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Cyclic Inelastic Analysis of RC Shear Walls and Plates

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Framework

Performance based design methodology

Seimic Hazard Analysis

Response Analysis

Damage Analysis

Loss Analysis

Framework

Performance based design methodology

Seimic Hazard Analysis

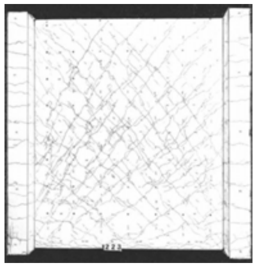
Response Analysis

Damage Analysis

Loss Analysis

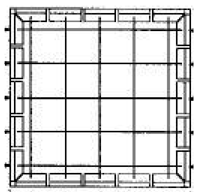
Background

Experimental Investigations



Maier and Thürlimann 1985

Stevens et al. 1991

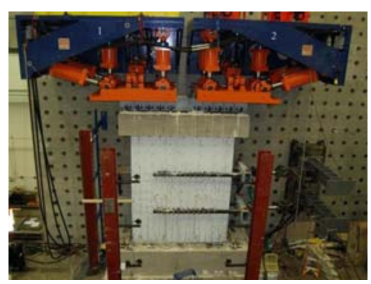


Mansour and Hsu 2005

JNES 2006

Recent Tests by NEES

Univ. of Michigan



Univ. of Illinois

Univ. of Minnesota

Univ. of CA Berkeley

Existing Models

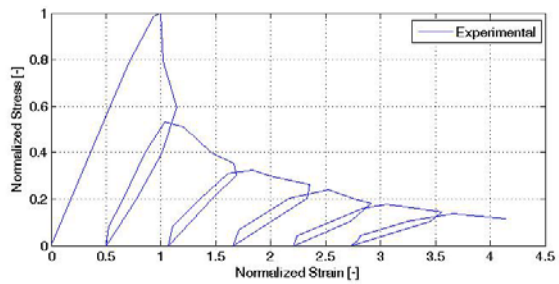
- They can be subdivided in two categories:
  - Plane stress models for all types of RC elements
  - Fiber beam models for particular RC members
  - Some incorporated in commercial software
- Plane stress FE models seem to have issues of accuracy for general RC stress states, computational efficiency for large scale, or robustness
- Fiber beam models with shear appear to be limited to cases of moderate shear demand

Objectives of the Current Work

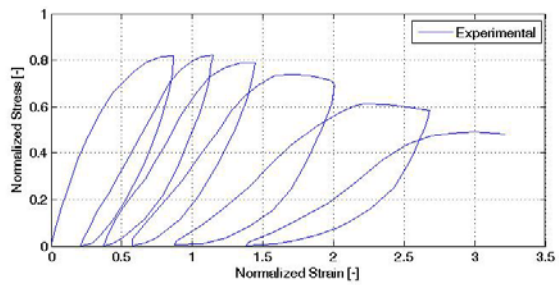
- The current work aims at developing an efficient membrane and plate model for the simulation of RC structural elements under cyclic loads with the following features:
  - general and suitable for several types of RC elements under high shear with normal force and bending moment
  - accurate and computationally efficient to be suitable for the earthquake analysis of large structures
  - plastic and damage evolution laws describe plastic strain and stiffness degradation at the material level
- The membrane and plate model is implemented in a general purpose platform so that it can be combined with other finite elements, such as beam or column elements, for modeling an entire structure

Experimental Evidences in Uniaxial Conditions

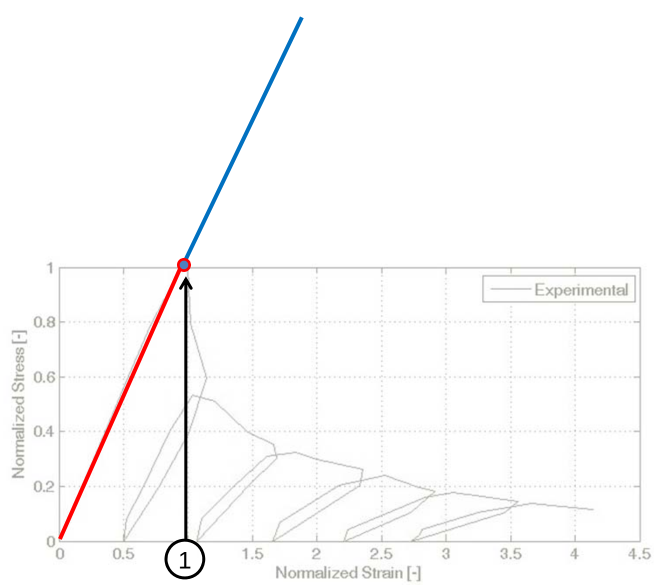
Tension



Compression



Envelope



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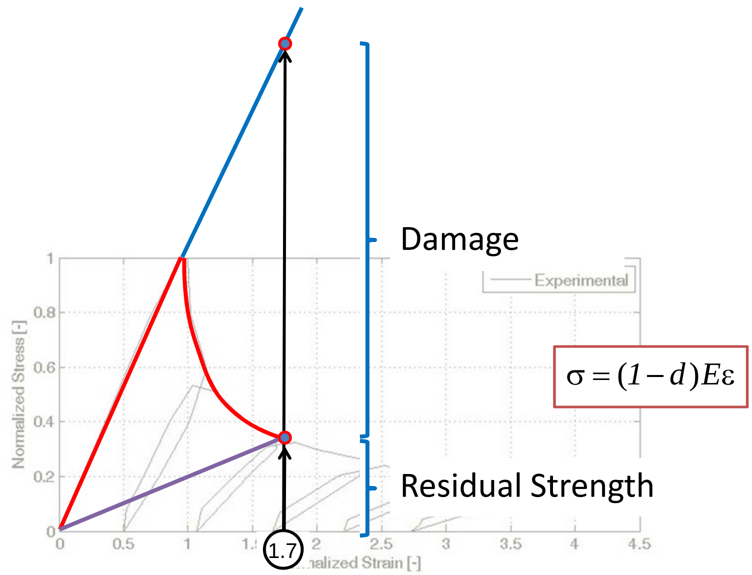
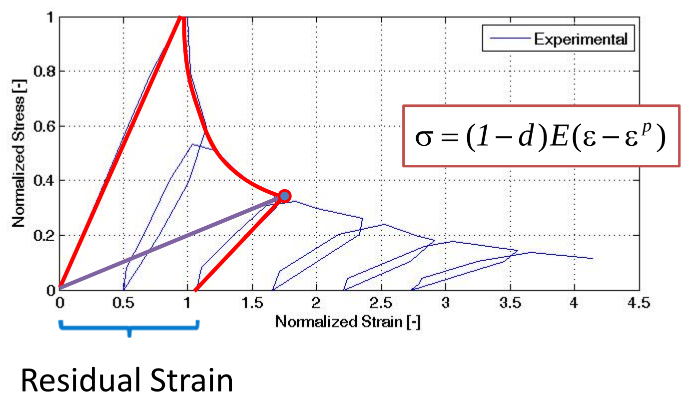


Cyclic Loading



Features of the Presented Model

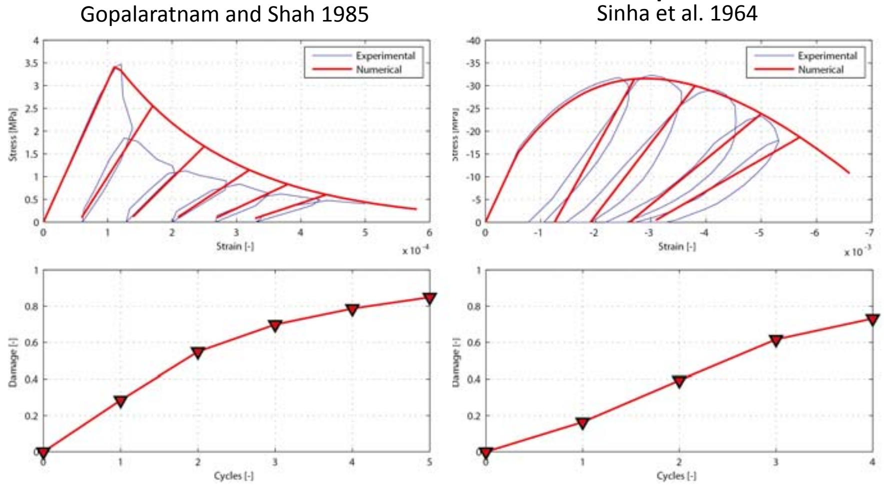
- The features of the presented concrete constitutive law are:
  - it is a general three-dimensional law that can be used with all types of finite elements
  - both tensile and compressive damage modes are taken into account by means of two scalar damage parameters
  - a simplified plasticity evolution law represents the residual strains for all stress states
  - it uses a straight forward algorithm for material state determination
- The material parameters are calibrated once from experimental data and used consistently in applications (no parameter "tuning")
- The 3d concrete law is constrained to a plane stress state for the RC membrane element
- The out-of-plane stress of the 3D concrete law is condensed out for use with the RC plate element

Plastic-Damage Concrete Model

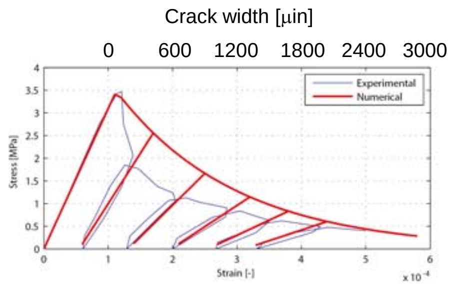
Separate scalar damage parameters for tension and compression; these arre coupled under multi-axial stress states

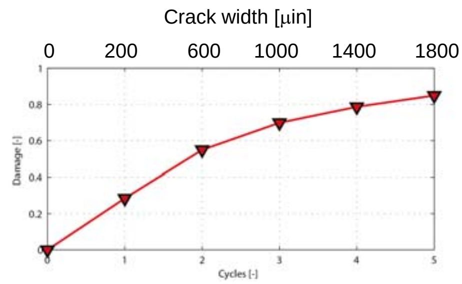
Tension
Gopalaratnam and Shah 1985

Compression
Sinha et al. 1964



Crack Width



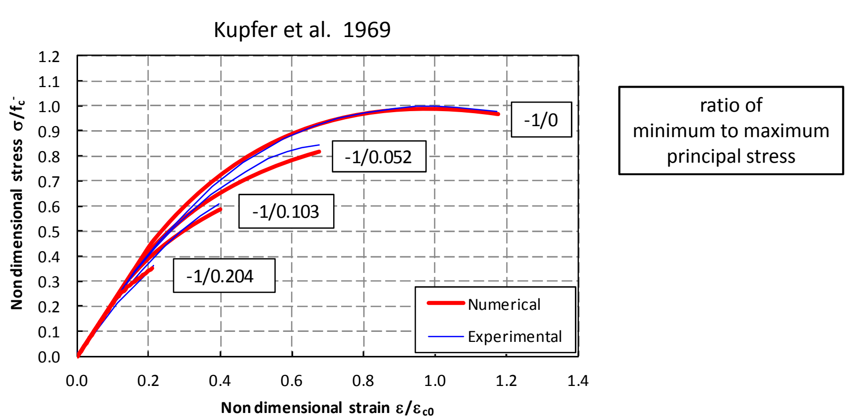


- The correlation between average concrete tensile strains, tensile damage parameter and crack width can be derived from experimental measurements
- The correlation holds only for micro-cracks; this may be suitable for structural durability studies
- For the estimation of large crack widths under seismic excitations the reinforcing steel strains should be used

Multi-Axial Conditions

The concrete constitutive law is developed in three-dimensions and can be used with all types of finite elements

For the analysis of RC shear walls the most significant biaxial stress state is tension-compression



RC Membrane Model

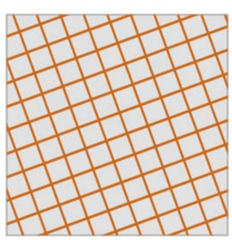
The 3d concrete law is constrained to a plane stress state

Concrete

Uniaxial Steel layer

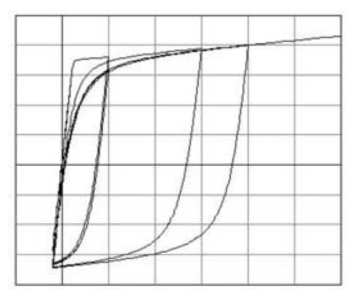
RC Membrane Model

The 3d concrete law is constrained to a plane stress state



Reinforced Concrete

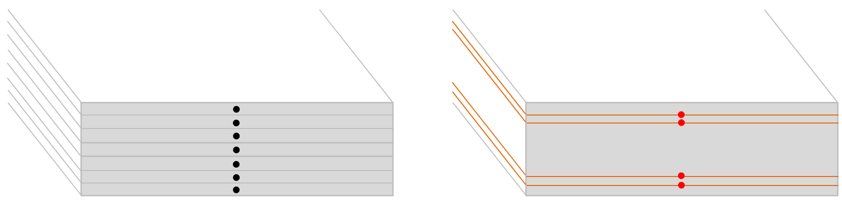
Uniaxial steel constitutive relations



Filippou et al. (1983)

RC Plate Model

The out-of-plane stress of the 3d concrete law is condensed



numerical integration over the thickness: e.g. 7 mid-points

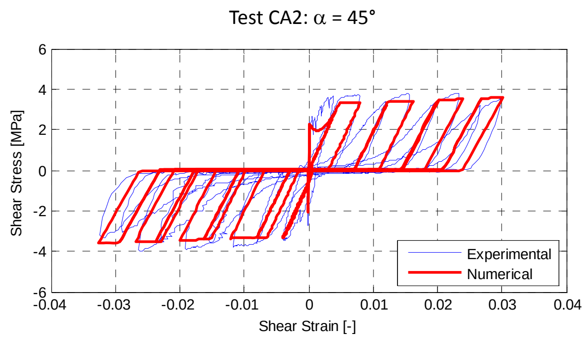
Insertion of reinforcing layer at actual locations e.g. 2 reinforcement nets

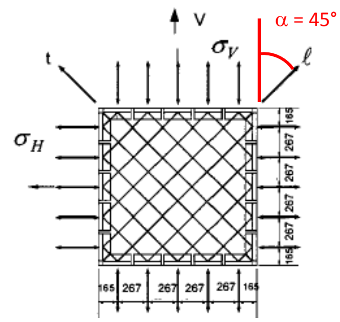
Correlation with experiments

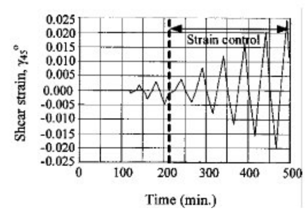
The material parameters are calibrated once from experimental data on the concrete material and used consistently in the correlation studies (no parameter "tuning")

RC Panels

Mansour and Hsu (2005)

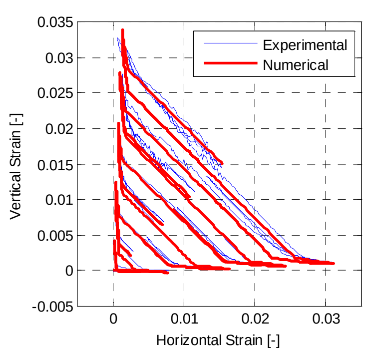


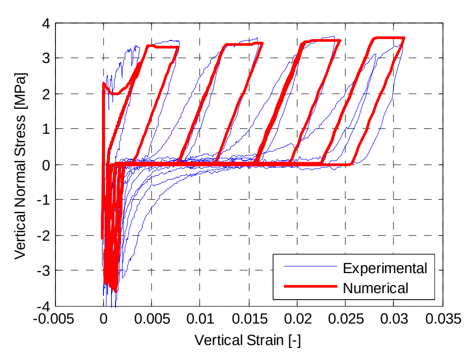




RC Panels

vertical vs. horizontal strain and vertical normal stress vs. strain

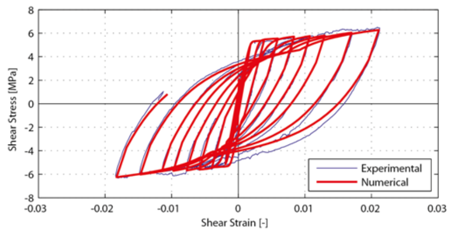


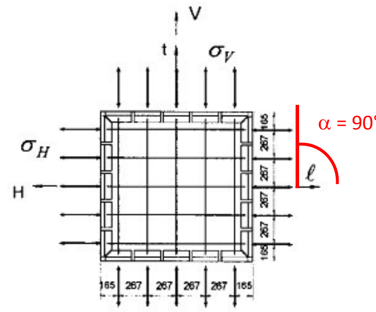


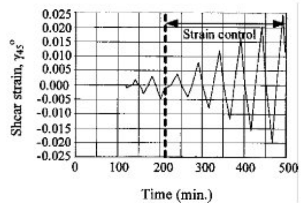
RC Panels

Mansour and Hsu (2005)

Test CE3: $\alpha = 90°$

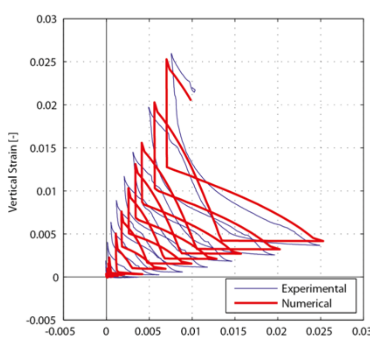


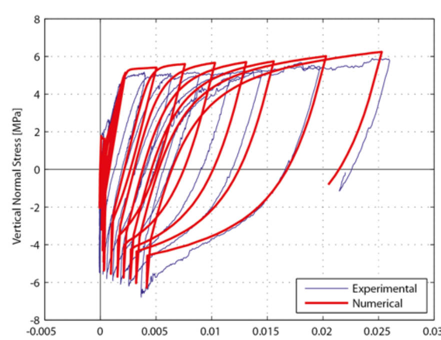




RC Panels

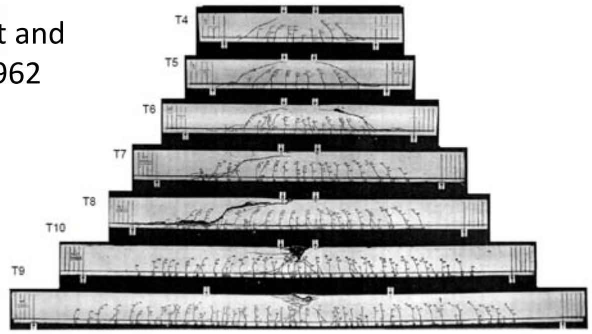
vertical vs. horizontal strain and vertical normal stress vs. strain

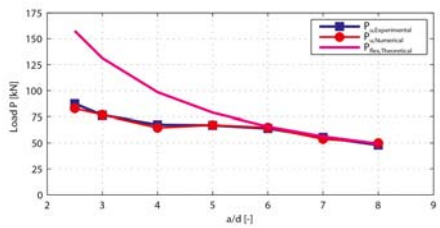




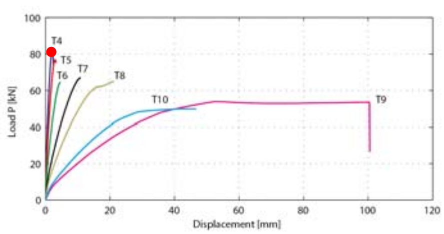
RC Beams w/o Shear Reinforcement

Leonhardt and
Walter 1962

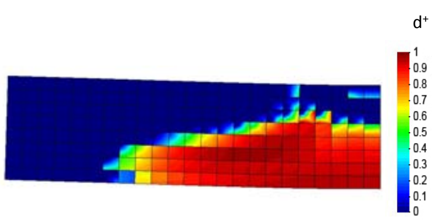


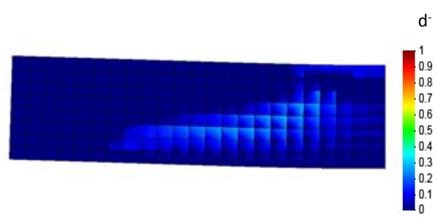


Shear Failure

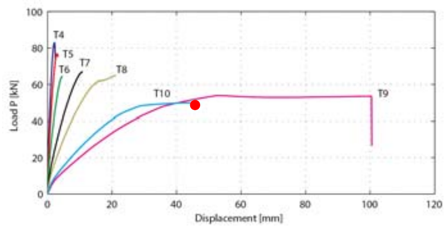


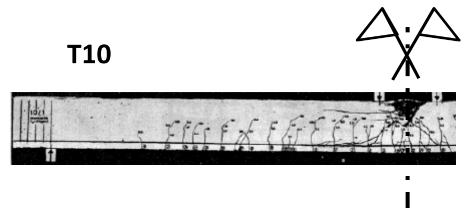
T4

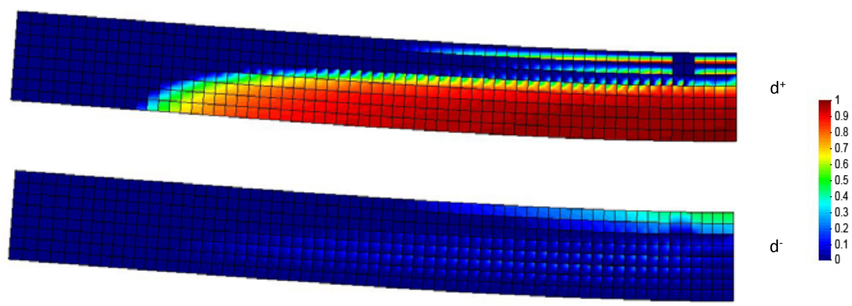




Flexural Failure

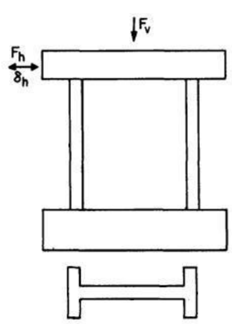




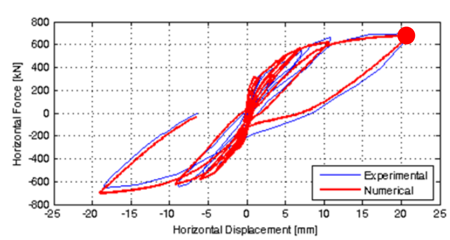


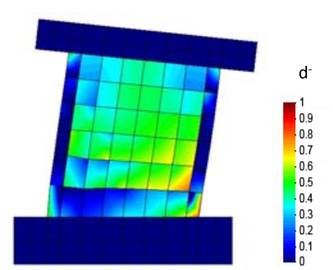
RC Planar Shear Walls

RC Panel with boundary elements (Maier and Thürlimann 1985)



Height: 1200 mm ≈ 47 in
Aspect ratio: 1
Thickness: 100 mm ≈ 4 in
Vertical reinforcement ratio: 1.16%
Horizontal reinforcement ratio: 1.03%
Axial load: 416 kN ≈ 94 kips

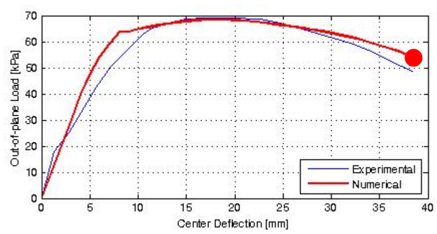




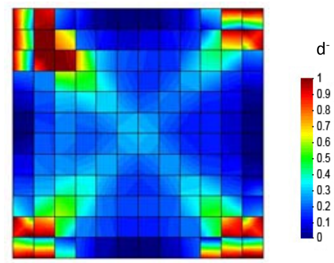
RC Plates

RC Plates under combined
in-plane and lateral loads
(Ghoneim and MacGregor 1994)

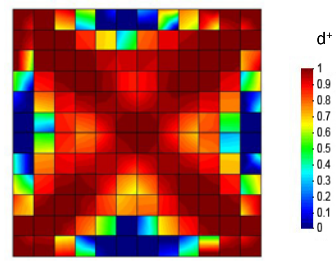
Size: 72 in ≈ 1829 mm
Thickness: 2.65 in ≈ 67.4 mm
Isotropic reinforcement ratio: 0.77% in two grids
In-plane biaxial compression: 1400 psi ≈ 9.8 MPa
Transverse load carrying capacity: 1440 psf ≈ 69 kPa



Compressed layer



Tensed layer

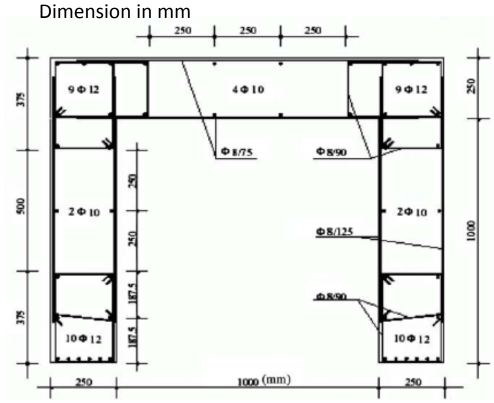


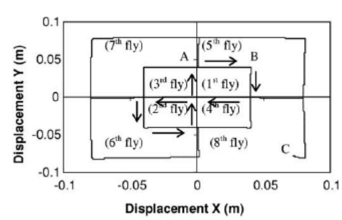
RC U-shaped Shear Wall (1)

U-shaped shear wall
(Pégon et al., JRC Ispra, 2000)

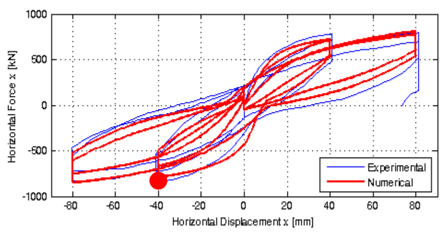
Height: 3.6 m ≈ 11 ft 10 in
Axial load: 2MN ≈ 450 kips

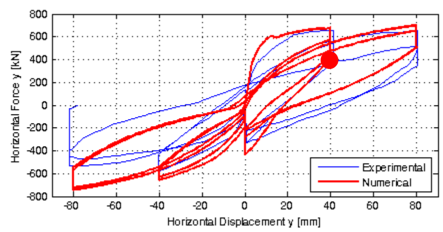
Dimension in mm

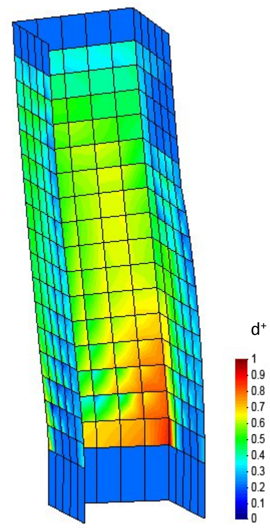




RC U-shaped Shear Wall (2)







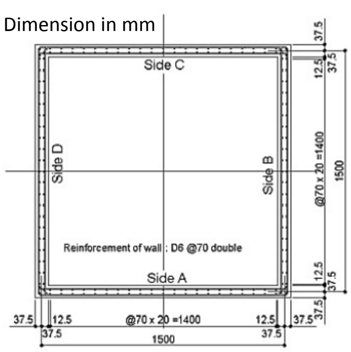
4.45 kN ≈ 1 kips

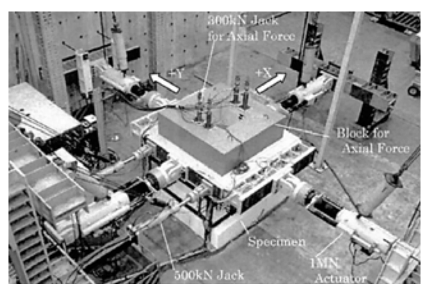
RC Box Shear Wall (1)

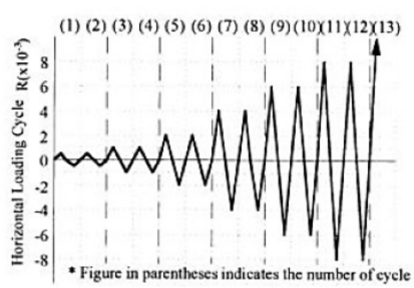
Box-shaped shear wall
(Japan Nuclear Energy Safety Organization 2006)

Height: 1.0 m ≈ 3 ft 3 in
Axial load: 670 kN ≈ 150 kips

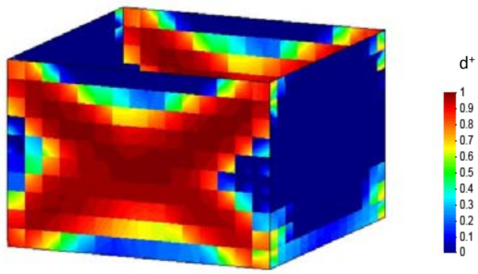
Dimension in mm

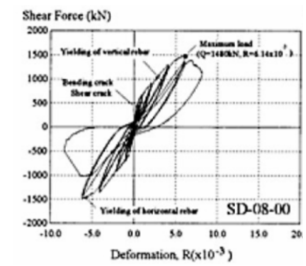


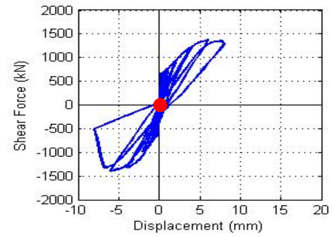




RC Box Shear Wall (2)

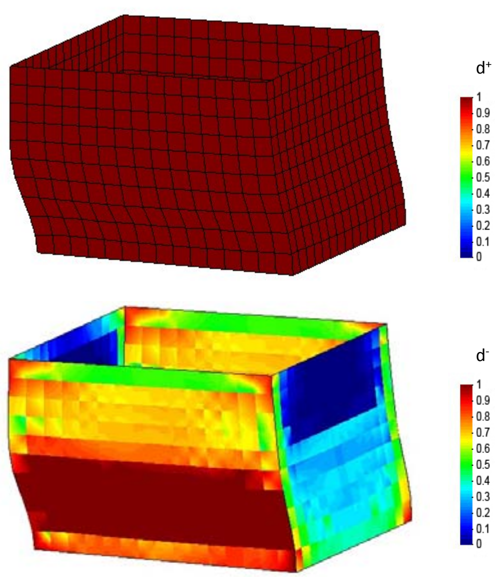


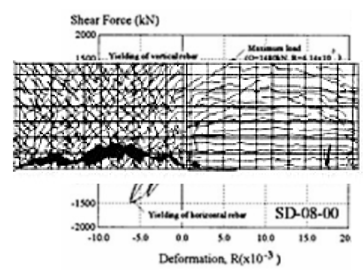


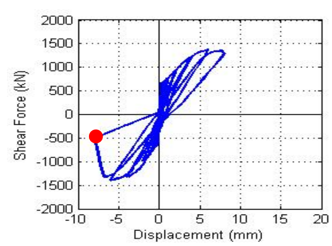


4.45 kN ≈ 1 kips

RC Box Shear Wall (2)







Conclusions (1)

- Excellent agreement with correlation studies was observed for different specimens
  - concrete cylinders and prisms under cyclic loads (uniaxial stress states)
  - concrete prisms under combined tension and compression
  - RC panels under cyclic shear loads (uniform stress state)
  - beams without shear reinforcement (complex stress states)
  - planar, U- and box-shaped RC shear walls under axial force and cyclic lateral loads (complex stress states)
- The tensile and compressive damage parameters of the concrete constitutive law permit the interpretation of observed experimental behavior in regard to
  - accumulated structural damage
  - failure mechanisms
  - tensile cracks location and orientation
  - micro-cracks width
  - concrete compression strut location and orientation

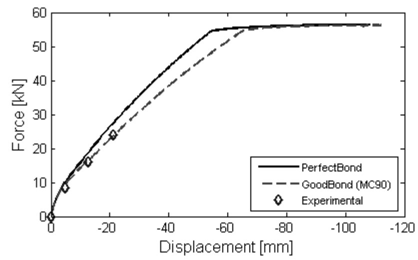
Conclusions (2)

- Neglecting the dowel action and bond-slip of reinforcing bars does not seem to affect the agreement of the model with the experimental data regarding strength. However,
  - some discrepancy in unloading and reloading is evident
  - the dowel action of the reinforcement is statistically significant in affecting the unloading stiffness the more the orientation of the reinforcing bars deviates from the principal stress directions
- The robustness and consistency of the proposed RC membrane and plate model over a range of structural elements under different stress states holds significant promise for its use as reliable tool for the simulation of structural systems under earthquake excitations

Current Work (1)

Influence of bond-slip and Bond degradation

T10



Current Work (2)

Shear Deficient Columns