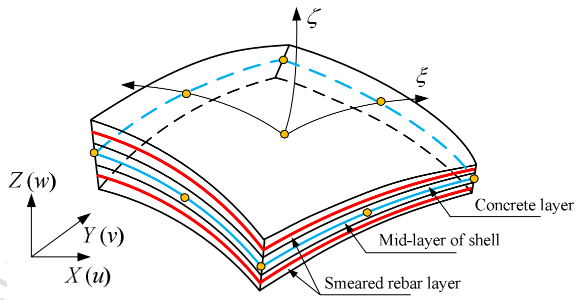
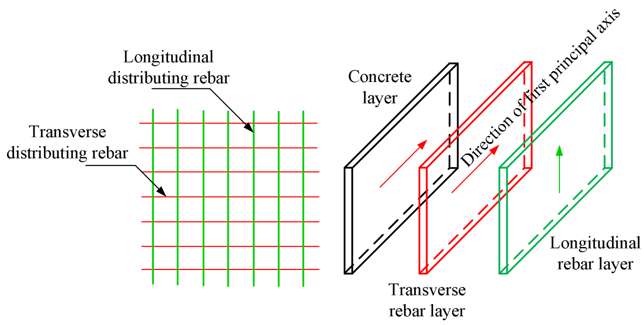
A multi-layer shell element for shear walls based on OpenSEES--THUShell

The research group of Disaster Prevention and Mitigation in Tsinghua University has developed a multi-layer shell element for the simulation of shear wall components. The program can be downloaded at http://www.luxinzheng.net/download/OpenSEES/THUShell.zip.

The multi-layer shell element is based on the principles of composite material mechanics. It is made up of a number of layers with different thicknesses and different material properties (i.e., concrete layers or rebar layers), as shown in Figure 1(a). The strains and curvatures of the middle-layer of the shell element are firstly obtained during the computation, and the strains in other layers can be determined based on the "plane-in-plane" assumption. Then, the stress in each layer will be calculated through the material constitutive law, and the internal force of the shear element (force and bending moment along the section) can be determined via the numerical integration of the stress in all layers. The multi-layer shell element is capable of simulating coupled in-plane/out-of-plane bending as well as in-plane direct shear and coupled bending-shear behavior of RC shear walls. The rebars are smeared into one or more layers and these rebar layers can be either isotropic or orthotropic depending on the reinforcement ratio in the longitudinal and transverse directions, as shown in Figure 2(b).



(a) Multi-layer shell element



(b) Location of the rebar layers

Figure 1. The Principal of multi-layer shell element

In this research, the corresponding multi-dimensional concrete material model, steel reinforcement model and multi-layer shell element model are developed in OpenSEES. The multi-layer shell element is based on the ShellMITC4 element that is already provided by OpenSEES. The framework of the proposed multi-layer shell element in OpenSEES is shown in Figure 2.

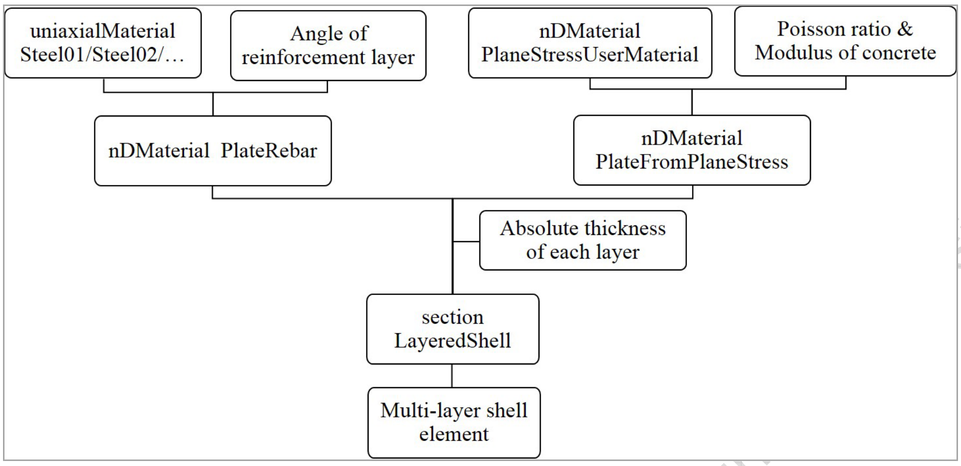


Figure 2 .The framework of the multi-layer shell element in OpenSEES

1 Multi-dimensional concrete model.

This command is used to create the multi-dimensional concrete material model that is based on the damage mechanism and smeared crack model.

nDmaterial PlaneStressUserMaterial $matTag 40 7 $fc $ft $fcu $epsc0 $epscu $epstu $stc

$matTag	integer tag identifying material
$fc	concrete compressive strength at 28 days (positive)
$ft	concrete tensile strength (positive)
$fcu	concrete crushing strength (negative)
$epsc0	concrete strain at maximum strength (negative)
$epscu	concrete strain at crushing strength (negative)
$epstu	ultimate tensile strain (positive)
$stc	shear retention factor

nDmaterial PlateFromPlaneStress $newmatTag $matTag $OutofPlaneModulus

$newmatTag	new integer tag identifying material deriving from pre-defined PlaneStressUserMaterial
$matTag	integer tag identifying PlaneStressUserMaterial
$OutofPlaneModulus	shear modulus of out plane

2. Multi-dimensional Reinforcement Material

This command is used to create the multi-dimensional reinforcement material.

nDmaterial PlateRebar $newmatTag $matTag $sita

$newmatTag	new integer tag identifying material deriving from pre-defined uniaxial steel material
$matTag	integer tag identifying uniaxial steel material
$sita	define the angle of steel layer, 90 º (longitudinal steel), 0º (tranverse steel)

3. Define the Section of the Multi-layer Shell element

This command will create the section of the multi-layer shell element, including the multi-dimensional concrete, reinforcement material and the corresponding thickness.

section LayeredShell $sectionTag $nLayers $matTag1 $thickness1...$matTagn $thicknessn

$sectionTag	unique tag among sections
$nLayers	total numbers of layers
$matTag1	material tag of first layer
$thickness1	thickness of first layer
….	
$matTagn	material tag of last layer
$thicknessn	thickness of last layer

4. Examples

Two solid shear wall specimens are chosen to demonstrate the feasibility of the proposed multi-layer shell element.

Table 1. Parameters of the specimen

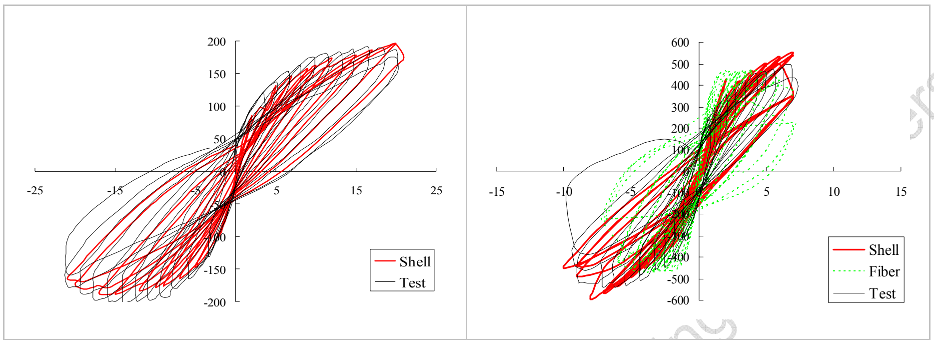
Specimen	Dimension (mm) ($H \times W \times t$)	High/width	Concrete strength	Width of boundary zone	Axial load ratio	Longitude reinforcement	Stirrups
SW1-1	2000×1000×125	2.0	C30	200	0.1	6D10	D6@80
SW2-1	1000×1000×125	1.0	C40	200	0.3	6D10	D6@80

Table 2. Parameters of the concrete

Specimen	fc(MPa)	ft(MPa)	fcu(MPa)	epsc0	epscu	epstu	stc
SW1-1	20.7	2.07	-4.14	-0.002	-0.006	0.001	0.08
SW2-1	30.8	3.08	-6.16	-0.002	-0.005	0.001	0.05

The stirrups is smeared into orthotropic rebar layers along 0º direction, whereas the longitude reinforcement is smeared into orthotropic rebar layers along 90º direction. The concentrated reinforcement in boundary zone is modeled with truss element, whose node is shared with the shell element to achieve the displacement compatibility.

The boundary zone and the other part of the wall are separately defined with two different multi-layer sections. The boundary zone is divided into 10 layers while the wall is divided into 8 layers.



(a) SW1-1 | (b) SW2-1

Figure 3. Force-displacement of the specimens

Test date: Zhang HM, Study on the Performance-based Seismic Design Method for Shear Wall Structures, Doctoral Thesis, Tongji University, Shanghai, 2007.

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