Experimental Techniques in Earthquake Engineering
Module 4

Static Laboratory Testing of Large-Scale Structures
4. Static Laboratory Testing of Large-Scale Structures

(a) reinforced concrete components
(b) two-story reinforced masonry building
(c) brick shear walls extracted from existing building
(d) masonry infill panels
(e) brick masonry cladding on steel frames
(f) retrofitted masonry piers
(g) hybrid masonry steel frames
(h) large-scale static tests by others
References

REFERENCES TO RESEARCH STUDIES
D.P. Abrams, University of Illinois at Urbana-Champaign

A. Tests of 10-Story Frame-Wall Reinforced Concrete Buildings


B. Tests of Full-Scale, Two-Story Reinforced Masonry Building Systems


equipment for static testing

(a) reaction structure  
(b) test apparatus  
(c) test structure  
(d) loading actuators  
(e) D-to-A controllers  
(f) sensors  
(g) A-to-D data acquisition system
(a) reinforced concrete components
large-scale static test of RC beam-column joints

<table>
<thead>
<tr>
<th>Test Structure Size</th>
<th>Loading Rate</th>
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(a) reinforced concrete components

interior beam-column joints
(a) reinforced concrete components

exterior beam-column joints
(a) reinforced concrete components

large-scale static test of RC columns

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(a) reinforced concrete components

large-scale static test of RC columns
(a) reinforced concrete components

large-scale static test of RC columns
(b) 3-story reinforced masonry buildings

large-scale static test

![Image of reinforced masonry test structure]

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(b) reinforced masonry building

see References B.1 though B.4
(b) reinforced masonry building
(b) reinforced masonry building

prestressed concrete diagonal

servo-hydraulic actuators

reference frame
(b) reinforced masonry building

displacement transducers (LVDT)
(b) reinforced masonry building
measured force-deflection relation
(b) reinforced masonry building
measured force vs. pier diagonal extension
(b) reinforced masonry building

measured force vs. pier diagonal extension
(b) reinforced masonry building
measured force vs. pier axial extension
(b) reinforced masonry building

final crack pattern
(b) unreinforced brick shear walls

extraction of older masonry piers

gymnasium, circa 1919
(c) unreinforced brick shear walls

saw cut of 4-wythe brick wall

see References D.1 though D.9
(c) unreinforced brick shear walls

extracted brick walls

trimmed wall

test structure

vertical hydraulic jack

servo hydraulic actuator

laboratory strong floor
(c) unreinforced brick shear walls

unreinforced masonry test wall

prestressed masonry reaction wall

erservohydraulic loading actuators

Nirav Shah
(c) unreinforced brick shear walls

- steel prestressing rods
- prestressed concrete masonry reaction wall
- concrete base footing
- concrete top beam
- test wall
(c) unreinforced brick shear walls
(c) unreinforced brick shear walls

\[ f_a = \frac{P}{A} \]

\[ H = \frac{PL}{2h} \left[ 1 - \frac{4f_a}{3f_m} \right] \]

wall width = b
(c) unreinforced brick shear walls
(d) masonry infill panels

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<td>Dynamic: shaking table</td>
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<tr>
<td>Large-Scale</td>
<td>Static: reaction wall</td>
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<tr>
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<td>Dynamic: instrumented building</td>
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(d) masonry infill panels

- reinforced concrete frame
- brick or block masonry infill panel
- servohydraulic loading actuators
- Newmark Laboratory strong floor

see References F.1 though F.6
(d) masonry infill panels

- hydraulic jack for column prestress
- steel frame for support of actuators and instrumentation reference
- infill-frame test structure
(d) masonry infill panels

- prestressed masonry reaction wall
- infill-frame test structure
- brick wall test structure
(d) masonry infill panels

loading strengthened infill panel normal to its plane with airbag

concrete frame
(d) masonry infill panels

crack pattern for brick infill panel subjected to in-plane and out-of-plane loadings

\[ q_{in} = 0.7 \frac{f'_m \lambda^2}{\left( \frac{h}{t} \right)} \times 144 \]
(d) masonry infill panels

strengthening damaged brick infill panel with ferrocement coating
(d) masonry infill panels

reduced-scale masonry infill panel with reinforced concrete frame

shaking table

firstly subjected to in-plane earthquake motions

secondly subjected to out-of-plane earthquake motions
(e) brick cladding on steel frames

- diagonal tension shear cracks
- brick cladding surrounding steel beams and columns

1989 Loma Prieta Earthquake, Oakland

see References H.1 and H.2
(e) brick cladding on steel frames

Steve Favierie

- steel beam
- unreinforced brick masonry cladding
- steel column
- pin connection
(e) brick cladding on steel frames

- Servo-hydraulic actuators
- Brick masonry cladding
- Steel top beam
(e) brick cladding on steel frames
(f) retrofitted masonry piers

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- Reduced-Scale: ???
- Large-Scale: reaction wall, instrumented building

- Loading Rate: Static, Dynamic
- Test Structure Size: Reduced-Scale, Large-Scale

- Instrumented building: shaking table
(f) retrofitted masonry piers

- servo-hydraulic actuator in load control
- prestressed masonry reaction wall
- servo-hydraulic actuator in displacement control
- unreinforced brick masonry test pier (cantilever)

see References J.1 though J.4
(f) retrofitted masonry piers

control specimen: un-retrofitted

Horizontal Force, kN
Drift, %

Load (kN)
-60
-40
-20
0
20
40
60
-3 -2 -1 0 1 2 3
Drift (%)

6F (Non-rehabilitated, 0.59 MPa compressive stress)
(f) retrofitted masonry piers

ferro-cement coating
(f) retrofitted masonry piers

reinforced cores

Horizontal Force, kN

Drift, %
(f) retrofitted masonry piers

fiber reinforced polymer

Horizontal Force, kN

Drift, %

Drift (%)

Load (kN)

Load (kips)

3F (FRP)

P

H

P

(f) retrofitted masonry piers

shotcrete

Horizontal Force, kN

Drift, %
(f) retrofitted masonry piers comparison
(f) retrofitted masonry piers
reticulated reinforcement

Sacramento Municipal Utility District, California
(f) retrofitted masonry piers

reticulated reinforcement

Displacement

Force
(g) hybrid masonry

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Loading Rate

see References L.1 though L.13
(g) hybrid masonry

- steel connector plate or fuse
- gap
- slotted hole and through bolt
- reinforcing bars
- figure from IMI
(g) hybrid masonry
Connector Tests
NEES* MUST SIM**

* Network for Earthquake Engineering Simulation
** Multi-Axial Full-Scale Sub-Structured Testing & Simulation
(g) hybrid masonry

Load Boundary Condition Box (LBCB)

structural steel frame

steel connector plates

reinforced concrete masonry structural panel

5.5m 18'-0"

9'-0" 2.8m
(g) hybrid masonry

from T. Gregor
(g) hybrid masonry
measured lateral force vs. deflection relations

![Graph showing measured lateral force vs. deflection relations for weak and strong connectors.](image)

weak connector
strong connector
TS1 with Weak Fuses
TS2 with Strong Fuses
(g) hybrid masonry
measured lateral force vs. deflection relations
TS4 with Strong Link Plates
(g) hybrid masonry
measured lateral force vs. deflection relations

![Graph showing measured lateral force vs. deflection relations for hybrid masonry with weak and strong connectors.](image)

- **Lateral Force, kN**
- **Roof Drift, %**

- TS5
- TS1

- **Weak connector**
- **Strong connector**
TS5 with Strong Link Plates
Other Types of Hybrid Masonry

Type II
- Shear (in-plane)
- Type II shear wall

Type III
- Shear (in-plane)
- Type III shear wall

TEMPORARY FORMWORK FOR GROUT

3/4" DIA. x 3/8" HEADED STUDS @ 5 (DESIGN SPACING) O.C.

OPTION 3: GROUT SOLID FOR TYPE II OR TYPE III HYBRID ONLY

BOND BEAM AT TOP COURSE

GROUT & REINFORCING AS REQ'D

UNDERSIDE OF BEAM OPTION 3: PREFERRED TYPE II & TYPE III OPTION
DETAIL 02.120.1203 REV. 09/20/11

figure by Scott Conwell, IMI
(h) large-scale static tests by others

5-Story Reinforced Masonry Test Structure
Building Research Laboratory, Tsukuba, Japan
(h) large-scale static tests by others

5-Story Reinforced Masonry Test Structure
University of California at San Diego
(h) large-scale static tests by others

2-Story Unreinforced Masonry Test Structure, Georgia Institute of Technology

photo and figures from R. Leon and F. Moon
(h) large-scale static tests by others

2-Story Unreinforced Masonry Test Structure, Georgia Institute of Technology