

***EXPECTED PERFORMANCE  
OF URM'S  
IN MEMPHIS, TN***

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***EXPECTED PERFORMANCE  
OF URM'S  
IN MEMPHIS***

## Expected Performance of Memphis/Shelby County URM's

### Prior studies

- Hwang & Lin - Univ of Memphis 1997  
(also fire and police stations)
- *Inventory of Essential Facilities Memphis, St Louis, and Charleston* - MAEC 2001
- MAE Center - *Memphis Test Bed* as part of MAEViz development (inventory) 2006
- MAE Center - *Impact of New Madrid Seismic Zone on the Central USA* 2009
- South Main Demonstration Project  
(in progress 2012)

## Expected Performance

### Key issues

Level of hazard considered

Inventory

Occupancy

Type URM (construction, height, size, vintage)

Location

Value/contents

Vulnerability

Fragility

Results

Typical damage

Memphis/Shelby County

Suggested priorities and conditions

## Expected Performance

Level of hazard considered

- M7.5-M7.9 NMSZ  
MAEC studies
- M7.0 Southern segment NMSZ (Hwang)
- M6.2+ Southern segment NMSZ  
Lower threshold for damaging ground motions

## Inventory

Occupancy

Type URM (construction, height, size, vintage)

Location

Value/contents

Principal reliance on 2006 MAEC Memphis Test  
Bed inventory (Steve French/GA Tech et al)

Based on Shelby County Tax Assessor office  
data

Performance results from MAE Center – *Impact  
of New Madrid Seismic Zone on the Central  
USA* 2009

## Inventory

### Occupancy

Commercial/institutional/multi-family residential  
(single family excluded)

- 292,438 buildings in Memphis/Shelby County incl. single family residences
- 266,618 single family residences [approx. 25,000 S1 URML]
- Population approx. 930,000 (approx. 3.5 persons/dwelling unit)

## Inventory

### Occupancy

Commercial/institutional/multi-family residential  
(single family excluded)

- 25,820 buildings other than single family residences
- 6,302 URM's
- 24% of building stock (vs. 23% W1 Light wood - 26% S3 Light steel - 10% RM Reinforced masonry)
- But URM comprise only 14% of gross bldg area

## Inventory

Type URM (construction, height, size, vintage)

Construction

- Typically unreinforced clay brick masonry (some stone/ashlar masonry)
- Conventional CMU excluded

Height

- 85% URM's – 1 story
- 9% URM's – 2 story
- 5% URM's – 3-5 story
- 23 6-10 stories

## Inventory

Type URM (construction, height, size, vintage)

Size

- 40% less than 2500 sf
- 23% 2500-5000 sf
- 17% 5000-10,000 sf
- 17% 10,000-50,000 sf
- 4% greater than 50,000 sf

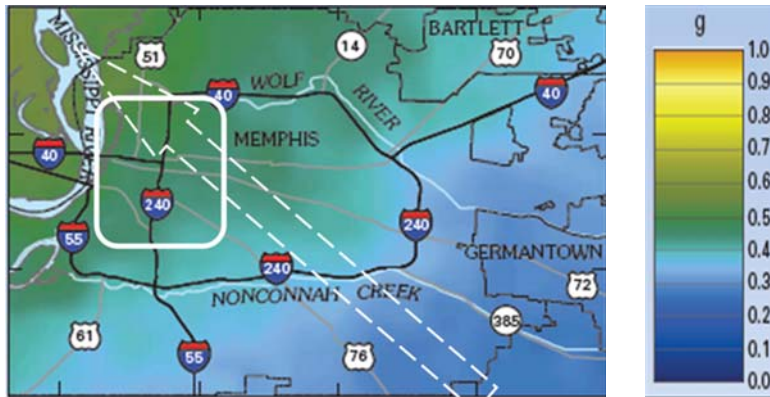
Vintage

- 33% URM's pre-1939
- 38% 1940-1960
- 28% 1960-1980

## Inventory

### Location

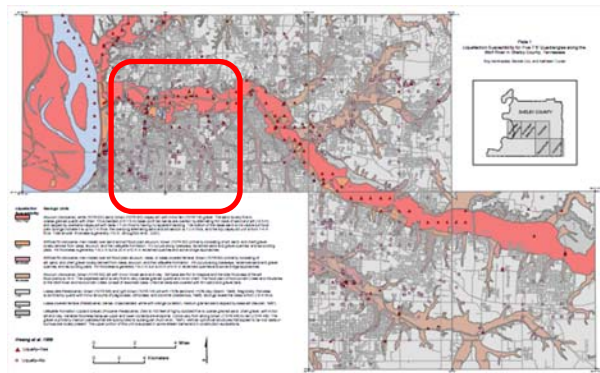
- URM's concentrated in older areas of Memphis (Downtown & Midtown)



## Inventory

### Location

- URM's typically not impacted by liquefaction hazard



## Inventory

### Value/contents

- *Appraised value*
- 72% URM's less than \$100,000 in value
- 27% URM's less than \$1,000,000 in value
- 8 worth more than \$5,000,000
- URM's value relative to building stock
- \$1.23B vs. total building stock \$40.07B (not including single family residential)
- *URM's 3% of value of total building stock*

## Inventory

### Value/contents

#### *Contents value* (Shelby Co Appraisal Office)

- 73% URM's less than \$100,000 in contents
- 25% URM's \$100,000 - \$1,000,000 in contents
- 5 with more than \$5,000,000 in contents

## URM Vulnerability

- Fragility curves
- Strengthened?

Fragility curves conventional method of assessing damage to groups or classes of buildings on a regional basis

Typically NOT appropriate for facility-specific loss evaluation without careful use

Essentially no seismic retrofit/strengthening in Memphis-Shelby County. Maintenance of masonry questionable, including and especially historic properties.

## URM Vulnerability

### Fragility curves

#### Bases

- Documented experience
- Expert engineering judgment
- Analytical

Limited fragility curves available for URM

- ATC-13 (expert judgment) 1985 CA
- HAZUS MH2 (expert judgment)
- Numerous recent studies (Italy, NZ, USA, etc.) including Analytical Fragility Assessment of Low-Rise URM Buildings (Park Goodno et al) 2008

# URM Vulnerability

## Fragility curves

Analytical Fragility Assessment of Low-Rise URM Buildings (Park Goodno et al) 2008

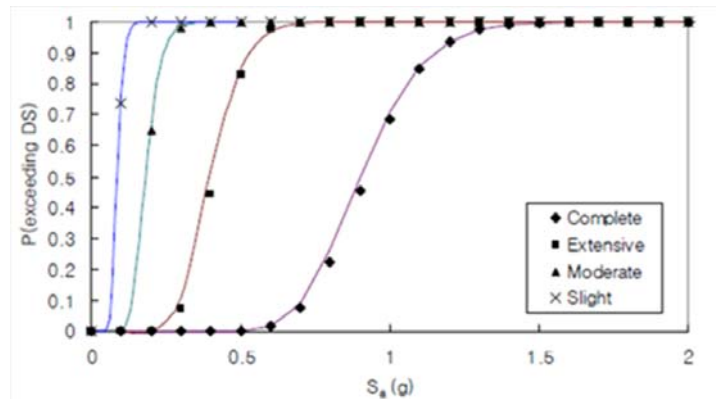


Figure 6: Fitted Fragility Curves

## Results

Typical damage  
Memphis/Shelby County

## URM Damage

### Unreinforced Masonry Bearing Walls (URM):

**Slight Structural Damage:** Diagonal, stair-step hairline cracks on masonry wall surfaces; larger cracks around door and window openings in walls with large proportion of openings; movements of lintels; cracks at the base of parapets.

**Moderate Structural Damage:** Most wall surfaces exhibit diagonal cracks; some of the walls exhibit larger diagonal cracks; masonry walls may have visible separation from diaphragms; significant cracking of parapets; some masonry may fall from walls or parapets.

**Extensive Structural Damage:** In buildings with relatively large area of wall openings most walls have suffered extensive cracking. Some parapets and gable end walls have fallen. Beams or trusses may have moved relative to their supports.

**Complete Structural Damage:** Structure has collapsed or is in imminent danger of collapse due to in-plane or out-of-plane failure of the walls. Approximately 15% of the total area of URM buildings with Complete damage is expected to be collapsed.

## URM Damage

*Moderate* damage or beyond:

- Building cannot be occupied post-quake
- Building is likely beyond economical repair
- Building is likely a total loss and needs to be demolished, perhaps as part of Emergency Response and Recovery with or without Owner concurrence

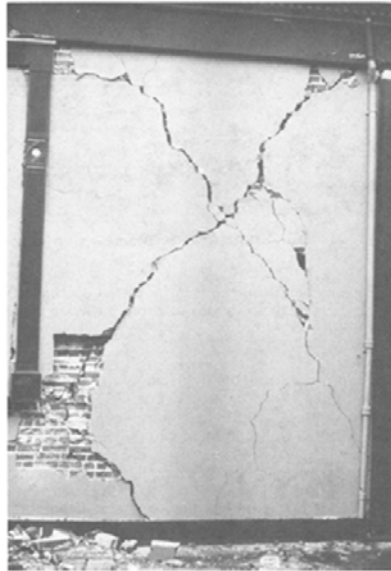


FIG. 2. In-Plane Shear Failure of URM Masonry Wall (Santa Cruz, Loma Prieta Earthquake)

## URM Damage

(Photos from *State-of-the-Art  
Report on Seismic  
Performance of Unreinforced  
Masonry Buildings* (Bruneau  
– after Loma Prieta EQ))



FIG. 4. In-Plane Shear Failure of URM Pier (Oakland, Loma Prieta Earthquake)

## URM Damage

## URM Damage



FIG. 6. Out-of-Plane Failure of URM Top-Story Wall (San Francisco, Loma Prieta Earthquake)



FIG. 7. Out-of-Plane Failure of URM Wall at Center of Building due to Excessive Diaphragm Flexibility (Santa Cruz, Loma Prieta Earthquake)

## URM Damage

## URM Damage



FIG. 8. Parapet Failure of 100 Front Street Building (Watsonville, Loma Prieta Earthquake)

## URM Damage



(Photos from From City of San  
Diego Development Services  
website)



## URM Damage



## URM Damage

(Photos from *The M6.3 Christchurch Earthquake – Performance of (URM) Buildings in CBD* – Sri Sritharan/Iowa State University 2011)



URM  
Damage



URM  
Damage





## URM Damage

### Lessons

- URM – performed poorly but not surprising
- Retrofitted URM – prevented structural collapse but experienced damage

## *M&SC - URM FIRE STATIONS*

(Univ of Memphis – Hwang & Lin - *Seismic Performance Evaluation of Fire Stations in Shelby County, TN 1977*)

Table 1. Statistics of the structural types of fire stations in the Memphis area

Structural Type	Number of Fire Stations
Unreinforced masonry (URM)	50
Steel frame buildings with URM infill walls (S5)	13
Reinforced masonry (RM)	3
Wood buildings (W)	3
Concrete frame buildings with URM infill walls (RC)	1
Light metal building (S3)	1

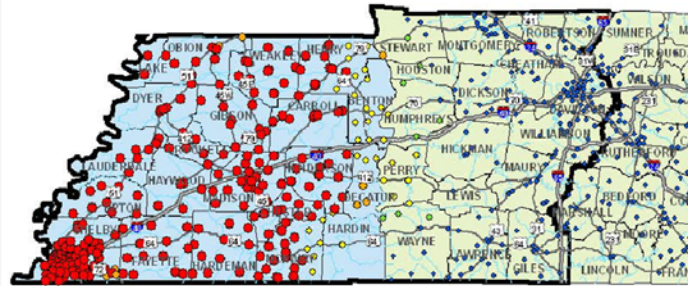
Table 5. Statistics of damage states of fire stations caused by two scenario earthquakes

Damage State	M = 6.5	M = 7.0
No Damage	1	1
Insignificant Damage	11	0
Moderate Damage	21	3
Heavy Damage	38	67

## *M&SC - URM FIRE STATIONS*

(MAE Center *Impact of New Madrid Seismic Zone on Central United State 2009*)

Fire Station Damage - New Madrid Seismic Zone: M7.7 Event



## *M&SC - URM FIRE STATIONS*

(MAE Center *Impact of New Madrid Seismic Zone on Central United State 2009*)

State of Tennessee - Critical Counties (37)

County	Total No. of Facilities	At Least Moderate Damage	Complete Damage	County	Total No. of Facilities	At Least Moderate Damage	Complete Damage
Benton	10	0	0	Humphreys	9	0	0
Carroll	11	11	0	Lake	2	2	1
Cheatham	11	0	0	Lauderdale	7	7	7
Chester	10	10	0	Lawrence	18	0	0
Crockett	7	7	7	Leads	1	0	0
Davidson	37	0	0	McNairy	22	16	0
DeKalb	8	3	0	Madison	22	22	0
Dickson	12	0	0	Maury	12	0	0
Dyer	6	6	6	Montgomery	17	0	0
Fayette	13	13	4	Obion	10	10	6
Gibson	12	12	9	Perry	7	0	0
Giles	12	0	0	Robertson	13	0	0
Hardenman	12	12	0	Shelby	73	73	96
Hardin	3	0	0	Stewart	8	1	0
Haywood	5	5	5	Tipton	10	10	10
Henderson	14	14	0	Wayne	10	0	0
Henry	17	10	0	Weakley	12	12	6
Hickman	7	0	0	Williamson	22	0	0
Houston	2	0	0				

## *M&SC - URM FIRE STATIONS*

(MAE Center Impact of New Madrid Seismic Zone on Central United State 2009)

County	Total No. of Facilities	At Least Moderate Damage	Complete Damage	County	Total No. of Facilities	At Least Moderate Damage	Complete Damage
Ben Lick	10	0	0	Humphreys	9	0	0
Carroll	11	11	0	Lake	2	2	1
Cheatham	11	0	0	Lauderdale	7	7	7
Chester	10	10	0	Lawrence	18	0	0
Crockett	7	7	7	Leair	1	0	0
Davidson	37	0	0	McNairy	22	16	0
Deaon	8	3	0	Madison	22	22	0
Dickson	12	0	0	Maury	12	0	0
Dyer	6	6	6	Monktonery	17	0	0
Fayette	13	13	4	Obion	10	10	6
Gibson	12	12	9	Perry	7	0	0
Giles	12	0	0	Robertson	13	0	0
Hardenan	12	12	0	Shelby	73	73	96
Hardin	3	0	0	Shewart	5	1	0
Haywood	5	5	5	Tipton	10	10	10
Henderson	14	14	0	Vasne	10	0	0
Henry	17	10	0	Veahley	12	12	6
Holman	7	0	0	Williamson	22	0	0
Houston	2	0	0				

## *M&SC - URM SCHOOLS*

(Yumei Wong – ASCE Workshop/EERI Annual Meeting/2012 National Earthquake Conference)

Charleston, SC

- Scenario risk 220 schools with significant damage.
- Closed 6 schools due to seismic risk in 2011

Memphis

- 286 URM schools at risk (moderate or higher) – late awareness – current codes (MAEC study 7.7 Hwang and Lin 1997)

## URM Damage

*Moderate* damage or beyond:

- Building cannot be occupied post-quake
- Building is likely beyond economical repair
- Building is likely a total loss and needs to be demolished, perhaps as part of Emergency Response and Recovery with or without Owner concurrence

## Suggested priorities and conditions

Suggested priorities and conditions

- Funding is the key issue
- "Benefit/cost analysis" approach essential

## Suggested priorities and conditions

Suggested priorities and conditions

- Low value of typical URM does not support retrofit of most URM's (unless there are special interests and funding)
- Retrofit of schools and emergency response facilities is critical (or replace them)
- Important cultural or historic facilities must have \$\$ support for retrofit consistent with declared importance

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**QUESTIONS??**