# Displacement-based Seismic Design of Masonry Shear Wall Structures

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# important points of this presentation

- current seismic design does not always work well for shear-wall structures

- proposed displacement-based seismic design works well for shear wall structures
  - produces structures that behave reliably in strong earthquakes
  - more consistent and more transparent than current seismic design

# project participants

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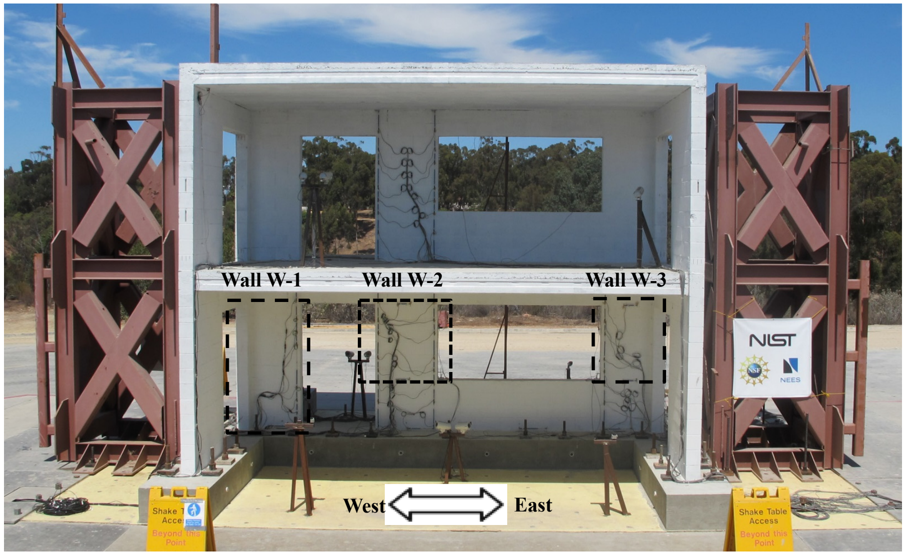
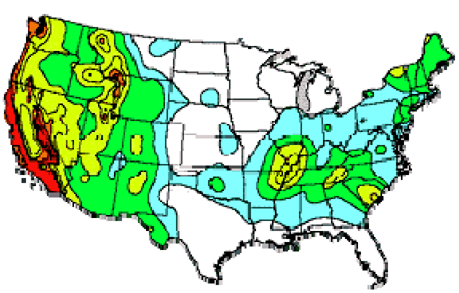
# contents of presentation

- review and examine current seismic design of masonry shear wall structures
- develop proposed displacement-based design
- check and validate displacement-based seismic design



# current force-based design approach …

- determine seismic design category (SDC) based on geographic location and soil
  - select from ASCE 7 list of permitted structural systems
  - special, intermediate reinforced masonry shear walls
  - prescribed detailing for each wall segment

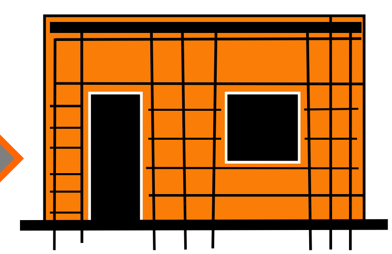


SDC

TABLE 12.2-1 DESIGN COEFFICIENTS AND FACTORS FOR SEISMIC FORCE–RESISTING SYSTEMS

| Seismic Force–Resisting System | ASCE 7 Section where Detailing Requirements are Specified | Response Modification Coefficient, $R^a$ | System Overstrength Factor, $\Omega_0^g$ | Deflection Amplification Factor, $C_d^b$ | Structural System Limitations and Building Height (ft) Limit[c] — Seismic Design Category: B | C | $D^d$ | $E^d$ | $F^e$ |
|---|---|---|---|---|---|---|---|---|---|
| A. BEARING WALL SYSTEMS | | | | | | | | | |
| 1. Special reinforced concrete shear walls | 14.2 and 14.2.3.6 | 5 | $2\frac{1}{2}$ | 5 | NL | NL | 160 | 160 | 100 |
| 2. Ordinary reinforced concrete shear walls | 14.2 and 14.2.3.4 | 4 | $2\frac{1}{2}$ | 4 | NL | NL | NP | NP | NP |
| 3. Detailed plain concrete shear walls | 14.2 and 14.2.3.2 | 2 | $2\frac{1}{2}$ | 2 | NL | NP | NP | NP | NP |
| 4. Ordinary plain concrete shear walls | 14.2 and 14.2.3.1 | $1\frac{1}{2}$ | $2\frac{1}{2}$ | $1\frac{1}{2}$ | NL | NP | NP | NP | NP |
| 5. Intermediate precast shear walls | 14.2 and 14.2.3.5 | 4 | $2\frac{1}{2}$ | 4 | NL | NL | $40^k$ | $40^k$ | $40^k$ |
| 6. Ordinary precast shear walls | 14.2 and 14.2.3.3 | 3 | $2\frac{1}{2}$ | 3 | NL | NP | NP | NP | NP |
| 7. Special reinforced masonry shear walls | 14.4 and 14.4.3 | 5 | $2\frac{1}{2}$ | $3\frac{1}{2}$ | NL | NL | 160 | 160 | 100 |
| 8. Intermediate reinforced masonry shear walls | 14.4 and 14.4.3 | $3\frac{1}{2}$ | $2\frac{1}{2}$ | $2\frac{1}{4}$ | NL | NL | NP | NP | NP |
| 9. Ordinary reinforced masonry shear walls | 14.4 | 2 | $2\frac{1}{2}$ | $1\frac{3}{4}$ | NL | 160 | NP | NP | NP |
| 10. Detailed plain masonry shear walls | 14.4 | 2 | $2\frac{1}{2}$ | $1\frac{3}{4}$ | NL | NP | NP | NP | NP |
| 11. Ordinary plain masonry shear walls | 14.4 | $1\frac{1}{2}$ | $2\frac{1}{2}$ | $1\frac{1}{4}$ | NL | NP | NP | NP | NP |
| 12. Prestressed masonry shear walls | 14.4 | $1\frac{1}{2}$ | $2\frac{1}{2}$ | $1\frac{3}{4}$ | NL | NP | NP | NP | NP |
| 13. Light-framed walls sheathed with wood structural panels rated for shear resistance or steel sheets | 14.1, 14.1.4.2, and 14.5 | $6\frac{1}{2}$ | 3 | 4 | NL | NL | 65 | 65 | 65 |
| 14. Light-framed walls with shear panels of all other materials | 14.1, 14.1.4.2, and 14.5 | 2 | $2\frac{1}{2}$ | 2 | NL | NL | 35 | NP | NP |

ASCE 7 list of permitted systems



prescriptive reinforcement

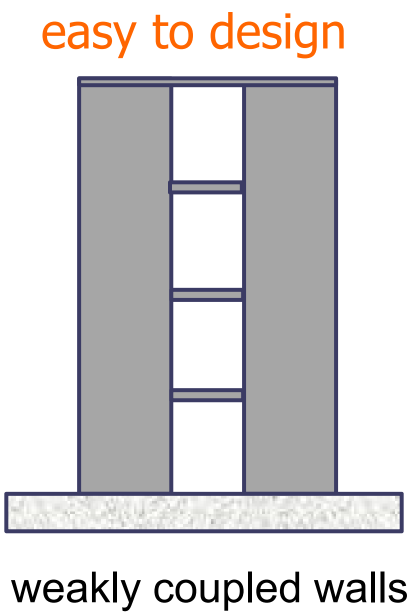
# … current force-based design approach

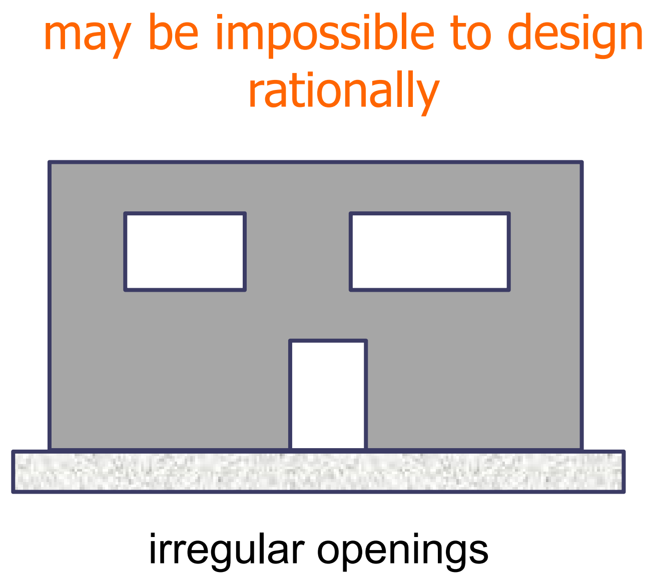
- based on structural system, assign seismic design factors (R, $C_d$, $\Omega_0$ )
  - design for elastic forces divided by *R*
  - design for elastic displacements multiplied by $C_d$
  - design elements that must remain elastic for elastic forces divided by *R* and multiplied by $\Omega_0$

| **Seismic-Load Resisting Systems** | ***R*** | $C_d$ | $\Omega_0$ |
|---|---|---|---|
| Special RM Load Bearing Shear Walls | **5** | **3 1/2** | 2 1/2 |
| Intermediate RM Load Bearing Shear Walls | 3 1/2 | 2 1/4 | 2 1/2 |

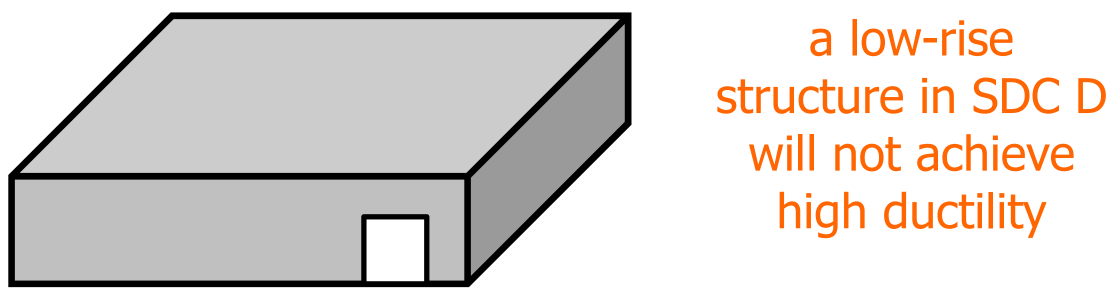
# force-based design does not always work well

- final behavior is not always consistent with design intent



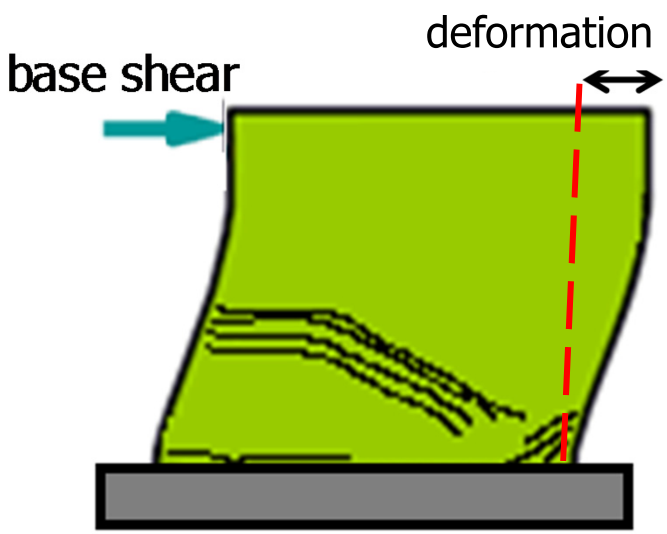



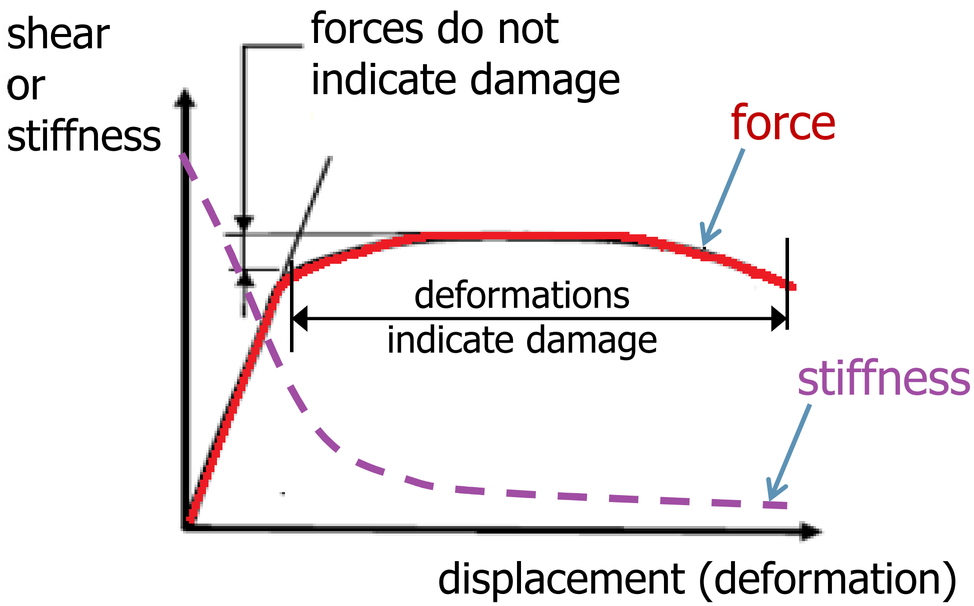

- ductility required by *R* and implied by detailing may not be available



# force-based design requirements are not reliable

- emphasis on forces instead of deformations is misguided

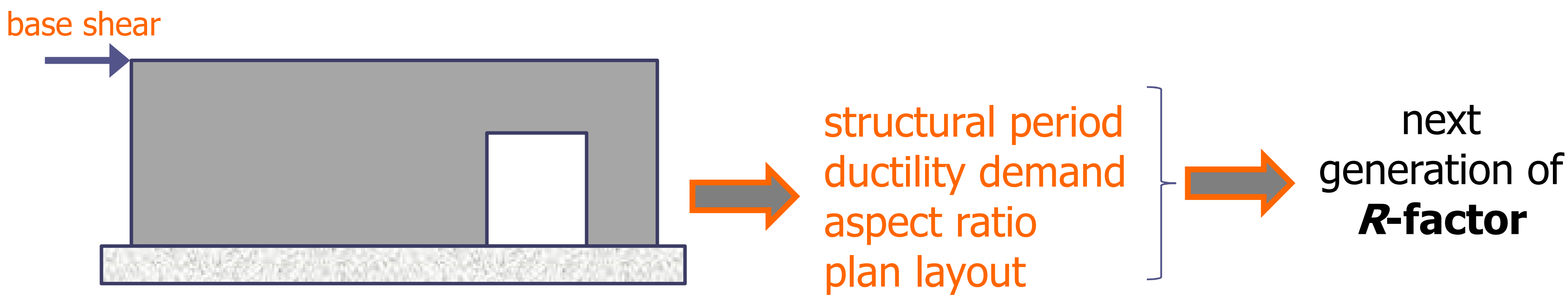


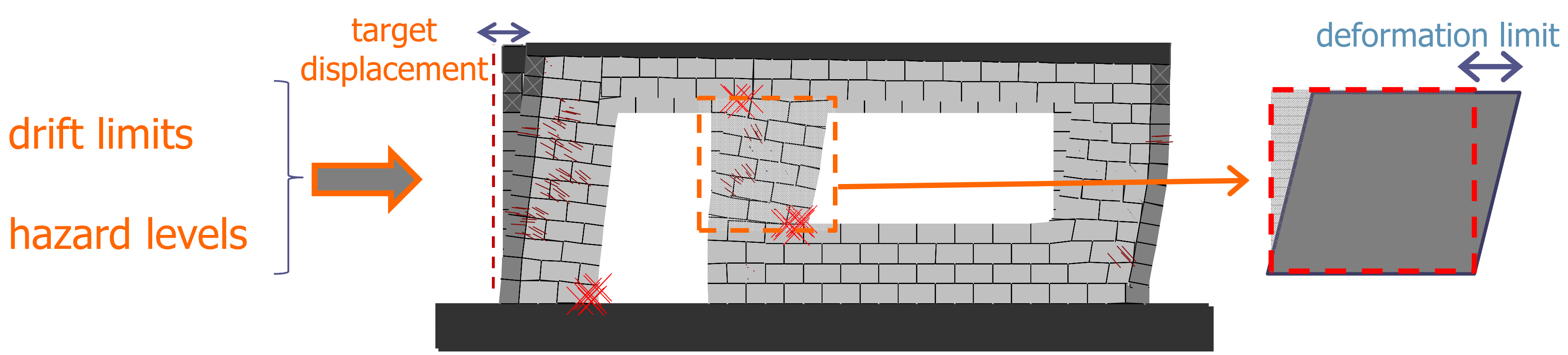

- force-based principle is not valid for short-period structures

# better design approaches?

- modified force-based
  - R-factor accounts for actual system behavior

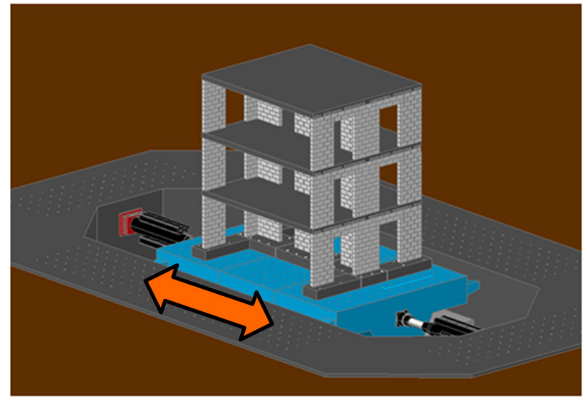


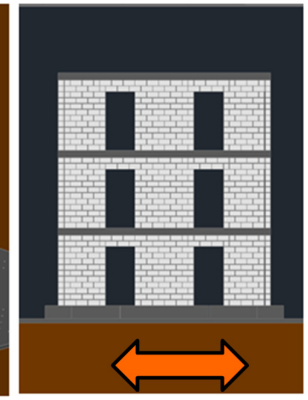

- displacement-based
  - emphasizes deformations
  - designer determines deformation limits



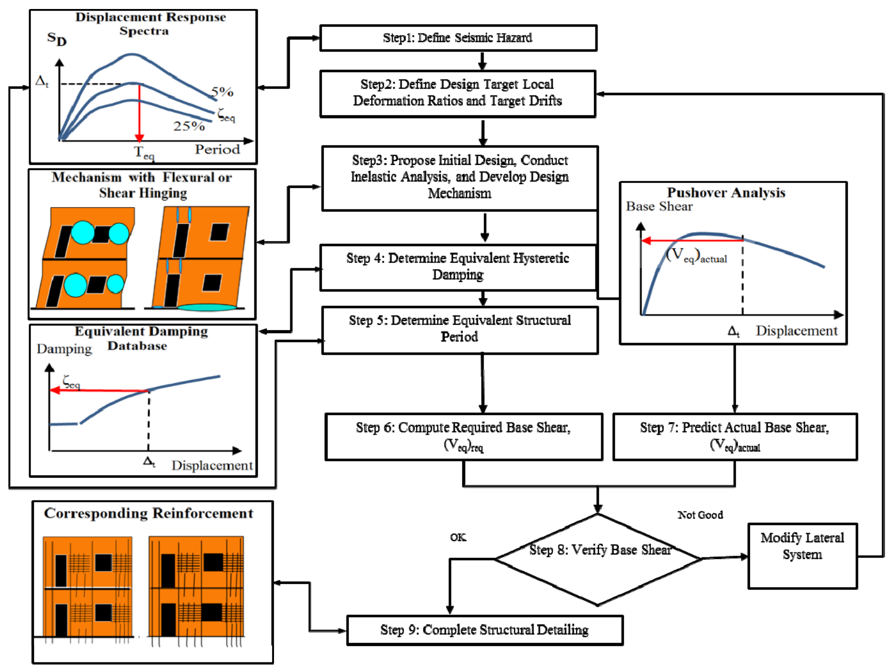
# 5 major tasks in this research . . .

- task 1- examined the behavior masonry buildings designed using force-based procedures



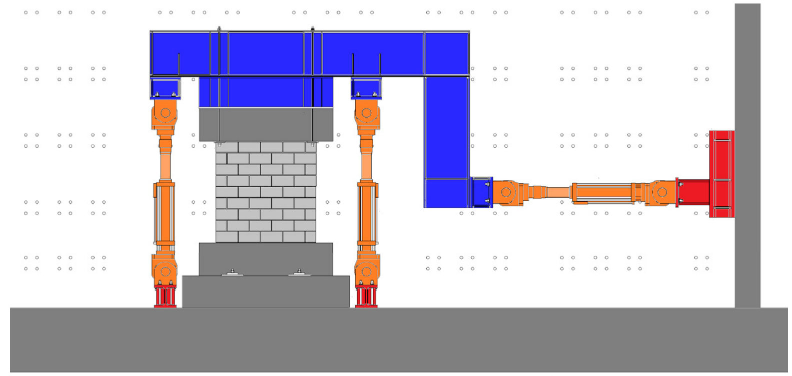


- task 2- developed displacement-based seismic design method

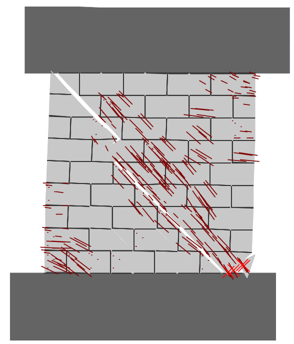


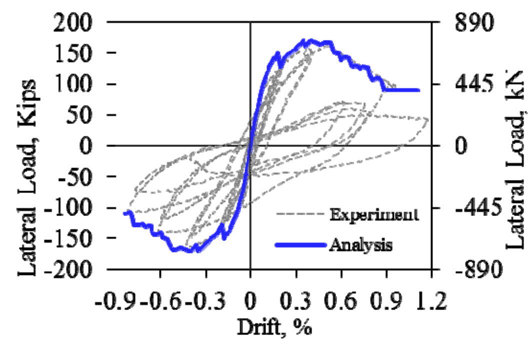
# . . . 5 major tasks in this research

- task 3- conducted cyclic-load tests on masonry wall segments at UT Austin and WSU

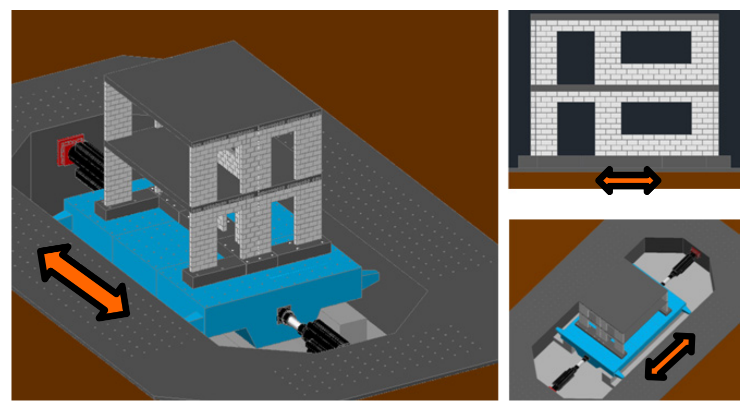


- task 4- improved analytical tools



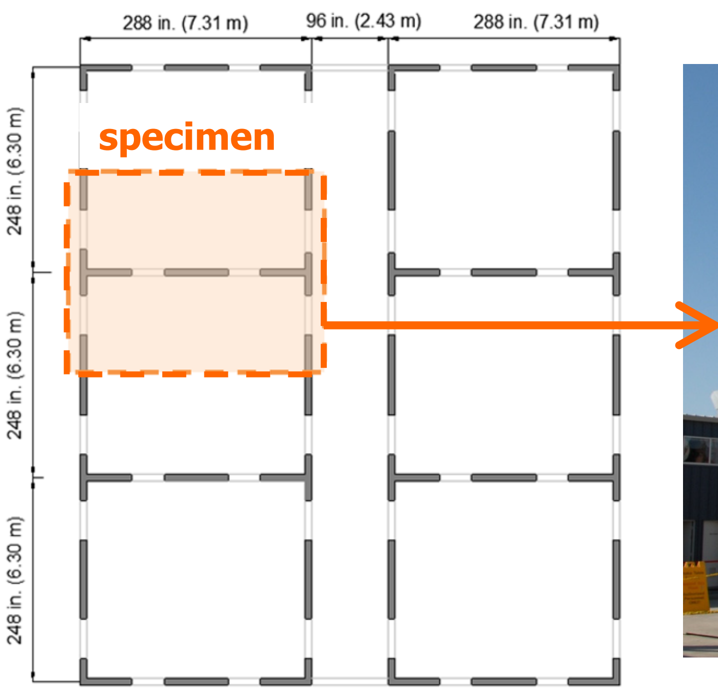



- task 5- validated displacement-based seismic design for masonry



# task 1- examine force-based procedures

- used shake-table tests to examine overall and local behaviors of masonry buildings
- evaluate the performance of special reinforced masonry walls
- assess the failure mechanism of a real wall system




plan view of prototype building

3-story specimen, UCSD-NEES

# 3-story specimen behaved well

- specimen was subjected to an extended series of ground motions

150 % Chi Chi 1990 ( 2 MCE )

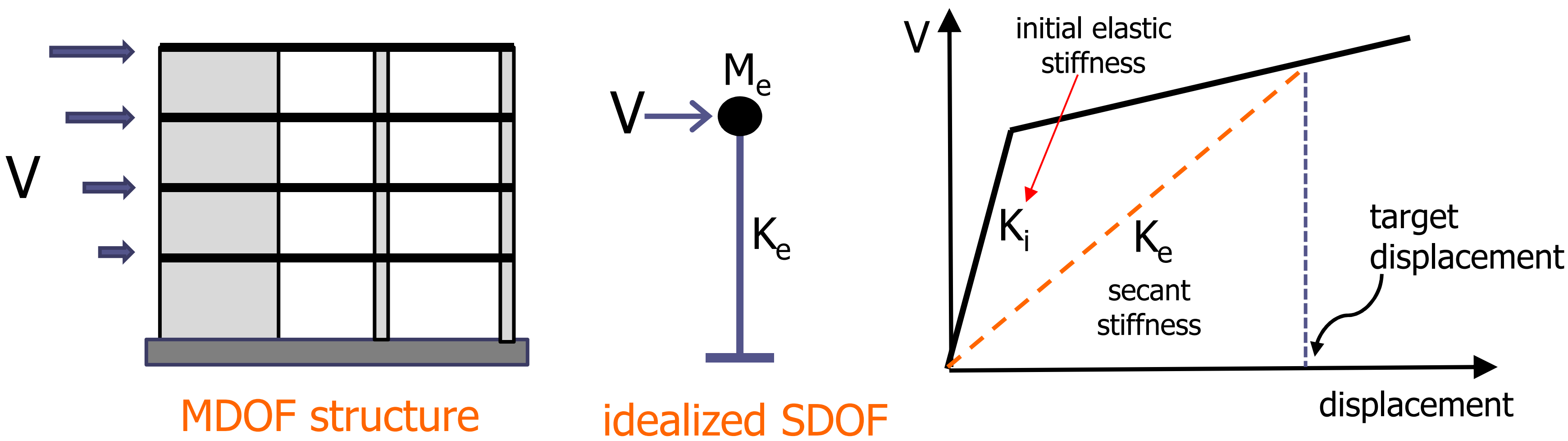
| Ground Motion | Scale Factor | Level of Excitation |
|---|---|---|
| Imperial Valley 1979 El Centro | 20% | |
| | 45% | |
| | 90% | |
| | 120% | DE |
| | 150% | |
| | 180% | MCE |
| | 250% | above MCE |
| Imperial Valley 1940 El Centro #5 | 300% | |
| Northridge 1994 Sylmar | 125% | MCE |
| | 160% | 1.25 MCE |
| Chi Chi 1999 | 150% | 2.0 MCE |


Design Earthquake (DE),10% in 50 years

Maximum Considered Earthquake (MCE), 2% in 50 years

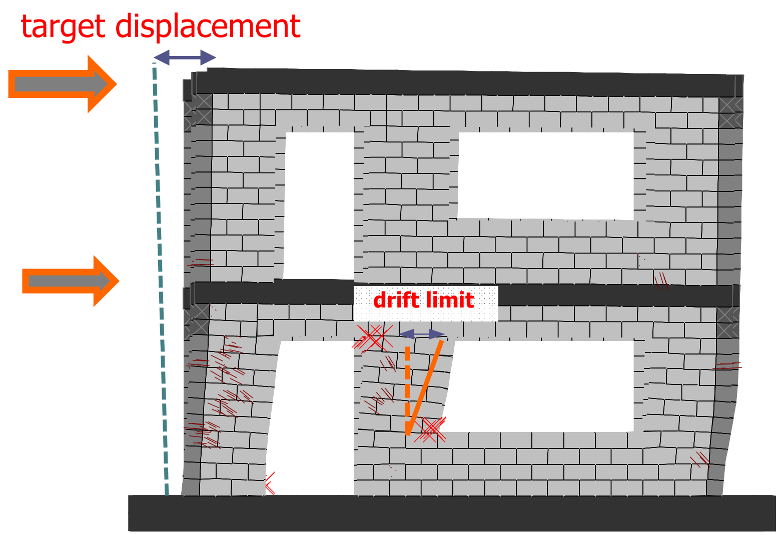
# task 2- develop displacement-based design

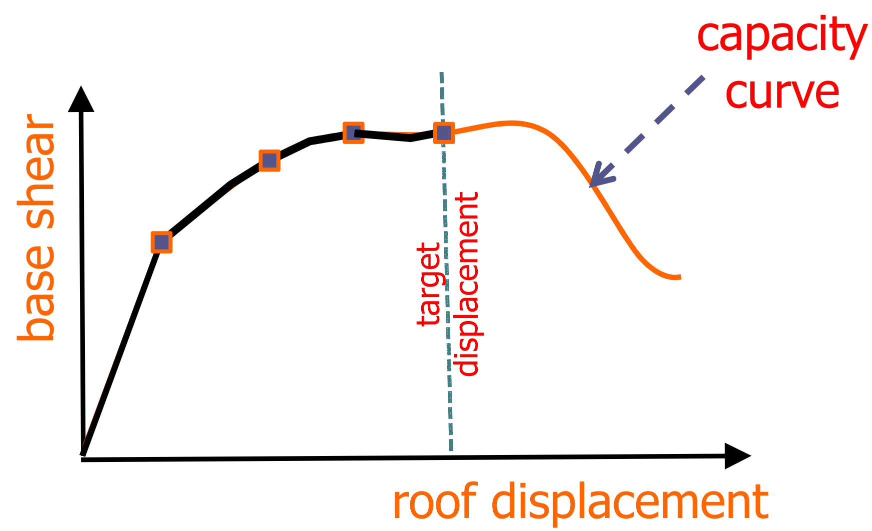
- based on achieving specified deformation limits under selected seismic hazard levels
- fundamental difference between force-based and displacement-based design



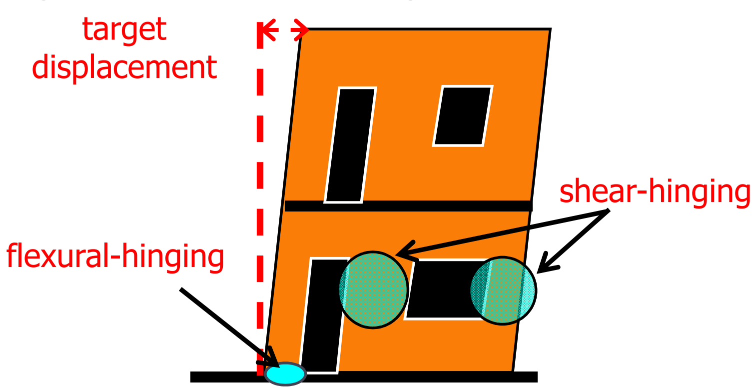
# technical basis for displacement-based method

- select a reasonable target mechanism for each hazard level

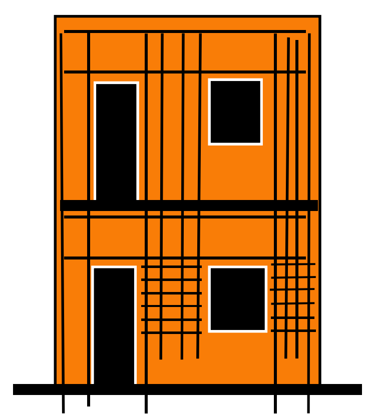



- identify the inelastic deformation demands and adjust strength or detailing



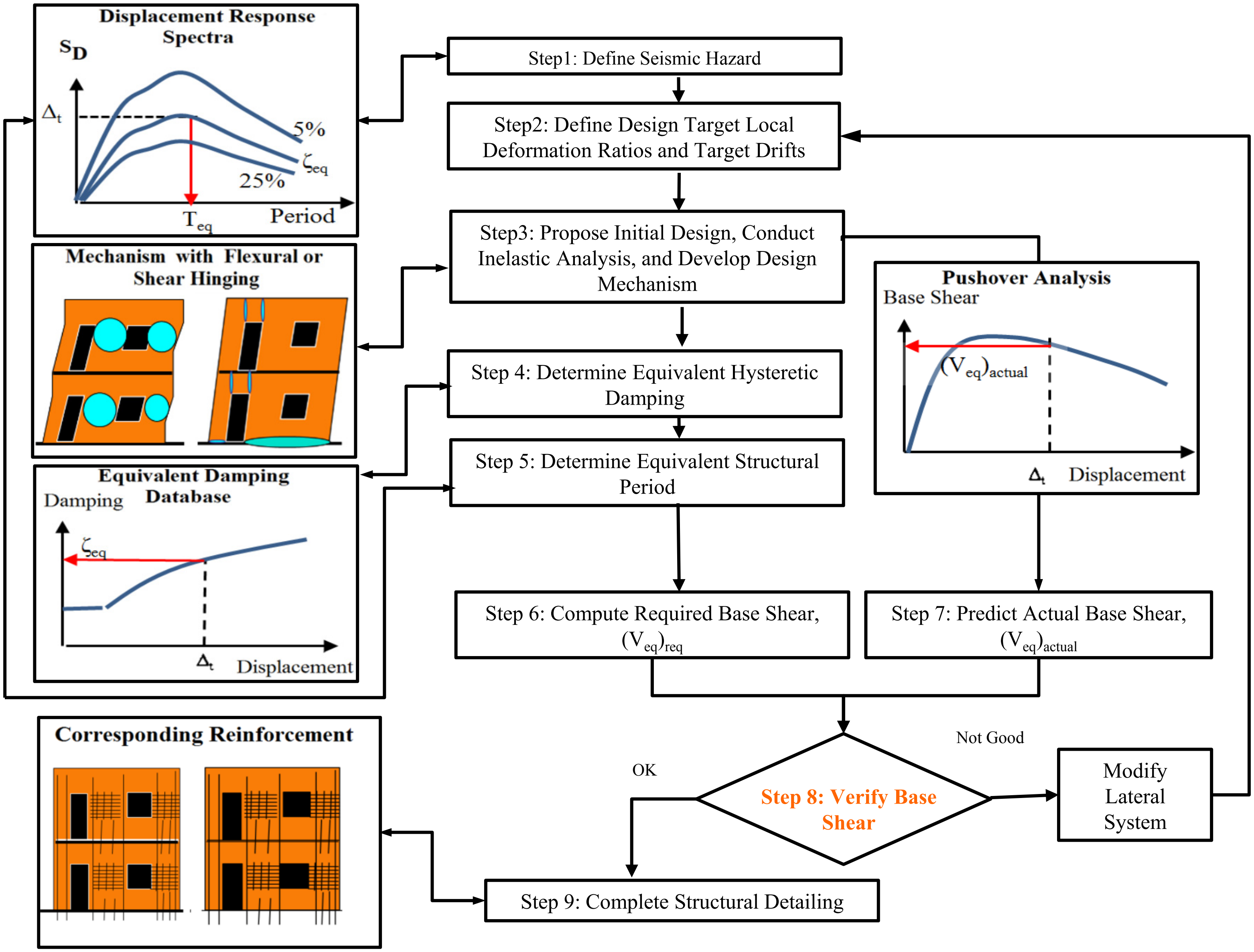

hinging regions



corresponding reinforcement

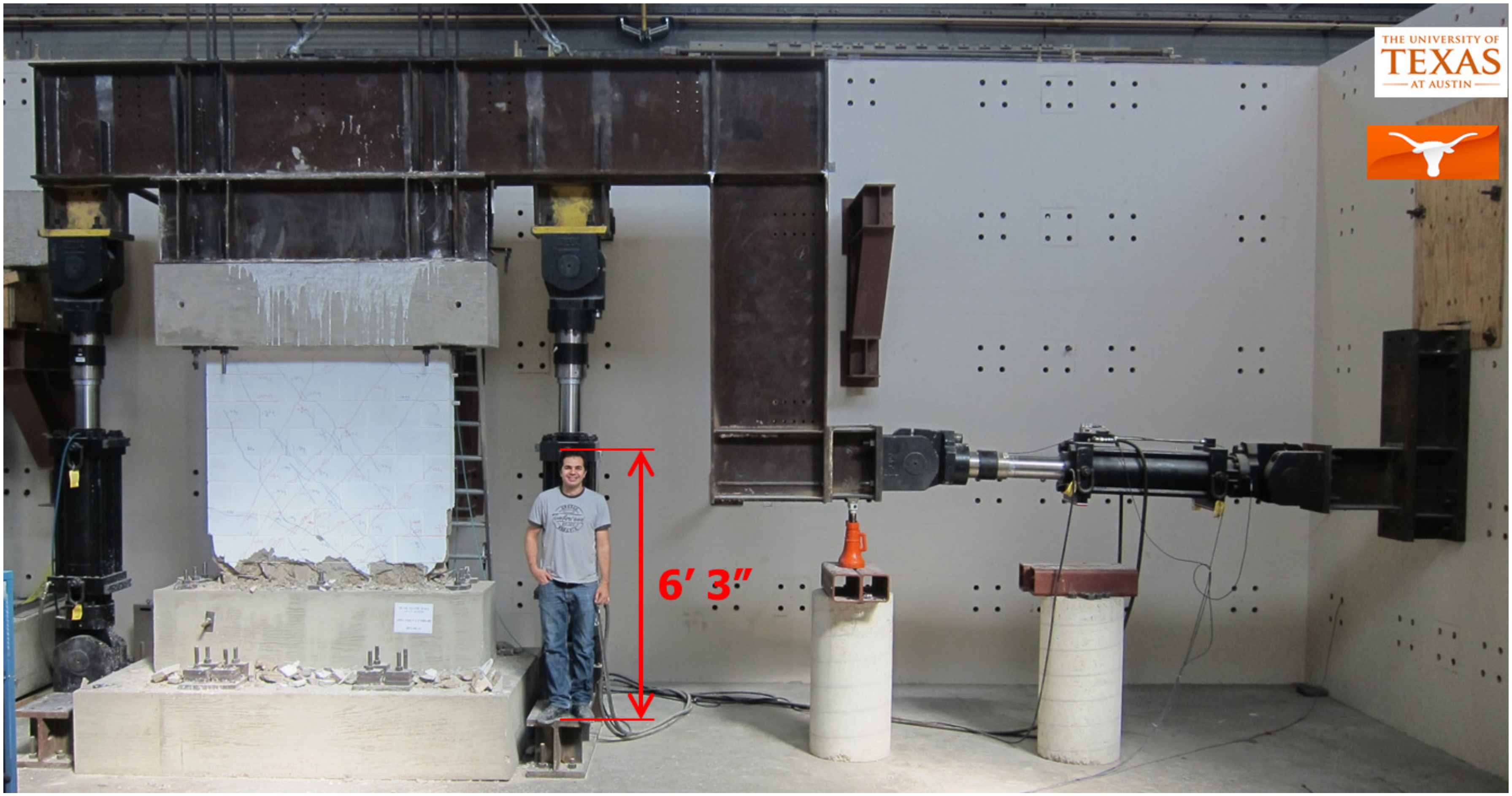
reinforce for sufficient inelastic deformation capacity in hinging regions

# fundamental steps



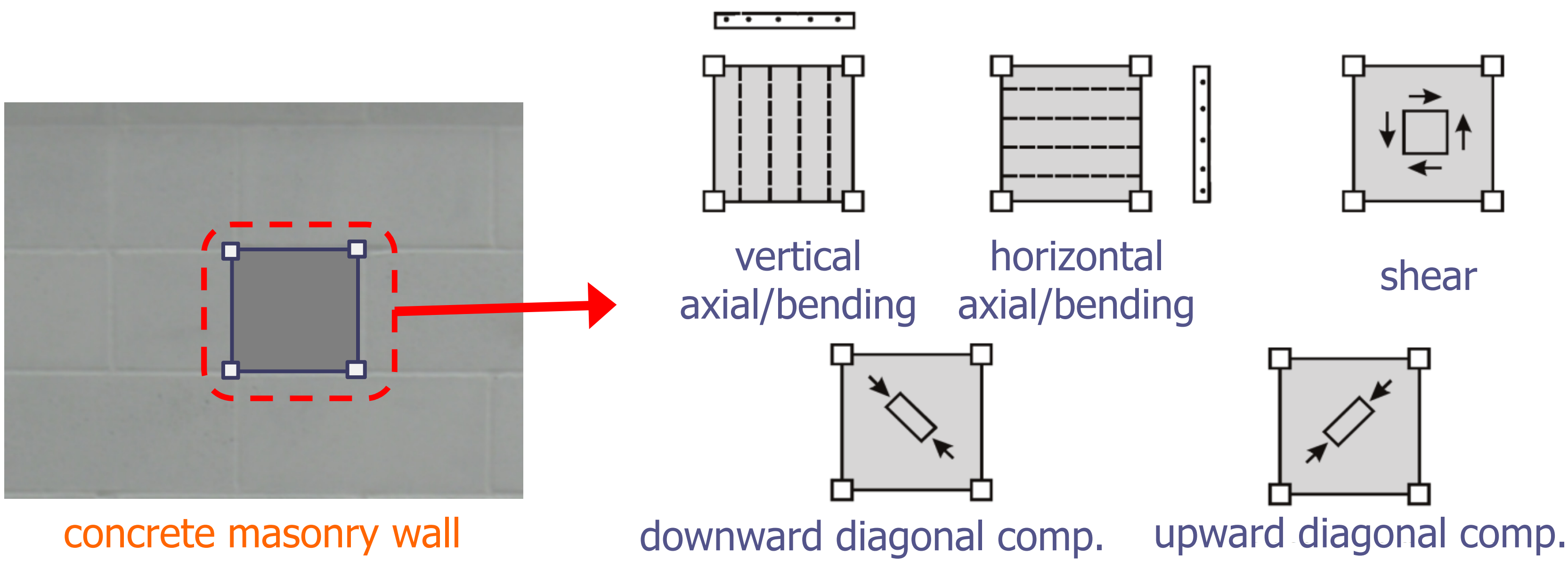
# task 3- conduct cyclic-load test of shear-walls

- designed and conducted cyclic-load tests of 41 masonry shear-walls at UT Austin and WSU



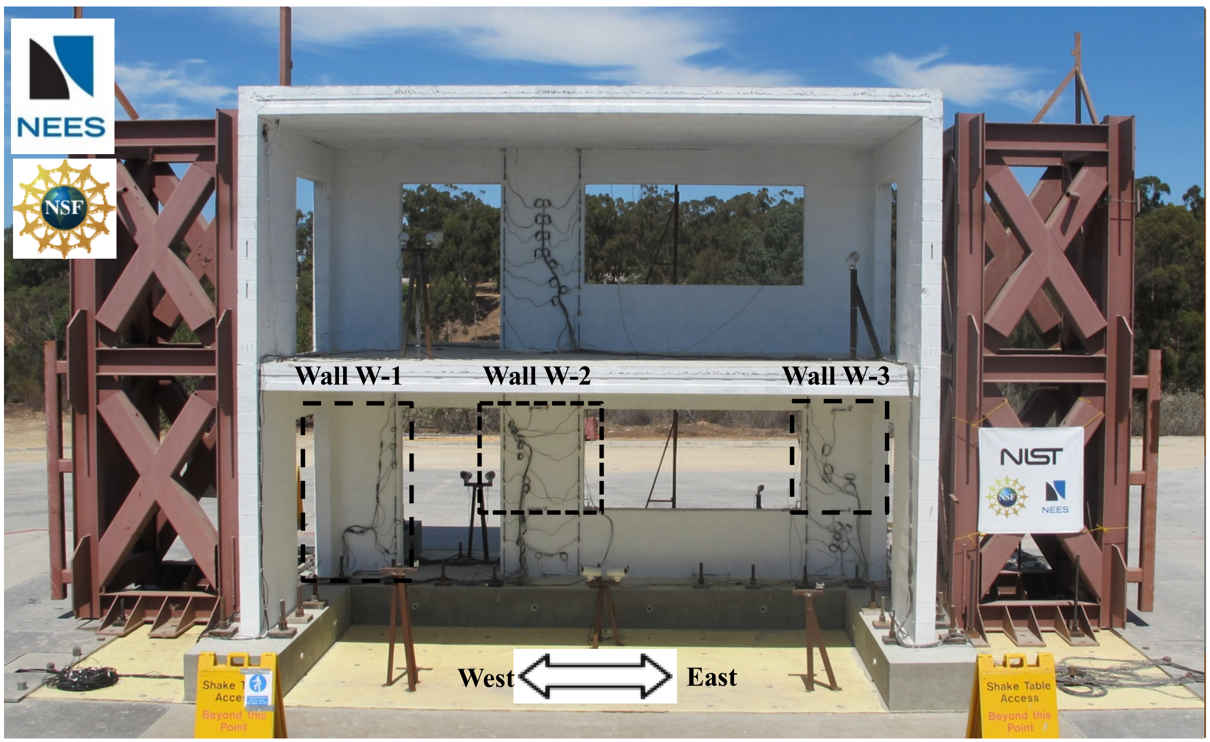
# task 4- improved analytical tools

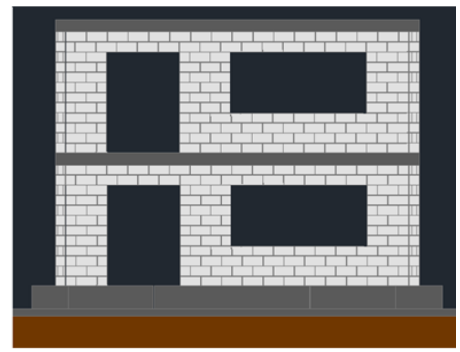
- predict nonlinear resistance and failure behavior
- predict local and global responses and deformations
- different modeling approaches were considered
  - nonlinear "macro" models, PERFORM 3D "General Wall Element"

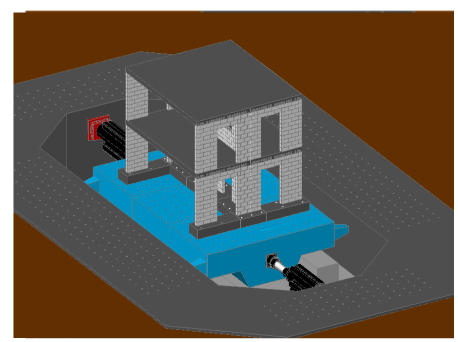


# task 5- validation of displacement-based design

- application of proposed displacement-based design and analytical tool
- a full-scale two-story reinforced masonry shear-wall system, complex geometry of openings

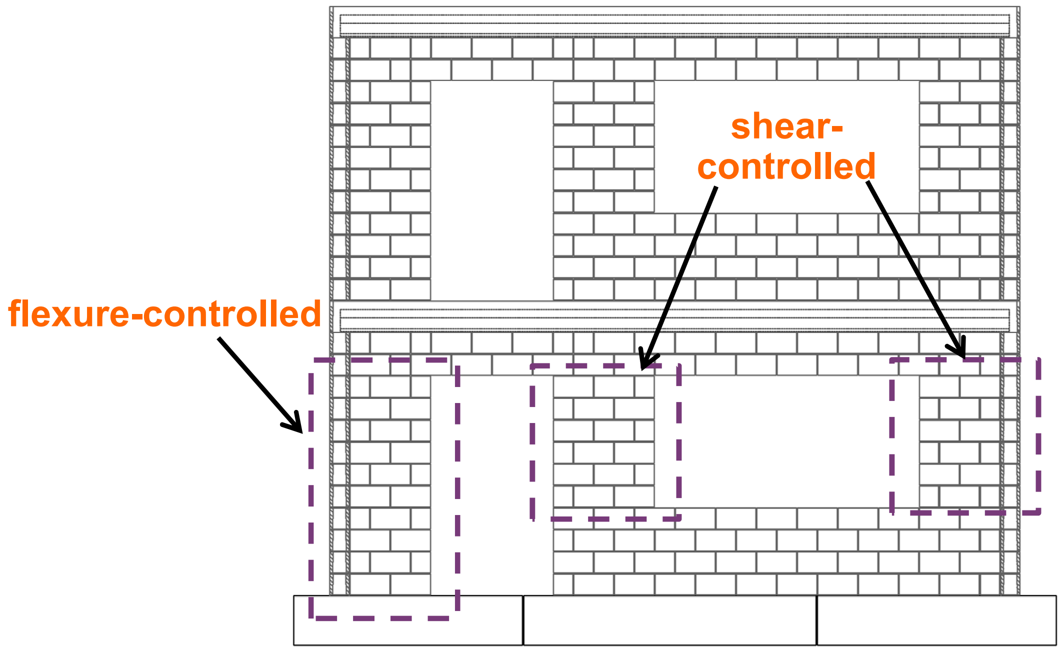




# select seismic hazard levels and target drifts

| seismic hazard Level | damage state | deformation limits | | corresponding inter-story drift ratios |
|---|---|---|---|---|
| | | flexure-controlled wall segments | shear-controlled walls segments | |
| Design Earthquake (DE ) | Safety Damage State | 0.8 % | 0.5 % | 0.3 % |
| Maximum Considered Earthquake (MCE) | Collapse Damage State | 1.5 % | 1.0 % | 0.6 % |

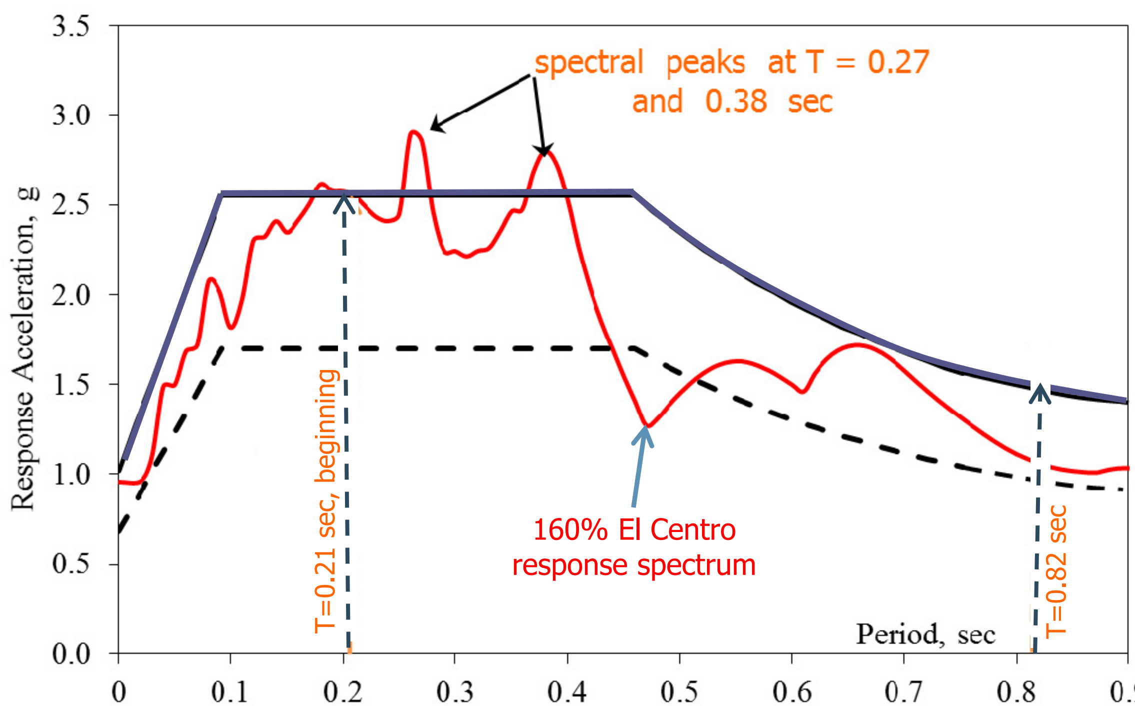


# shake table test of 2-story specimen




- specimen was subjected to an extended series of ground motions

| order | ground motion |
|---|---|
| 1 | 30% El Centro 1979 |
| 2 | 43% El Centro 1979 |
| 3 | 86% El Centro 1979 |
| 4 | **108% El Centro 1979** |
| 5 | 145 % El Centro 1979 |
| 6 | **160% El Centro 1979** |



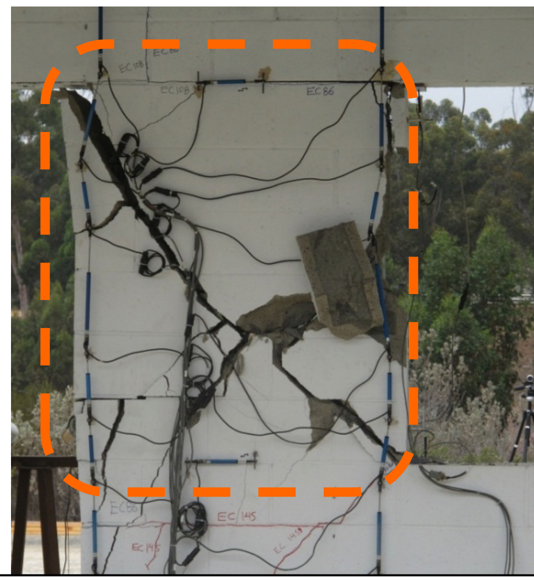
# shake-table test of specimen above MCE

- specimen successfully resisted repeated ground motions up to MCE

# measured vs. predicted responses

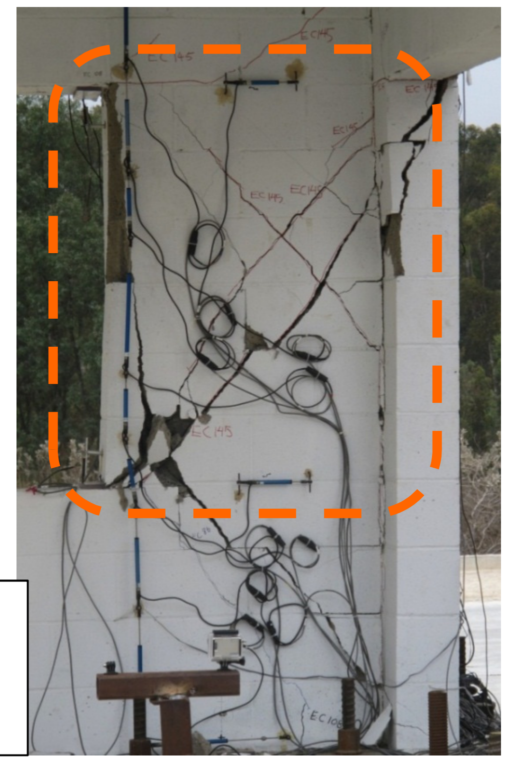
- walls exceeded expected deformation capacities

**Wall W - 1** was flexure - dominated , exceeded **1%** drift ratio



**Wall W - 2** was shear - dominated , exceeded **2%** drift ratio

**Wall W - 3** was shear - dominated one way , flexure - dominated the other way , exceeded **1%** drift ratio



# important points of this presentation

- current force-based seismic design does not always work well for reinforced masonry shear-wall structures

- proposed displacement-based seismic design works for masonry shear wall structures
  - it produces structures that behave reliably in strong earthquakes
  - it is more consistent and more transparent than current force-based seismic design