Industry–Academia Research Collaboration Event

“NEW GENERATION OF SUSTAINABLE AND RESILIENT REINFORCED MASONRY BUILDINGS”

A show case of collaborative research and development projects between
the Québec masonry industry and Concordia university

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PRESENTATION CONTENTS

- Structures Laboratory at Concordia University
- Snapshots of previous research projects
- Current research project supported by AEMQ
PART 1

STRUCTURES LABORATORY AT CONCORDIA UNIVERSITY
Upgrading the Structures Laboratory

Before

After
Strong Steel Reaction Frame to support the actuators

www.mts.com

3 Actuators for dynamic loads
1 Actuator for Shake Table

Hydraulic pump

Digital controller

Data acquisition systems for fibre optic and wireless sensors

Structural Testing Facility
Three Actuators for dynamic loads

Tested wall

Strong concrete transfer footing for anchoring
PART 2
SNAPSHOTS OF PREVIOUS RESEARCH PROJECTS
Structural Elements in a Typical Reinforced Masonry Building

- Beam
- Column
- Non-structural wall
- Shear wall
Snapshots of Previous Research Projects

1. Seismic rehabilitation of RM Columns
2. GFRP-reinforced masonry beams
3. GFRP-reinforced masonry walls
4. Strengthening URM walls for high wind loads
5. Seismic performance of RM Shear Walls
6. Sustainable Low-Energy Consumption Buildings
1- **Seismic Rehabilitation of RM Columns**

Construction of full-scale RM columns:

1. Grouting the cells
2. Shear reinforcement
3. Grouting the cells
4. Grouting the cells
5. Shear reinforcement
6. Grouting the cells
1- Seismic Rehabilitation of RM Columns

Glass FRP (GFRP) bar

Carbon FRP (CFRP) sheets

Examples of Fibre-reinforced Polymer (FRP) composites
Wrapping with FRP sheets
1- Seismic Rehabilitation of RM Columns

Test setup and Instrumentation
1- Seismic Rehabilitation of RM Columns

Test setup and Instrumentation
1- **Seismic Rehabilitation of RM Columns**

Rehabilitated RM column under axial and lateral loads
1- SEISMIC REHABILITATION OF RM COLUMNS

Lateral load-drift relationship

Lateral Drift (%) vs. Lateral Load (kN)
2- **GFRP-REINFORCED MASONRY BEAMS**

Construction of full-scale RM beams:
2- **GFRP-Reinforced Masonry Beams**

Construction of full-scale RM beams:
2- GFRP-Reinforced Masonry Beams

Test setup
2- **GFRP-Reinforced Masonry Beams**

Beams during testing
Description of the test specimens

3- GFRP-Reinforced Masonry Walls

Fully or partially grouted

Steel or GFRP rebar

Elevation

Cross-section
3- **GFRP-Reinforced Masonry Walls**

Construction of the walls:
3- GFRP-Reinforced Masonry Walls

Construction of the walls:
3- GFRP-Reinforced Masonry Walls

Test setup and instrumentation:
Load-deflection relationships of the tested masonry walls:
Examples of out-of-plane failure of URM walls
4- Strengthening URM Walls

Elevation of tested full-scale URM walls strengthened with FRP
4- Strengthening URM Walls

Strengthened Wall 4 before testing
4- STRENGTHENING URM WALLS

Strengthened Wall in the test setup
Comparison between the lateral capacity of strengthened and unstrengthened walls
5. Seismic performance of RM shear walls

Test setup at Concordia’s Structures Laboratory
5. Seismic performance of RM shear walls

Construction procedure
5. Seismic performance of RM shear walls

**Constructed Walls**
5. Seismic performance of RM shear walls

 Crack pattern of the tested walls at failure
Modeling and Design of a Solar House with Focus on a Ventilated Concrete Slab (VCS) Coupled with a Building-Integrated Photovoltaic/Thermal (BIPV/T) System
Modeling and Design of a Solar House with Focus on a Ventilated Concrete Slab (VCS) Coupled with a Building-Integrated Photovoltaic/Thermal (BIPV/T) System

CMHC initiative: EQuilibrium™
► Promote sustainable housing and Approach net-zero annual energy consumption

ÉcoTerra House built in Eastman city (Québec) in 2007
Modeling and Design of a Solar House with Focus on a Ventilated Concrete Slab (VCS) Coupled with a Building-Integrated Photovoltaic/Thermal (BIPV/T) System

**VCS construction:**

- Normal Density Plain Concrete (125mm (5"))
- Steel Deck (0.7mm (1/32") galvanized steel)
- Ventilation Channel (air cavity)
- Metal Mesh (8mm (1/4"))
- Water/Vapor Barrier
- Insulation (50mm (2") EXPS, RSI-1.7(R10))
- Gravel Backfill
- Earth

![Diagram of VCS construction with dimensions](image)
Modeling and Design of a Solar House with Focus on a Ventilated Concrete Slab (VCS) Coupled with a Building-Integrated Photovoltaic/Thermal (BIPV/T) System

ÉcoTerra - built environment

Family Room

Concordia Data Acquisition System

PV Monitoring

Basement
Modeling and Design of a Solar House with Focus on a Ventilated Concrete Slab (VCS) Coupled with a Building-Integrated Photovoltaic/Thermal (BIPV/T) System

ÉcoTerra - monitoring

House automation and monitoring system

HQ monitoring system

TC in the ground floor slab

TC in the VCS
Towards the Development of Sustainable Low-Energy Consumption Masonry Buildings

Schematic of the active charge and discharge processes with ventilated systems
Towards the Development of Sustainable Low-Energy Consumption Masonry Buildings

Conceptual thermal response of a zone with strong thermal coupling between passive Building-Integrated Thermal Energy Storage and the thermal zone.
PART 3

CURRENT RESEARCH PROJECT
SUPPORTED BY AEMQ
Simulation of critical panels of a reinforced masonry shear wall
Reinforced Masonry in the National Building Code of Canada (NBCC)

Pre-2015

- Better detailing
- Higher ductility
- Stronger walls

After 2015

- Boundary element
- Hoops
- Grout
- Tension
- Compression
- Masonry blocks
Example of a multi-story reinforced masonry building in Montréal
Current research project supported by AEMQ

Schematic of the layout of the RM shear walls and bearing walls
Current research project supported by AEMQ

Preferred boundary element orientation
Current research project supported by AEMQ

Veneer options with boundary element
Current research project supported by AEMQ

Embedment of boundary element reinforcement

Foundation with vertical wall reinforcement embedded
Current research project supported by AEMQ

Reinforcement requirements

50% of Boundary Element Vertical Steel

$1.5 \text{Ld}$

$s = \text{Cl. 12.2, Cl. 16.11.4, Cl. 16.11.6b}$

$L_p \text{ or Storey}$

$L_w/4 \text{ or } 1,200 \text{ mm}$

$1.5 \text{Ld}$

Starter Bars

Starter Bars for next storey
Current research project supported by AEMQ

Close-up of Boundary Element reinforcement cage lap splice detail
Current research project supported by AEMQ

Placement of Horizontal reinforcement
Complete the construction of the wall
Current research project supported by AEMQ

Cleanouts and lapped vertical reinforcement
Laying of boundary element units and cleanouts, then grout
Example of Reinforced Masonry Building
Example of Reinforced Masonry Building
Example of Reinforced Masonry Building
Videos

Construction of reinforced masonry shear walls with boundary elements

Concept of tall buildings constructed with reinforced masonry walls and concrete slabs

Testing reinforced masonry shear walls subjected to earthquake effects
Ongoing Activities in the Structures Lab at Concordia
Strengthening of the MTS testing frame
Strengthening of the MTS testing frame
Strengthening of the MTS testing frame
Construction of new strong foundation
Construction of new strong foundation
Construction of 120 boundary elements
Construction of 120 boundary elements
Construction of 120 boundary elements
Construction of 120 boundary elements
Construction of 120 boundary elements
Construction of 120 boundary elements
6. Confinement of RM Boundary Elements

Construction of full-scale reinforced concrete block boundary elements

Compression test setup
6. Confinement of RM Boundary Elements

stress-strain curves

Failure mechanisms
Construction of Phase 1 of RM walls
Construction of Phase 1 of RM walls
Construction of Phase 1 of RM walls
Construction of Phase 1 of RM walls
Construction of Phase 1 of RM walls
Construction of Phase 1 of RM walls
Construction of the Top Beam
Construction of the Top Beam
Wall Placement
Wall Placement
Testing reinforced masonry shear walls
Testing reinforced masonry boundary elements
**INDUSTRY-ACADEMIA RESEARCH COLLABORATION**

- Design | Rehabilitation | Sustainability
- Energy Efficient Systems

**Concordia**
- Full-scale testing
- Advanced systems
- Durability
- Safety
- Life Cycle Analysis

**AEMQ Architects & Engineers**
- Practical Expertise
- Design and Construction of Demonstration Innovative RM Buildings

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Energy Efficient Systems
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