioration. Specific concerns included: distress in the masonry due to the initial shrinkage of concrete, distress in the masonry due to differential thermal cycling between the concrete and masonry, and deterioration of the masonry due to migration of salts from the concrete. To address these concerns, the team conducted research, and undertook computer modelling, and analysis, showing that the insertion of the concrete liners, together with some additional provisions, would not create detrimental conditions. This paper describes the existing conditions of the towers, the concerns raised, and the studies undertaken to establish the viability of the proposed approach.

Keywords

Unreinforced masonry, mass masonry, Berea, Nepean, Wallace, sandstone, brick, concrete, seismic, historic, heritage building, thermal movements, finite element analysis, non-linear analysis.

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Mortar Mix Design for Development of Low-Carbon Structural Upgrading Details for Masonry Buildings

Farrokh Fazileh[i], Maryam Golestani[ii], Cameron Flude[iii], Bessam Kadhom[iv], Reza Fathi-Fazl[v]

ABSTRACT

Portland cement production is a major contributor to global CO_2 emissions. Low-carbon cements, which typically involve the replacement of some of the ordinary Portland cement (OPC) in the mixture with supplemental cementitious materials (e.g., fly ash and/or slag), are a way to reduce the carbon footprint of masonry construction. Newly developed products can completely replace the OPC in cementitious materials. Such cement-free binders have very little CO_2 emissions in their production process. This paper investigates the use of a low-carbon binder to create a fibrous mortar mixture that can be applied on the face of concrete masonry blocks as part of a structural upgrading technique. Mortar mixtures are designed and tested with a low-carbon binder to assess their viability as an alternative for developing low-carbon structural upgrading details.

KEYWORDS

Structural Upgrading, Unreinforced Masonry, Engineered Cementitious Composites, Ecofriendly Geopolymer Concrete, Low-carbon Concrete/Mortar

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Climate Change Impact on Built Environment: Definition of Surrogate Vulnerability Models

Sara Mozzon[i], Marco Donà[ii], Michol Rampado[iii], and Francesca da Porto[iv]

ABSTRACT

The built environment, particularly buildings, is susceptible to both structural and economic damage caused by a wide range of catastrophic events, including earthquakes, floods, landslides, debris flows, hurricanes, and tsunamis. In recent decades, the intensity and frequency of some of these natural hazards have increased due to ongoing climate change. Consequently, there is a growing need to investigate the effects of multiple interacting hazards and to adopt a multi-risk perspective. However, to date, the various metrics used in risk assessment for individual hazards are generally not comparable. Therefore, as a first step toward a comprehensive multi-risk evaluation, a multilayer assessment framework integrating different risks represents a significant contribution.

Italy is among the countries most affected by natural disasters, highlighting the importance of multidisciplinary approaches for developing multi-vulnerability models that estimate the impacts of such events on the built environment. The predominant structural types of residential buildings in Italy include unreinforced masonry and reinforced concrete, mainly in the form of frames with brick infill. To address this, an analytical model was developed to assess the out-of-plane response of masonry elements such as load-bearing walls and infill panels. The model simulates a dual arching mechanism within the wall thickness using an incremental procedure with out-of-plane displacement control. This model was then integrated into a Monte Carlo simulation, allowing for variability in both the geometric and mechanical properties of walls, which were previously classified into different categories. Finally, a surrogate vulnerability model was derived from the Monte Carlo results.

KEYWORDS

Climate change impact, masonry wall, Monte Carlo analysis, surrogate vulnerability models.

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WEDNESDAY JUNE 4TH, 2025

Paper Session 5

Assemblage Testing 2

Adam Room

A Laboratory Investigation of the Variability of the Coefficient of Friction in Unreinforced Clay Masonry

Lewis J. Gooch[i], Mark J. Masia[ii], Mark G. Stewart[iii], and Michele Spadari[iv]

ABSTRACT

The frictional resistance along a shear plane contributes significantly to the load carrying capacity of masonry structures, particularly those loaded under in-plane lateral forces. This resistance is typically defined simply in terms of a shear-friction coefficient. This property ranges significantly in the literature, with values observed from as low as 0.25 to greater than 1.0 for unreinforced clay-brick masonry. Despite this degree of uncertainty, few studies consider the variability of the shear-friction resistance. This limitation is particularly relevant to structural reliability-based analyses, where the result is highly dependent upon assumed variability of strength defining material parameters. This manuscript presents the findings of a laboratory investigation of the statistics of this shear-friction behaviour through the application of repeat testing of nominally identical specimens. Five distinct clay-brick masonry unit types (three extruded, perforated units, and two pressed, solid units) were utilised, with an Australian standard 1:1:6 (cement: lime: sand, by volume) mortar mix. Masonry couplets were constructed from these materials and were tested in shear under a constant vertical pre-compression. The data produced from these tests allowed for the determination of suitable statistical models to be developed to describe the variability of the shear-friction coefficient.

KEYWORDS

clay brick masonry, material characterisation, shear-friction, unreinforced, variability

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Shear Capacity of Pre-insulated Reinforced Concrete Masonry Walls

David Biggs[i], Jason Thompson[ii], and Arturo Schultz[iii]

ABSTRACT

In the United States, pre-insulated concrete masonry units (CMU) for single-leaf (single-wythe) have become more popular in the past decade due to their thermal performance. However, thermal considerations, coupled with broader objectives to increase operational energy efficiency, have driven the development of an array of various integrally insulated concrete masonry units that can be used with either partially grouted walls or fully (solid) grouted walls. These units were made possible by changes to ASTM C90, Standard Specification for Loadbearing Concrete Masonry Units, which now allows reduced web areas connecting the face shells. For the assemblies evaluated in this paper, the web height for the partially-grouted units is reduced only at the insulation inserts, while the full width of the webs is reduced for the fully-grouted units. In either case, however, the reduced webs increase the possibility of web shear failures.

This paper will present shear testing results from research that demonstrates such reduced-web units, when reinforced and partially- or fully-grouted, exhibit performance like the design models stipulated in TMS 402, *Building Code Requirements for Masonry Structures*, which were originally developed for uninsulated, full web height CMU. In addition, web shear test results will be presented and compared to ASTM and TMS design criteria.

KEYWORDS

Integrally-insulated, Concrete Masonry, Shear Strength, Web Shear, Partially Grouted, Insulation Inserts.

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In-Plane Cyclic Shear-Compression Tests on Stone Masonry Piers Strengthened with Composite- and Fiber-Reinforced Mortars

Larisa Garcia-Ramonda[i], Madalena Ponte[ii], Igor Lanese[iii], Gerard J. O'Reilly[iv], Elisa Rizzo Parisi[v], Francesco Graziotti[vi], Luca Pelà[vii], Andrea Penna[viii], Guido Magenes[ix], Rita Bento, [x] and Gabriele Guerrini[xi]

ABSTRACT

This paper discusses the effectiveness of Composite Reinforced Mortars (CRM) and Fiber-Reinforced Mortars (FRM) as seismic retrofit of existing stone masonry buildings, through experimental research carried out within the ERIES-RESTORING project at the EUCENTRE facilities in Pavia, Italy. The in-plane cyclic behavior of these innovative strengthening materials, compatible with historical masonry, was assessed on full-size piers, subjected to constant axial load and double-fixed boundary conditions. Four specimens were strengthened with CRM, consisting of a glass-FRP mesh embedded in natural hydraulic-lime mortar: CRM was applied to one or both sides of the specimen, while two different pier aspect ratios were investigated to study the flexural and shear behavior of strengthened walls. The FRM retrofit, consisting of a mortar with polymeric fibers, was applied directly to both sides of a single pier, with an aspect ratio inducing flexural behavior. Two bare masonry piers were also tested with identical aspect ratios and axial loads. A complementary mechanical characterization campaign on mortars, retrofit components, and bare or strengthened stone masonry wallettes provided information about material properties. The experimental results in terms of damage mechanisms, lateral strength, and deformation capacity, are presented herein. Ultimately, the project outcomes will form the basis for the development of design guidelines and code requirements for the retrofit of existing masonry structures with CRM and FRM.

KEYWORDS

composite reinforced mortars, fiber-reinforced mortars, quasi-static cyclic shear-compression tests, seismic retrofit of existing buildings, stone masonry.

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Investigation of the Shear-Compression-Load Bearing Behavior of Unreinforced Brick Masonry Using the Unit-Cell-Method

Jennifer Gebhardt[i], Johannes Froese[ii] and Oliver Fischer[iii]

ABSTRACT

Unreinforced brick masonry is a characteristic feature of historic buildings in Germany and Europe. Despite its widespread use, knowledge of its shear-compression performance under static and cyclic loading, particularly in relation to earthquake exposure, has stagnated for decades. A recent research project at the Technical University of Munich focuses on the shear-compression performance of traditional small-format brick masonry and the influence of different masonry thicknesses and the use of vertically perforated bricks, to fill this essential gap in knowledge.

To investigate the shear-compression behavior of unreinforced masonry (URM) in more detail in a cost- and space-saving manner the "unit-cell-method" was developed. In contrast to full-scale shear wall tests, the unit-cell-method allows for a cost-effective and flexible investigation of various parameters. For this purpose, small test specimens are tested for their shear-compression load-bearing behavior. Different test configurations enable the simulation of the load and stress state in the wall head, base or center under monodirectional static and cyclic loading of a URM shear wall.

This paper presents the innovative, less cost and space intensive unit-cell-method and provides an outlook on planned test series. The new findings will lead to a more in-depth understanding of the shear-compression performance of URM masonry through systematic investigations and the development of empirical models. This will not only contribute to the preservation and restoration of architectural heritage, but also improve the structural integrity and safety of existing buildings.

KEYWORDS

biaxial-load, brick, brick masonry, cyclic load, earthquake, shear-compression load, shear load behavior, small-format brick masonry, unreinforced masonry, unit cell, unit-cell-method

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Shear Design Provisions for Reinforced Concrete Masonry Beams in the TMS 402 Code: Is it Time for Change?

Salah Sarhat[i] and Edward G. Sherwood[ii]

ABSTRACT

Shear failures of reinforced concrete masonry (RCM) beams without stirrups can be brittle and sudden, with little to no warning of impending failure. Since it is difficult to provide web reinforcement in masonry, RCM beams are often constructed without stirrups. As such, the design provisions used to determine shear strength of RCM beams without web reinforcement must be accurate, safe, and rational. The objective of this paper is to assess the reliability and predictive capability of the shear design provisions of RCM beams in the TMS 402 code. A database of 133 shear tests reported in the literature on RCM beams without stirrups was used to conduct the evaluation process. The failure shear stresses of the beams covered in the assembled database were predicted using two North American masonry design standards (i.e. TMS 402-2022 and CSA S304-2024) and one reinforced concrete code (ACI 318-2019). The study showed that the TMS 402 predictions were associated with the highest coefficient of variation of the three analyzed codes along with the larger number of unsafe predictions. Although the recently revised shear design provisions of ACI 318-2019 produced a smaller number of unsafe predictions and smaller ratios of experimental to predicted shear strengths, there was only marginal improvement in the coefficient of variation. The CSA S304, on the other hand, had the lowest coefficient of variation with a small number of unsafe predictions. Further analysis indicated that CSA S304 can account accurately for all factors affecting the shear strength of RCM beams. These results highlight the need to revise the shear design provisions for RCM beams in the TMS 402 code and suggest that CSA S304-2024 provisions serve as a base for the needed revisions.

KEYWORDS

Beams, reinforced concrete masonry, size effect, shear strength, design codes.

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WEDNESDAY JUNE 4TH, 2025 **Paper Session 5**

Veneers 1

Laurier Room

Differential Movement – Beware the Backup Structure

Rebecca Herkes[i] and Peter M. Babaian[ii]

ABSTRACT

In the evolving landscape of low-rise multifamily construction, an increasingly popular approach involves multiple stories of wood framing over a concrete podium or slab. Many such buildings feature brick masonry exterior cladding systems to meet zoning ordinances, blend with the neighborhood's character, and reflect a premium design aesthetic. Integrating brick veneer with wood framing can be challenging; without careful attention to detail, this combination can result in significant issues due to differential movement, potentially leading to costly rework. This paper discusses the movement compatibility issues between wood framing and brick masonry, drawing on examples of failure to highlight effective strategies for avoiding these problems in future projects. Additionally, this paper explores how distinctive brick masonry design features can be successfully integrated into wood-framed or concrete podium structures when given the proper design consideration.

KEYWORDS

wood framing, wood shrinkage, differential movement, design, failure

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Design of Directly Bolted Shelf Angles Using Force Method and Virtual Work

Mark D. Hagel[i]

ABSTRACT

Shelf angle design represents the intersection of masonry design, steel design, and depending on the building's primary structural system, concrete, wood, or steel design. Therefore, shelf angle research in this area of masonry is often regarded as a "steel design" or "concrete design" problem, rather than a masonry design problem. There are few papers published on the topic and even less actual testing, with the experimental work to date focusing on shelf angles anchored to wood-frame floors. Complex interactions between the tied masonry veneer and the steel angle, as well as beam behavior of the brick veneer between anchor bolts are difficult to capture with models simple enough for hand calculations. A new design approach is proposed which more accurately accounts for the interaction between the tied masonry veneer and the shelf angle. The proposed design method more accurately reflects field observations of masonry veneer where a L102mm mm x 102mm x 6.4mm (L4in. x 4in. x ¼ in.) supports 7.315 to 9.144 m (24 to 30 feet) of 90 mm (3-5/8 in.) clay brick veneer without evidence of structural distress. This translates into a 5% to 8% cost savings on the shelf angle. The proposed design method uses the Force Method in combination with Virtual work to solve the 1-degree statically indeterminate system that results from the introduction of the tie restraining force at the first course of ties. This new method was then compared to the traditional statically determinate method as well as 2D and 3D finite element models. The proposed method also allows parameters like; veneer height, veneer type, shelf angle size and thickness, air space depth, and bolt hole location to be easily altered without the time-consuming effort of redrawing the system in finite element software.

KEYWORDS

Shelf Angle Design, Masonry Veneer, Deflection, Force Method, Virtual Work.

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Design and Detailing of Masonry Veneer Lintels

Scott W. Walkowicz[i] and W. Mark McGinley[ii]

ABSTRACT

Masonry veneer lintel design and detailing continues to be challenging for designers. Methods to economize loose lintel design have been previously studied and published but these methods have not been widely implemented. In addition, increasing cavity widths have created varying design solutions for masonry veneer openings and the design assumptions that designers must make regarding system behavior. Lintel designs may include heavy bolted angles or plated beam lintels that often lead to expensive detailing for both the lintel capacity requirements and cavity closures. This paper discusses how these systems typically behave and the range of design options that include reinforced and unreinforced brick veneer lintels. Detailed discussion of how to implement these system designs will be presented. Also presented will be options for providing cavity closure for commercial and residential window/door/louver assemblies when using veneer beam lintels.

KEYWORDS

Veneer, loose lintel, brick lintel, reinforced, unreinforced, wide-cavity, cavity closure.

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The Corrosion of Steel Wall Ties within Cavity Brick and Brick Veneer Wall Air Cavities

Lyndsey Terry[i], Igor Chaves[ii], Mark Masia[iii], Md Akhtar Hossain[iv], and Robert Melchers[v]

ABSTRACT

In brick veneer and cavity brick walls the steel wall ties are essential structural components linking the external leaf of masonry to the internal framework. Steel wall ties are susceptible to corrosion over time which can ultimately result in the complete deterioration of the material. Such corrosion significantly impacts the structural integrity of brick veneer and cavity brick walls, increasing the risk of failure under lateral forces from earthquake or wind. Detecting corrosion in embedded wall ties in masonry walls is difficult and often only becomes apparent after the wall has failed or been demolished. This limitation calls for a deeper understanding of the corrosion of steel wall ties within the air cavity of masonry walls. The current research provides data on the environmental conditions within the air cavity of a brick veneer and cavity brick wall structure, revealing the impact temperature and humidity have on the corrosion of galvanised and stainless-steel wall ties, and steel wall ties with no corrosion protection. After one year of exposure to the natural environment, the qualitative and quantitative data presented uncovers corrosion processes affecting wall ties in two types of masonry wall air cavities. The research reported herein signifies the influence that the cavity brick and brick veneer air cavity micro-climate have on wall tie corrosion over time.

KEYWORDS

Masonry, wall ties, cavity, corrosion.

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Identification of Wall Tie Deterioration using Finite Element Model Updating Method

Chee Yin Lam[i], Mark J. Masia[ii], Igor A. Chaves[iii], and Md Akhtar Hossain[iv]

ABSTRACT

Wall tie deterioration in masonry veneer and cavity wall systems is a critical issue that affects the structural reliability of many existing masonry structures. Destructive means are often used to assess the condition of ties, and this can be uneconomical and cause disruption to building use. A non-destructive, vibration-based method was utilized in this study to collect vibration measurements of a masonry veneer wall in its undamaged state along with four different wall tie deterioration cases. For damage identification purposes, a finite element model of the experimentally tested veneer wall was first constructed, and the updating process was then performed to optimize critical material properties that best simulate the experimentally recorded behaviour of the undamaged veneer wall. Utilizing the calibrated reference state model, sample points with varying Young's moduli of wall ties at different locations were strategically selected using the design of experiments methodology to generate an appropriate response surface polynomial model for each of the six natural frequencies. The simplified polynomial models replaced the complex model in the finite element analysis software and were further utilized in the optimization process. The optimization of the Young's moduli of wall ties was then performed to minimize the difference between the experimental and simulated natural frequencies. This finite element model updating approach showed promising performance in terms of condition assessment of wall ties, where the damaged states were reflected by the optimized Young's moduli of wall ties.

KEYWORDS

finite element model updating, masonry, optimization, response surface model, wall tie

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WEDNESDAY JUNE 4TH, 2025

Paper Session 6

Reinforced Out-of-Plane Walls

Drawing Room

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Raising Code Limits on Specified Reinforcement Strength by Adoption of High-Strength Steel Bars (HSRBs) in Structural Masonry

Dimitrios Kalliontzis[i], Waleed Khan[ii], Samvid Parajuli[iii], and Omar Khalid[iv]

ABSTRACT

In the United States, the adoption of high-strength non-prestressed reinforcing bars (HSRBs) in design was initiated by the reinforced concrete industry through ACI 318. The adoption was motivated by several factors including the ability to increase bar spacings, reduce steel congestion, reduce construction materials and costs, and minimize the building carbon footprint. It appears that this trend is continuing with the increasing availability of reinforcement of higher grades, making it imperative that the masonry industry be able to adapt. To ensure that the masonry industry adapts to these new developments, the University of Houston has embarked on a research program to investigate the feasibility of HSRBs in structural masonry design. This paper presents an overview of this program and current findings. So far, the program has completed a series of laboratory tests to evaluate existing TMS 402/602-22 provisions on lap-splice length and flexural design. Lap-splice tests indicated the need to incorporate a reinforcement grade factor of 1.15 for Grade 80 bars in the existing provisions. Lap-splice tests also showed the need to revisit the accuracy of the reinforcement size factor, as it is conservative for smaller and liberal for larger bar diameters. Out-of-plane wall tests were used to evaluate the flexural behavior of masonry walls with longitudinal HSRBs. The test results indicated that TMS 402/602-22, modified to account for Grade 80 bars, can provide satisfactory estimates of nominal strength with sufficient conservatism with respect to the experimental responses. Finally, the research program has performed several prototype beams, columns, walls, and full-scale building designs to investigate the potential benefits of utilizing HSRBs in masonry construction. Findings showed that reductions in reinforcing material costs can reach 25% by using Grade 80 versus Grade 60 bars. These benefits can be further increased considering reductions in material weights and cell grouting.

KEYWORDS

High-strength steel, Grade 80, ASTM 706, ASTM 615, lap splice, flexure, concrete masonry, clay brick.

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The Effect of high-strength Steel Bars on the Out-Of-Plane Flexural Response of Slender Masonry Walls

Ahmed Elsaadawy[i], Mahmoud Elsayed[ii], Clayton Pettit[iii], and Carlos Cruz-Noguez[iv]

ABSTRACT

Slender masonry walls with a slenderness ratio exceeding 30 are commonly used in single-story buildings in Canada. However, the design of these walls is subject to strict limits and requirements under the Canadian masonry standard (CSA S304-24), which can affect their capacity. One way to increase wall capacity and reduce the amount of reinforcement and grout used in conventional reinforcement masonry walls is by using high-strength reinforcement (HSR). High-strength reinforcement (HSR) are widely used in concrete standards such as (ACI 318-24) and (CSA A23.3:24). However, masonry standards such as (CSA S304-24) and (TMS 402/602-22) prohibit the use of high-strength reinforcement in all structural elements including beams, walls, and columns. Due to the limited information on this topic, this research aims to study the effects of detailing slender masonry walls with high-strength reinforcement. A numerical simulation was used to predict the expected out-of-plane performance of slender masonry walls with high-strength reinforcement and conventional steel. The same height-to-thickness ratio, loads, and boundary conditions were used to compare their performance. A parametric analysis was conducted to examine the effects of key parameters, including bar yield strength, block thickness, and bar diameter, on the flexural capacity of slender masonry walls. The results indicate that an increase in bar yield strength leads to a corresponding enhancement in the flexural capacity of the walls.

KEYWORDS

slender masonry walls, high strength reinforcement, analysis model, flexural capacity

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Towards Examining the Influence of Web Geometry on the Out-of-Plane Shear Resistance of Concrete Masonry Walls

Will Pahl[i], **and Lisa Feldman**[ii]

ABSTRACT

The current standards governing concrete masonry unit (CMU) geometry in Canada and the United States are CSA A165-14 - Concrete Masonry Units and ASTM C90-24 - Standard Specification for Loadbearing Concrete Masonry Units, respectively. Starting with its 2011 edition, ASTM C90 allows for a minimum web thickness of 19 mm irrespective of CMU size. In contrast, CSA A165 has maintained historically used minimum web thicknesses that increase with CMU size, starting at 26 mm for 100 mm nominally sized CMUs. The reduced CMU weight resulting from minimizing web geometry reduces the likelihood and severity of workplace injuries to masons. Additionally, the use of thinner webs increases the energy efficiency of masonry walls.

Webs are responsible for the transfer of shear forces within masonry assemblages. However, limited information was identified during a literature review relating to out-of-plane shear behavior and test methods for shear transfer in masonry assemblages. A recent experimental investigation at the University of Saskatchewan showed that grout columns in partially grouted and reinforced walls as typically constructed obscured the behavior of the CMU webs. This paper therefore provides the background and experimental design of a novel investigation underway at the University of Saskatchewan. Walls with unbonded reinforcement anchored at their top and bottom are being constructed and subject to out-of-plane loading to evaluate the shear capacity of CMUs with varying web geometries. The use of unbonded reinforcement isolates the effect of varying web geometry on shear capacity. Four CMU geometries are included for evaluation: regular stretcher CMUs meeting the minimum web thickness requirements specified in either CSA A165 or ASTM C90, and two types of knock-out CMUs. The experimental investigation as described herein will begin in Spring 2025.

KEYWORDS

Concrete masonry units, out-of-plane loading, shear, web geometry, unbonded reinforcement

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Parametric Analysis of Out-of-Plane Seismic Behaviour of Unreinforced Masonry Infill Walls: An Analytical Study

Marco Gaspari[i], Marco Donà[ii], and Francesca da Porto[iii]

ABSTRACT

Masonry infill walls are a common technique in reinforced concrete (RC) frames. These elements, defined as non-structural, strongly influence the seismic performance of RC frames and can be responsible for brittle failure mechanisms, such as out-of-plane infill collapse.

This paper aims to present the application of an analytical model for evaluating out-of-plane (OOP) lateral behaviour in a comprehensive parametric analysis of the main parameters governing the OOP behaviour of masonry infills. The variation of the geometric and mechanical properties of the masonry, the slenderness and aspect ratio of the infill. The analytical model incorporates vertical and horizontal arch mechanisms, considering the flexibility of the RC frame elements surrounding the panel and considering potential external reinforcement solutions. The reliability of the proposed model was also demonstrated by comparison with experimental results.

KEYWORDS

Analytical model, arch mechanisms, Masonry infill wall, Out-of-Plane (OOP) capacity, Parametric Study.

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WEDNESDAY JUNE 4TH, 2025

Paper Session 6

Infill Walls

Adam Room

Seismic Performance of the Masonry Infill RC Frame Structure Strengthened with ECC

Subodh Kumar[i], Rajat Avasthi[ii], and Durgesh C. Rai[iii]

ABSTRACT
Masonry infill walls in reinforced concrete (RC) frames are susceptible to horizontal forces in both in-plane and out-of-plane directions during seismic events. These forces can lead to brittle out-of-plane failures due to the loss of flexural strength. Therefore, effective strengthening techniques are required to enhance the seismic performance of masonry structures by improving ductility and energy dissipation. Engineered Cementitious Composites (ECC) offer a promising alternative for strengthening masonry infills due to their strain-hardening behaviour and ability to undergo multiple cracking. This study investigates the seismic performance of masonry infill RC frames strengthened with a single layer of ECC under combined in-plane and out-of-plane loading. In this study, a cost-effective ECC was developed utilizing locally sourced polyester fibers, which were ten times less expensive and four times weaker than commonly used Polyvinyl Alcohol (PVA) fibers. The ECC was prepared using readily available materials such as Portland Pozzolana Cement (PPC), river sand, and Fly Ash, which contributed to a significant reduction in manufacturing costs. As a result, the total cost was approximately five times lower than that of standard PVA-based ECCs. The cost-effective ECC demonstrated a tensile strain capacity of 1.88% and a tensile strength of 2.17 MPa. An experimental study was conducted on the single bay half-scaled model of the masonry infill RC frame structure strengthened with the ECC layer on the single side of the wall. The in-plane loading was applied using a servo-hydraulic actuator, followed by the out-of-plane loading using a unidirectional shaking table. The experimental study showed that the ECC layer protected the infill masonry wall panel from severe cracking. It was found that the use of ECC improved the in-plane strength of the strengthened specimen by approximately 20% as compared to the unstrengthen specimen. The ECC layer effectively prevented severe cracking in the infill, safeguarding the masonry fragments from falling during out-of-plane loading. The ECC layer enhanced the stability of the masonry infill in the out-of-plane direction, ensuring that the infill remained intact even after the surrounding frame was damaged.

KEYWORDS
ECC, Masonry, RC frame, Shake table, In-plane loading

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Numerical Analysis of Infill Wall Interaction with Frames

Daniel Quiun[i] and Qenti Herencia[ii]

ABSTRACT

Many buildings with reinforced concrete (RC) frames have infill walls. In Peru, the common masonry units used in such walls are horizontally-hollow or perforated clay bricks. An experimental program was done in 2016 at the Structures Laboratory of the "Pontificia Universidad Católica del Perú" to study the interaction between an existing RC frame and a new infill wall built using horizontally-hollow bricks. The cyclic lateral load test proved how the interaction occurred, which ended with mixed failures in the infill wall. The present paper shows two numerical models that try to replicate the load-displacement capacity curve of that cyclic lateral load test: 1) 3D simple micro model using ABAQUS; and 2) seven 2D macro models using ETABS with the equivalent strut method. For both cases, the Concrete Damage Plasticity law was used to simulate the behavior of the concrete elements and the masonry panel. In the macro model, axial stiffness degrading equations dependent on the properties of the equivalent strut were used.

The simple micro model had the best representation of the capacity curve and the plastic deformations followed the cracking pattern of the wall as the experimental test. Regarding the macro model, five gave good results, among them the model in which the width of the equivalent strut is taken as ¼ of the diagonal of the masonry panel. This model is also the one adopted by the Peruvian Masonry Code.

KEYWORDS

Infill wall, Concrete Damage Plasticity, Equivalent Strut, Hollow brick, Load-displacement curves

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Seismic Performance Assessment and Fragility Analysis of Masonry Infilled RC Frames Using a New Macro Model

Nima Maymandi[i] and Yi Liu[ii]

ABSTRACT

This paper presents the results of seismic performance assessment of masonry infilled reinforced concrete frame systems. A macro model featuring bi-strut and a shear spring was implemented in OpenSees to simulate the seismic response of representative infilled system archetypes, each characterized by distinct design parameters. The analysis involved conducting incremental dynamic analysis utilizing a set of 30 pairs of strong ground motion records to obtain fragility curves of these archetypes. The performance of archetypes as indicated by fragility curves for Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP) performance limit states was presented and discussed in this paper. The results augmented the database of numerical studies on seismic behaviour of masonry infilled frames. The impact of adding an infill on the seismic performance of the frame structure was shown. The seismic performance evaluated in this paper focuses on the strength of the frame structure. This study also shows the effect of several parameters such as location of soft storey on the seismic performance of infilled frames. The results also reveal that the infill design provisions in the current Canadian masonry design standard will lead to overestimate of infill strength in the context of seismic design.

KEYWORDS

Seismic Performance Assessment, masonry infilled frames, reinforced concrete frame, fragility curves, incremental dynamic analysis.

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Cyclic In-Plane Behavior of Masonry Infilled RC Frames with Detailed Interpretation of Damage Using Digital Image Correlation

Zeeshan Manzoor Bhat[i] and Yogendra Singh[ii]

ABSTRACT

This paper investigates the cyclic behavior of reinforced concrete (RC) frames with various types of masonry infills: burnt clay bricks, fly ash bricks, and autoclaved aerated concrete (AAC) blocks. The RC frames were designed in compliance with the latest provisions of the Indian seismic code. To assess the impact of masonry infills, four specimens-one bare frame and three masonry infilled frames-were subjected to cyclic loading. Digital Image Correlation (DIC) was employed to provide a detailed analysis of damage progression throughout the testing process. The study focused on key parameters such as stiffness, strength, and energy dissipation, and a comparison with available analytical models was conducted. Infilled frames were found to exhibit greater stiffness, strength, and energy dissipation compared to the bare frame. Due to the seismic code-compliant design, a ductile failure mode was observed in both the bare and infilled frames. The experimental results showed good agreement with certain analytical models regarding strength and stiffness. The infills restrained deformation at the base of the surrounding columns, resulting in dispersed flexural cracks in the columns, while cracks in the bare frame columns were concentrated at the base.

KEYWORDS

AAC block, cyclic testing, DIC, fly ash brick, masonry infill, RC frame

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Effective Seismic Retrofit Technique of a Previously Tested Confined Masonry Wall Made with Perforated Bricks

Daniel Quiun[i] and Lady Luza[ii]

ABSTRACT

A large number of informal housing buildings in Perú are built using perforated clay bricks or concrete blocks for confined masonry structural walls. The Masonry Code specifies that structural walls must be constructed with solid bricks (less than 30% of holes in the bed area). However, the lack of supervision, the desire to minimize costs, the general lack of seismic conscience of the owners, among other factors, explain the use of inadequate perforated bricks (more than 45% of holes in the bed area) for bearing walls of buildings up to 5 stories. The brittle failure of the masonry made with such units make them vulnerable under the combined action of gravity and seismic loads.

Several experimental projects have been conducted to study reinforcing techniques to enhance the strength of these structures. In this project a confined masonry wall with an axial load equivalent to two stories, was subjected to a cyclic lateral load until shear failure occurred. Then, the wall was repaired and reinforced with jacketing of welded wire mesh on both surfaces. The retrofitted wall was tested under the same conditions as the original one, with improved behavior, a flexural failure, and an increase of lateral load of 40%. The retrofitting technique proved to be efficient and could be used in real buildings to increase and enhance their structural safety.

KEYWORDS

Confined masonry, hollow bricks, cyclic load test, retrofitting, wire mesh.

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WEDNESDAY JUNE 4TH, 2025

Paper Session 6

Assemblage Behaviour

Laurier Room

15th Canadian Masonry Symposium
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Evaluating the Bond Strength in Mortarless Masonry

Yehia Aboziada[i], Belal AbdelRahman[ii], and Khaled Galal[iii]

ABSTRACT

Masonry construction has been a reliable method that offers cost-effectiveness and strength for decades, particularly mortarless block systems. These systems have gained popularity due to their reduced cost and construction time compared to conventional masonry. Understanding the mechanical properties of the dry-stack interlocking masonry (DSIM) blocks is important for designing masonry structures, particularly those subjected to horizontal forces such as wind. Among these properties is the bond strength, which is considered the key parameter in the design. Numerous studies and standards investigated and suggested different methods of testing to evaluate the tensile bond strength between the blocks. This paper presents an experimental investigation focused on determining the flexural bond strength normal to bed joints in a specific dry stacking system known as a Sparlock block. The test was conducted to assess the bond strength using a bond wrench according to ASTM C1072-22. The effect of adding grout to the empty cells was studied. The findings were compared to the allowable bond stresses stated in CSA 304-24 and other results from the literature. The experimental results showed that the tensile bond strength of the Sparlock blocks is comparable to that of the conventional block, as the interlocking mechanism compensates for the missing mortar layer between the blocks. Also, the flexural bond strength obtained from the joint of the Sparlock grouted prism was 2.86 times greater than that of the ungrouted ones.

KEYWORDS

Masonry, Mortarless, bond Wrench, Interlocking, Flexural strength

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Spatial Correlation of Flexural Tensile Bond Strength in Unreinforced and Ungrouted Concrete Masonry Walls

Lewis J. Gooch[i], Chee Yin Lam[ii], Lyndsey G. Terry[iii], Mark J. Masia[iv], and Mark G. Stewart[v]

ABSTRACT

The flexural tensile bond strength of masonry is critical to defining the out-of-plane bending resistance of unreinforced and ungrouted masonry walls (URM). This is particularly relevant to concrete URM which is often utilised in the construction of retaining walls, load-bearing internal wythes of masonry cavity wall construction, and other structural elements typically subject to out-of-plane loading. Due to its dependence on workmanship, mortar quality and brick/block typology, the flexural tensile bond strength of masonry has been observed to be highly variable. Furthermore, previous investigations of the spatial variability of clay brick masonry indicate that the sequential nature of construction for masonry walls often introduces a correlation between the properties of adjacent mortar joints. Understanding this spatial variability will improve the accuracy of probabilistic models of URM and is an important consideration in a structural reliability-based analysis of URM performance. The current study presents a laboratory investigation in which three concrete masonry walls – two concrete block and one concrete brick – were sequentially deconstructed using the bond wrench test method. From this testing, the spatial variability of the flexural tensile bond strength of each wall specimen has been quantified. Furthermore, the spatial variability of mortar joint thicknesses has also been analysed to quantify the correlation between adjacent joint thicknesses, as well as to assess any relationship between the thickness and strength of individual mortar joints.

KEYWORDS

concrete block, concrete brick, flexural tensile strength, spatial variability, ungrouted, unreinforced

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Test Procedure for Evaluating Tensile Bond Strength of Rendering Mortar Applied to Structural Masonry at High Temperatures

Renato Veronese[i], Guilherme Parsekian [ii], and Armando Moreno [iii]

ABSTRACT

In the event of a fire, the detachment of the mortar applied to the substrate compromises the performance of rendered structural masonry walls. The wall surface is often protected by a layer of cement-lime mortar, which helps to delay the temperature rise within the concrete block section. While fire rating tests of masonry walls with rendering mortar have revealed instances of debonding over time, the behavior of rendering mortar at elevated temperatures remains insufficiently understood. A key question is how the high temperatures affect the tensile bond strength of rendering mortar, and there is no standard method that allows obtaining this parameter. The standard method commonly used for room temperature cannot be used for determining tensile bond strength at high temperatures, and a new method must be developed. This study proposes a procedure for determining the tensile bond strength of rendering mortar applied to a concrete masonry substrate when exposed to high temperatures. This information, along with other material properties, is critical for evaluating the fire resistance rating of walls constructed with various material combinations of block and render, and for facilitating numerical modelling of concrete block masonry under elevated temperature conditions. To conduct the investigation, hollow concrete block prisms were manufactured, rendered, and subjected to different test scenarios, varying factors such as the force application mechanism, the sample area and the heating curve. Preliminary results indicate a favorable response in terms of failure mode, and these findings are presented herein. This work may contribute to future research on materials exposed to high temperatures or fire conditions, and the proposed method could be adapted for studies involving different substrates and rendering materials.

KEYWORDS

Fire situation, high temperatures, rendering mortar, structural masonry, tensile bond strength, test procedure.

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Residual Compressive Strength of Structural Masonry Clay Unit

Tiago Montanha Padilha[i], Renato Baiochi Alves Veronese[ii], Armando Lopes Moreno Junior[iii], and Guilherme Aris Parsekian[iv]

ABSTRACT

The ability of load-bearing clay unit masonry walls to maintain their mechanical integrity after severe thermal events is essential to guaranteeing the protection of lives and property in a fire situation. Reoccupying a building after a fire requires a thorough assessment, especially of changes in the mechanical properties of its components, such as the unit and mortar. There are, however, gaps regarding the changes in mechanical properties that can occur with the sintering of mineral phases at high temperatures in the ceramic material. This study investigates the residual compressive strength of burnt clay structural masonry units after exposure to high temperatures. A compression test was carried out on clay units at room temperature to establish a reference parameter for residual compressive strength. Subsequently, another sample of units was subjected to a thermal test in an electric furnace, where they were heated at 400°C, 800°C and 1000°C. After slow cooling, the units were tested for compression to evaluate changes in their compressive strength. The results indicate that structural masonry clay units retain their compressive strength even after being exposed at 1000°C. This work is part of a larger program that is currently under development.

KEYWORDS

Structural burnt clay blocks. Residual compressive strength. Fire safety.

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WEDNESDAY JUNE 4TH, 2025

Paper Session 7

Innovations in Masonry

Drawing Room

Numerical Analysis of TPMS Masonry Assemblages

Fahimeh Yavartanoo[i] and Damon Bolhassani[ii]

ABSTRACT

Masonry structures have been used in construction for centuries due to their durability, ease of maintenance, and availability of materials. However, in recent years, with the rising costs of labor and the pressures of conserving natural resources, which have led to a scarcity of traditional materials, masonry has lost its edge against steel and concrete. Moreover, traditional unreinforced masonry structures are often considered vulnerable under seismic conditions due to their brittle nature and high mass. While these concerns have influenced design preferences in some regions, modern innovations such as reinforced or confined masonry have demonstrated improved seismic performance and remain widely adopted. This study aims to further advance masonry design by exploring lightweight, structurally optimized units using the Triply Periodic Minimal Surface (TPMS) approach. This method reduces material usage while maximizing surface coverage, enhancing sustainability, and providing high structural strength, making them highly cost-effective. Their lightweight nature also facilitates easier transportation and handling, reducing labor demands. Furthermore, their unique and visually appealing design allows for use as combined structural and non-structural elements or as architectural elements such as decorative walls or facades. First, three TPMS units, P.Schwarz, Gyroid, and Hybrid, were designed, and their performance was evaluated experimentally and numerically. All TPMS units showed good mechanical performance under compression, though Gyroid was superior to P. Schwartz, and Hybrid had the higher resistance among them. Then, by applying Finite element (FE) models developed in ABAQUS, two types of assemblages were designed using TPMS units to investigate the behavior of prisms and diagonal tension assemblages to compressive load.

KEYWORDS

TPMS units, Minimal surface, Masonry structures, Finite element models, ABAQUS.

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Lath Fastening: An Examination of the Suitability of Prescriptive Requirements

Matthew Innocenzi[i] and Patricia Aguirre[ii]

ABSTRACT

Adhered masonry veneer and exterior portland cement-based plaster (stucco) have been successfully applied over lath fastened to exterior framing members in accordance with prescriptive lath fastening requirements provided in ASTM C1063, Standard Specification for Installation of Lathing and Furring to Receive Interior and Exterior Portland Cement-Based Plaster, for decades. Over the last 25 years, ongoing data collection and improved modeling has led to a better understanding of wind load pressures, and design and construction standards have been revised accordingly. In general, this resulted in increased design wind pressure values, particularly in hurricane-prone regions. However, the ASTM C1063 prescriptive spacing requirements have not changed since the standard's inception in 1986. With this increase in wind load pressures, the adequacy of the prescriptive fastening requirements in high wind regions has been questioned. It has been suggested that additional fasteners should be added between framing members to provide additional pull-off resistance even though this would violate other ASTM C1063 requirements. This paper examines the existing ASTM C1063 prescriptive fastening requirements and presents a comparative analysis of available laboratory test results to date to determine the suitability of the existing requirements.

KEYWORDS

adhered masonry veneer, lath, lath fastening, stucco, wind resistance

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Evaluation of Belite Calcium Sulfoaluminate (BCSA)-Based Concrete Mixtures for High Early Strength and Low-Carbon Concrete Masonry Units (CMUs)

Tesfaalem Gereziher Atsbha [i], Wei Victor Liu [ii], and Yuxiang Chen [iii]

Abstract

The masonry industry worldwide is seeking thermally efficient masonry materials, sustainable manufacturing and construction practices, and the integration of these technologies. Belite Calcium Sulfoaluminate (BCSA)-based concrete offers a promising solution, with benefits such as a 34–48% reduction in carbon footprint, rapid strength development, reduced drying shrinkage, and enhanced durability. This study is the first part of research program that aims to develop new BCSA-based concrete mixtures to produce high-performance concrete masonry units (CMUs) and assess their early-age mechanical properties and dimensional stability.

The study presents a review of CSA-based concrete and describes an ASTM- and ACI-based aggregate preparation process for normal-weight CMU production, following ACI 211 grading guidelines. The well-graded particle distribution, characterized by a fineness modulus (FM) of 3.79, is expected to enhance packing density, minimize voids, and improve mechanical performance. A carefully designed cement-aggregate mix was developed to balance cement content, water-to-cement ratio, and aggregate proportions for optimal fresh and hardened properties.

An experimental approach following ASTM standards will systematically evaluate material properties and mixture performance based on lab-scale samples. Expected outcomes, which will be presented at the conference, include improved early-age mechanical properties, enhanced dimensional stability, reduced curing time, and lower production costs by minimizing reliance on energy-intensive processes, such as high-temperature and high-pressure steam curing, typically used to accelerate early strength gain, contributing to a lower-carbon CMU manufacturing process.

Keywords

belite calcium Sulfoaluminate cement, concrete masonry units, durability, mechanical properties, sustainable construction, thermal performance

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Changes Introduced in the 2024 Edition of CSA S304

Nigel Shrive[i] and Bennett Banting[ii]

ABSTRACT

The 2024 edition of CSA S304 has seen some significant changes compared to the 2014 edition. Empirical Design was removed to the engineered section except for empirical design of arches. The strength of concrete masonry was increased as the standard shifted to strength based on a height to width ratio of two, rather than the previous five. The design of reinforced and unreinforced walls and columns was changed, including changes to the effective flange width and when to ignore slenderness. The design of beams was altered to require full continuity of grout, allowing the removal of the χ and λ factors. The design of fully grouted shear walls was upgraded to Simplified Compression Field Theory, thus making shear design consistent between walls and beams. Areas identified where more information is needed to make adjustments, were the design of slender walls, the definition of material shear strength and the design of partially grouted shear walls.

KEYWORDS

Standards, design, strength, compression, seismic, shear.

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WEDNESDAY JUNE 4TH, 2025

Paper Session 7

Unreinforced Masonry 3

Adam Room

Assessment of the Dynamic Behavior of Unreinforced Masonry Bell Towers Using Ambient Vibrations and Numerical Modeling – A Case Study

Jimmy-Lee Mc Lellan[i], Rola Assi[ii] and Jean-Philippe Ouellette[iii]

ABSTRACT

While unreinforced masonry (URM) is prevalent in Quebec's cultural and religious heritage, very few practical and simplified methods are available to predict its behavior when subjected to dynamic loading (such as the sounding of the bells), and seismic events. Through a case study of the Notre-Dame Basilica of Montreal (NDB), the dynamic behavior and stresses within the unreinforced masonry bell towers resulting from vibrational forces were assessed using a reliable numerical model developed and calibrated with ambient vibration measurements (AVM). AVMs were acquired using Tromino® in both towers to obtain their dynamic behavior under 3 conditions: i. ambient solicitations without bell ringing; ii. the influence of bell ringing: a carillon with multiple bells for the East tower and a single bourdon for the West tower; iii. the influence of the bell ringing from both towers simultaneously. To complement the dynamic characterization, the bells were also modeled to assess potential resonance with the towers' structural modes and to isolate their vibration effects from the global response. Subsequently, the recorded signals were processed in the modal operational analysis software ARTeMIS® to obtain the tower's modal properties. Finally, a global finite element model comprising both towers and the narthex façade was constructed using the SAP2000® software and was calibrated using the AVM results. After calibrating the model to the first three fundamental vibration modes, the discrepancies between the initial model and the experimental results obtained through the AVMs were reduced by 52.9%, 23.5%, and 5.3%, respectively, for each mode. The calibration and the modeling process provide a deeper and more realistic understanding of the dynamic behavior of unreinforced masonry bell towers, enabling an accurate assessment of internal stresses and the identification of vulnerable locations in terms of structural integrity.

KEYWORDS

Dynamic analysis, unreinforced masonry (URM), churches, ambient vibration measurements (AVM), modal analysis, finite element model, Notre-Dame Basilica of Montreal (NDB).

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Seismic Performance of Traditional Brick-Mortar and Interlocking Compressed Earth Brick Walls under Cyclic Loading

Junaid Shah Khan[i], Azam Khan[ii], and Tatheer Zahra[iii]

ABSTRACT

This study investigates the seismic performance of traditional mortar-bonded masonry and interlocking compressed earth brick (ICEB) masonry walls under lateral cyclic loading. An experimental program was developed to test full-scale specimens of both masonry types, assessing parameters such as initial stiffness, peak lateral resistance and lateral drift. The traditional mortar-bonded masonry wall constructed with first class bricks and 1:5 cement-sand mortar illustrated high initial stiffness but collapsed in a brittle manner. In contrast, the units of ICEB masonry wall made from a sustainable blend of sand, stone dust, and cement, with cavities grouted with 1:2:4 cement-sand-aggregate mixture demonstrated lower initial stiffness but significantly higher ductility and drift capacity, sustaining larger displacement without catastrophic failure.

KEYWORDS
brick-mortar walls, compressed earth blocks, ductility, lateral drift, seismic performance, structural resilience

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Comparative Study of Shear Interface Behavior in Calcium Silicate Bricks with Thick Mortar Joints and Blocks with Thin Mortar Joints

Navid vafa[i], Paul Korswagen [ii] and Jon Rots[iii]

ABSTRACT
Terraced buildings with cavity walls are among the most common types of construction in the northern part of the Netherlands. Since 1980, the inner walls of these buildings have been constructed using either calcium silicate bricks (214 × 102 × 75 mm) with thick mortar joints (10 mm) or, more recently, calcium silicate blocks (437 × 198 × 100 mm) with thin mortar joints (3 mm). The shear properties of these units play a crucial role in the seismic response of buildings, particularly in regions like Groningen, which is prone to seismic activity due to artificial extraction. This study investigates the shear interface behavior of these two types of masonry units by testing multiple triplet samples under varying levels of normal stress at the interface. The results provide detailed insights into the shear properties of both brick and block masonry, offering valuable data for enhancing the accuracy of numerical simulations and predicting the structural capacity of these types of masonry buildings.

KEYWORDS
Calcium Silicate Masonry, Shear Triplet, Cohesion, Friction.

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Influence of Opening Size and Internal Tie-columns Around Openings on the Seismic Response of Confined Masonry Walls: A Numerical Investigation

Nemanja Krtinić[i], Matija Gams[ii] and Marko Marinković[iii]

ABSTRACT

Confined masonry (CM) is one of the popular structural systems embraced by many countries as an earthquake-resistant and affordable solution for building construction. Despite this, there are still gaps in the knowledge about seismic response. This paper presents a comprehensive numerical investigation into the seismic response of CM walls with openings, utilizing a micro-modelling approach in Abaqus software. A finite element (FE) model, validated on two cyclic shear tests of full-scale CM wall specimens, is employed for a parametric study exploring the effects of varying wall aspect ratios and opening configurations (no opening, door opening, window opening). The primary objective is to examine the influence of opening size and on the lateral resistance of CM walls, focusing on in-plane behavior, stiffness, strength, and ductility.

The results from the numerical simulations demonstrate that the presence of tie-columns around openings and shape of the openings significantly affect the seismic performance of CM walls. As the opening size increases, the strength reduction becomes more evident, with walls having AR = 0.71 showing a substantial decrease in load-bearing capacity due to the amplified effect of larger openings. Furthermore, the size of tie-columns around openings is recognized as crucial in mitigating strength losses. These findings underscore the necessity of further experimental tests to fully validate these conclusions.

KEYWORDS

confined masonry, numerical simulation, micro-modelling, Abaqus, window opening, door opening

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Damage From Ups and Downs: Investigating Cracking in Unreinforced Masonry Structures Exposed to Settlement and Uplift Cycles Using Finite Element Analyses

Alfonso Prosperi[i], Michele Longo[ii], Paul A. Korswagen[iii], Mandy Korff[iv] and Jan G. Rots[v]

Abstract

Cycles of settlement and uplift beneath existing masonry structures can lead to visible cracks, which not only affect the aesthetic appearance and functionality of the building but can also compromise its structural integrity and undermine the occupants' sense of safety. These cyclic ground movements can be triggered by seasonal actions, such as fluctuation in the groundwater table. In the Netherlands, many existing masonry structures on shallow foundations rest directly on the subsurface, making them vulnerable to cyclic ground movements. Settlement and uplift cycles cause "breathing" masonry cracks, which open and close over time without fully sealing. This study uses finite element analyses to investigate and assess the damage of structures subjected to cyclic quasi-static ground movements. A case study is presented for the analyses, featuring the geometry of an existing low-rise masonry structure with an age exceeding 50 years. A 3D non-linear shell-element model is used to evaluate the structural response, featuring an unreinforced strip foundation and including the non-linear tensile softening and cracking behaviour of masonry. Heaving and sinking displacements are applied to a non-linear interface simulating the soil-foundation interaction, at the bottom of the strip foundation. The intensity of the ground displacements is quantified by their angular distortion. A damage parameter objectively assesses the severity of damage by considering the number, length, and width of cracks. Results indicate that repeated cycles of settlement (and uplift) have been observed to cause irreversible cracking damage in the model, with crack widths ranging from 1 to 5 mm, progressively increasing over time. Damage occurring during settlement is, on average, twice as severe as that during uplift. Overall, cycles of settlement and uplift may induce cracking damage up to twice as high as that caused by cycles of settlement alone, depending on the magnitude and shape of the ground movements.

Keywords

Settlement, uplift, cyclic ground movements, unreinforced masonry, cracking damage, damage assessment, finite elements

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WEDNESDAY JUNE 4TH, 2025

Paper Session 7

Veneers 2

Laurier Room

The Effects of Cyclic Wind-Driven Rain Events on the Brick Masonry Veneers

Mohsen Khanverdi[i] and Sreekanta Das[ii]

ABSTRACT

Masonry is a widely used construction method globally, with building facades being particularly vulnerable to wind-driven rain that combines rainwater and wind pressure. Driving rain is the primary moisture source in buildings, leading to significant damage such as moisture transfer, mold growth, discoloration, erosion, and structural degradation. The effects of driving rain are intensified by climate change, highlighting the need for realistic evaluations under various climatic conditions. Existing studies have explored masonry wall behavior under wind-driven rain, focusing on material properties, rain load, and air pressure effects. There is a gap in the literature regarding the behavior of masonry veneers under cyclic wind-driven rain conditions with varying drying time intervals. This study addresses this gap by experimentally investigating water penetration in large-scale masonry veneers constructed with clay bricks and mortar. The research evaluates the impact of wetting-drying cycles on the performance of these veneers. The findings reveal that total water leakage under cyclic wind-driven rain conditions can increase by more than 85% compared to the reference test. This significant increase highlights the need to account for frequent rain exposure in the design of masonry members, rather than relying on designs intended only for occasional rain events.

KEYWORDS

clay brick, experimental study, masonry veneers, water penetration, wind-driven rain

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Damage to Brick Veneer Due to the Combination of Prefabricated Units and Traditional Masonry

Birger Gigla[i]

ABSTRACT

The construction of veneer facades has significantly changed in recent years. In the past, the area of veneer surpassed that of the windows, and the brickwork above the openings was supported by masonry arches. Veneer was unmistakably considered part of the masonry construction and was executed by skilled masons. Today, due to demands for views, lighting, and accessibility, window areas often exceed masonry. As a result, facing masonry has developed into a precast masonry construction, combining traditional masonry with precast concrete units or thin brick masonry veneer panels.

Those 'composite veneer walls' can lead to damage, especially in the anchoring of precast elements. In construction practice, supports designed for facing lintels are used, but they are unsuitable for bearing larger elements. The connection between traditional masonry and larger precast components is not governed by established standards. Additional challenges arise when traditional masonry is placed atop precast elements. In practice, there are also interface issues between masonry and precast concrete work and the planning of anchors and fastenings. Due to different expansion behaviors between masonry and concrete, movement joints and sealing tapes must also be given special consideration. The paper provides an overview of precast masonry construction and gives guidance on damage prevention.

KEYWORDS

veneer, prefabricated units, construction, concrete units and traditional masonry, masonry veneer panels, damage prevention.

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Early Veneer Walls: A Learning Step in the Evolution from Mass Masonry to Cavity Walls

Danielle DiDomizio[i], Amarantha Quintana-Morales[ii], and Matthew Normandeau[iii]

ABSTRACT

Contemporary cavity wall assemblies are the result of much trial and error over the last century. During the transition from mass masonry walls to the "four barrier" (i.e., water, air, vapor, and thermal barrier) assemblies of modern construction, came what the industry now calls "early veneer walls" of the mid-to-late twentieth century. Early veneer wall systems represented an improvement upon masonry systems that came before and were a beneficial step toward developing today's contemporary rainscreen assemblies. Yet, these assemblies lack many of the necessary components that comprise an effective building enclosure system, and, due to this, often lead to failure of the system. This paper discusses the transition from mass masonry wall systems to early veneer walls. It reviews the typical construction and material properties of early veneer walls and presents their shortcomings. It also examines these issues in the context of a case study, which included investigation of an early veneer wall system and remediation to address common issues. Additionally, it discusses the transition from early veneer walls to contemporary cavity wall systems, and the changes in codes and standards that followed.

KEYWORDS

brick, cavity, early veneer, enclosure, failure, masonry

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Machine Learning-Based Surrogate Modeling for Efficient Estimation of Linear Transmittance in Brick Veneer Building Envelopes

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ABSTRACT

The pursuit of energy-efficient building design has intensified with the recent National Energy Code of Canada for Buildings (NECB), which mandates comprehensive accounting of thermal bridges in building envelope assessments. This study addresses the challenge of cataloging linear transmittance values for brick veneer envelopes with concrete masonry unit (CMU) backup walls. To capture the extensive variability in wall configurations, parameterized models are needed, enabling systematic exploration of thermal performance across diverse scenarios. However, the computational burden of simulating every possible variation remains prohibitive. To overcome this, we integrated machine learning models trained on a subset of parameterized simulations, allowing the prediction of thermal performance for unmodeled configurations by learning the influence of key design parameters. This method reduces modeling time by over 99% while maintaining high accuracy, enabling rapid, informed design decisions and supporting the development of high-performance, NECB-compliant building envelopes.

KEYWORDS

Thermal performance, brick veneer envelopes, machine learning, parametric modeling, surrogate modelling

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