

Numerical Simulation of Super Tall Buildings Based on OpenSees



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Outline

- Introduction
- Multi-layer Shell Element and nDMaterial Concrete
- Modeling Technology and Pre-/Post- Process
- 64-bit Version and Selection of Analysis Domain
- Examples

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Introduction

- Initiative:**
 - Simulation Super-Tall Buildings with OpenSees
 - From National Nature Science Foundation of China (NSFC)
- Challenge:**
 - Element Model for Shear Walls/Core Tubes
 - Large Scale Computing
 - Modeling Complicated Structures

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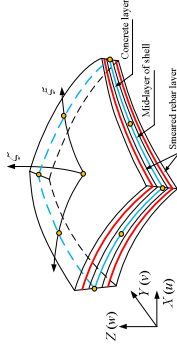
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- Introduction
- **Multi-layer Shell Element and nDMaterial Concrete**
- Modeling Technology and Pre-/Post- Process
- Selection of Analysis Domain and 64-bit Version
- Examples

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Multi-layer Shell Element

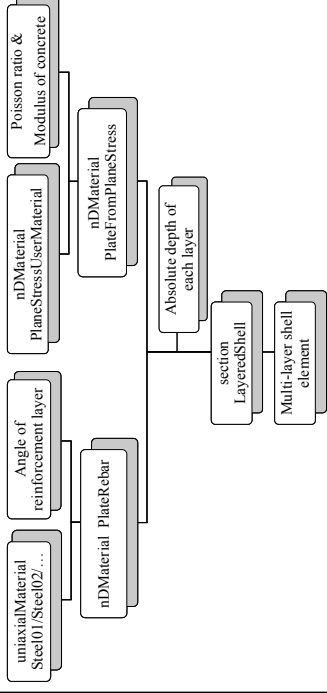
- Features
 - Composite Material Mechanics
 - Coupled in-plane/out-of-plane Bending and in-plane Direct Shear
 - Coupled Bending-shear



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Multi-layer Shell Element

- Framework of the element

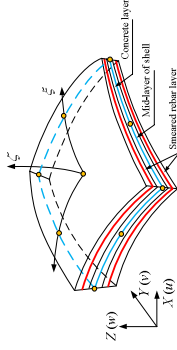


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Multi-layer Shell Element

- Features

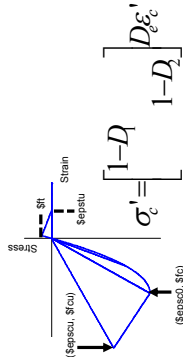
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nDMaterial Concrete

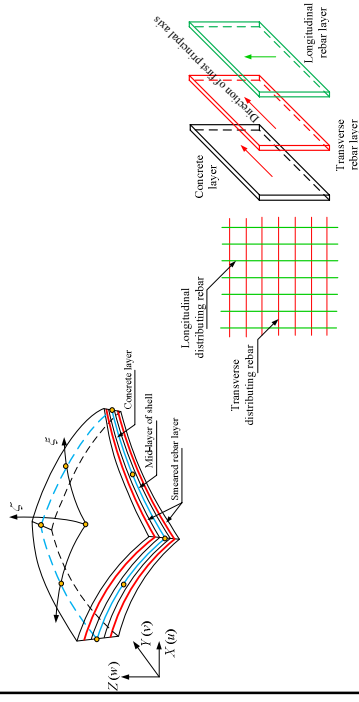
- 2D plane stress constitutive model
- A very simple concrete model
 - Damage mechanism and smeared crack
 - Compression: Løland model
 - Tension: Mazars model



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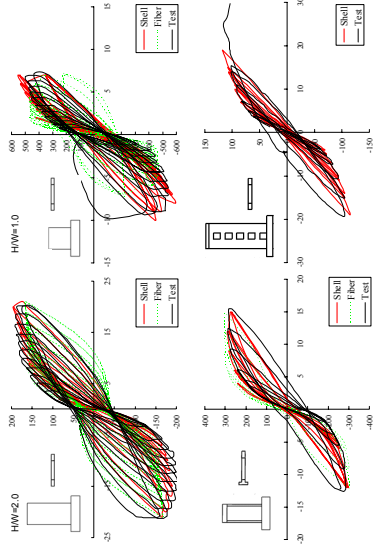
Multi-layer Shell Element

- Shell MITC4



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Validation with Experiments



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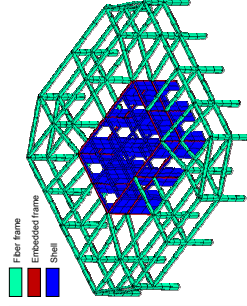
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Modeling technology

- Fiber beam elements for beams and columns
- Multi-layer shell elements for shear walls and coupling beams
- Embedded beam elements to connect fiber beam elements and multi-layer shear wall elements



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Pre-/Post- Process



GUI Preprocess
(* .dat file)

Fiber beam (THUFiber)
Multi-layer shell (Shell 75)

GUI Postprocess
(* .t19 file)

Fiber beam
Multi-layer shell

Results

The models in MSC Marc can be found in Collapse simulation of reinforced concrete high-rise building induced by extreme earthquakes, *Earthquake Engineering & Structural Dynamics*, 2013, 42(6): 705-723.

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64-bit Version

- Model size:
 - Nodes > 53,000; Elements > 88,000
 - DOF > 300,000
- Recompile OpenSees.exe in 64-bit environment
- Maximum thread memory size > 28 GB

应用程序	进程	名称	用户	CPU	CPU 时间	内存使用	虚拟内存
explorer.exe	user00	user00	user00	00	0:00.00	11,624 K	28.7
chrome.exe	user00	user00	user00	00	0:00.00	1,012 K	3.2
OpenSees.exe	user00	user00	user00	00	0:00.00	3,394 K	5.7
cmd.exe	user00	user00	user00	00	0:00.00	2,112 K	5.7
cmd.exe	user00	user00	user00	00	0:00.15	2,112 K	6.2
cmd.exe	user00	user00	user00	04	0:00.38	28,058,592 K	28.000

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cmd.exe	user00	user00	user00	00	0:00.00	2,112 K	5.7
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cmd.exe	user00	user00	user00	04	0:00.38	28,058,592 K	28.000

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Selection of Analysis Domain

- Matrix solver
 - BandGeneral SOE: Failed
 - BandSPD SOE: Failed
 - ProfileSPD SOE: Failed
 - SuperLU SOE: Failed
 - Mumps: Failed
 - UrmfPack SOE: Works but Slow
 - SparseSYM SOE: Feasible

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Selection of Analysis Domain

- Eigen solver
 - Symmetric Arpack: Failed
 - Band Arpack : Failed
 - Profile SPD: Feasible
- Constraints
 - Plain: Failed
 - Lagrange: Failed
 - Penalty: Failed
 - Transformation : Feasible

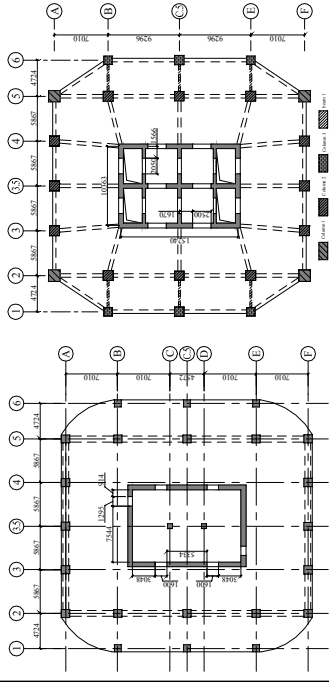
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TBI Building 2



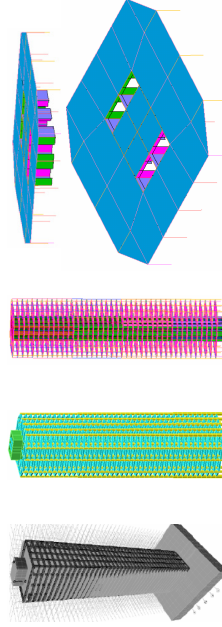
US Design

Chinese Design

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TBI Building 2

- H=141.8m, 42 stories
- 8,469 nodes
- 9,744 fiber elements
- 4,707 shell elements



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TBI Building 2

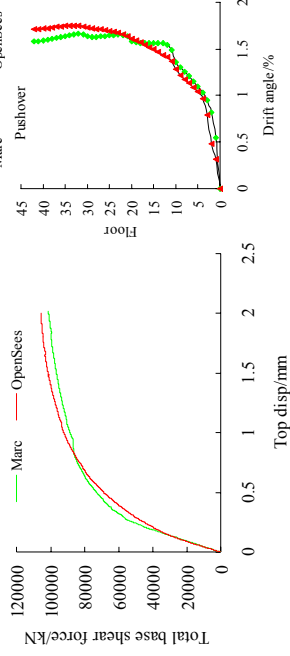
- Gravity and vibration period

	Marc	OpenSees	Relative Error
T_1 (X translation)	1.791	1.815	1.3%
T_2 (Y translation)	1.580	1.579	0.06%
T_3 (Torsion)	0.900	0.890	1.1%
Gravity (ton)	5.4964×10^4	5.4964×10^4	0%

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TBI Building 2

■ Static Pushover



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TBI Building 2

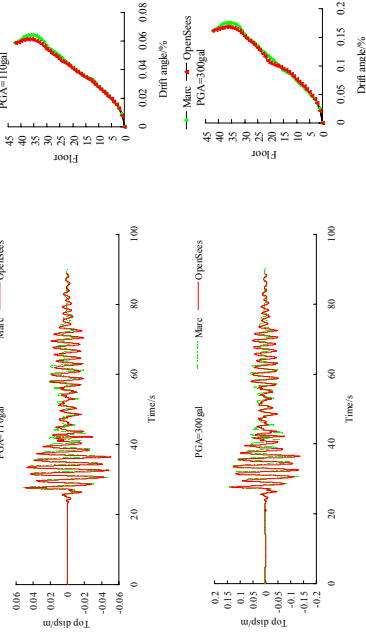
■ Nonlinear time history analysis

- Chi-Chi: 110gal, 300gal, 510gal & 1000gal
- El-Centro: 1000gal
- Northridge: 1000gal

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TBI Building 2

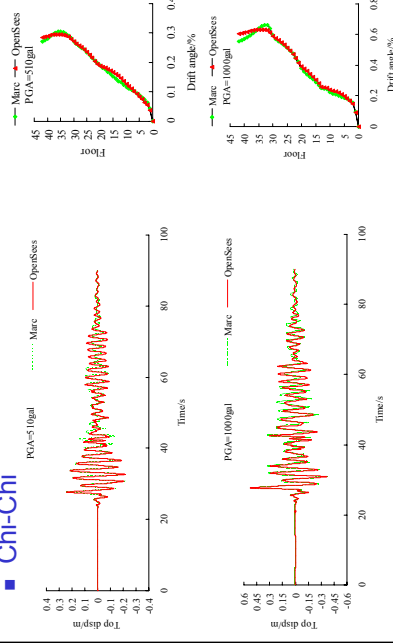
■ Chi-Chi



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TBI Building 2

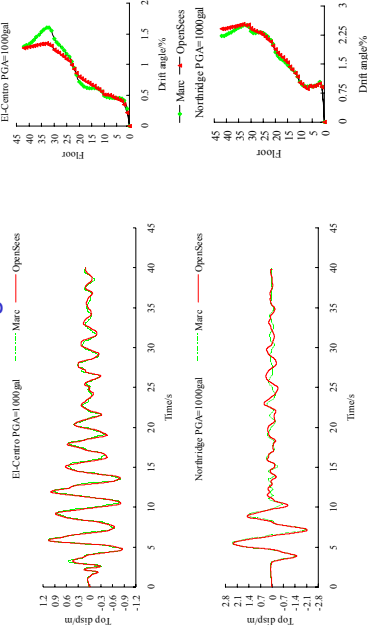
■ Chi-Chi



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TBI Building 2

EI-Centro & Northridge



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Fortune Plaza

- H=315.47m, 62 stories
- 46,028 nodes
- 31,556 fiber elements
- 37,160 shell elements

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Fortune Plaza

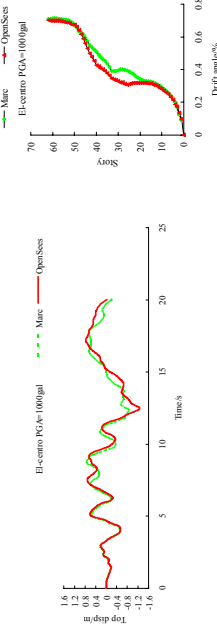
Gravity and vibration period

	Marc	OpenSees	Relative Error
T_1 (X translation)	4.9925	4.9261	1.33%
T_2 (Y translation)	3.2940	3.3290	1.06%
T_3 (Torsion)	1.051	1.061	0.95%
Gravity (ton)	4.90894×10^5	4.90894×10^5	0%

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Fortune Plaza

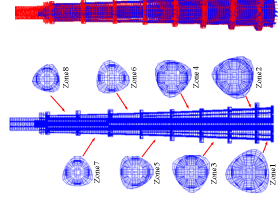
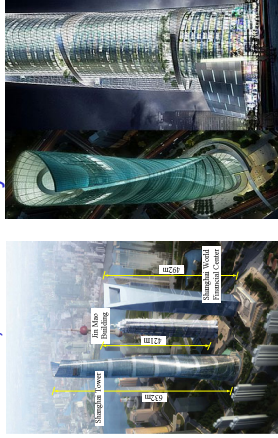
Nonlinear time history analysis



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Shanghai Tower

- H=632m, 121 stories
- 53,006 Nodes
- 48,774 fiber beam elements
- 39,315 Multi-layer shell elements



Shanghai Tower

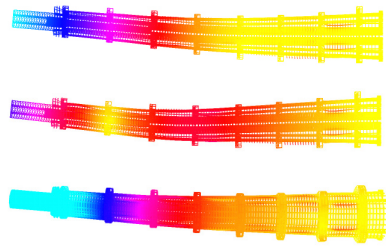
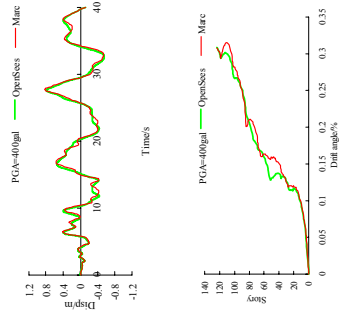
- Gravity and vibration period

	Marc	OpenSees	Relative Error
T_1 (X)	9.6525	9.5238	1.33%
T_2 (Y)	9.5511	9.4518	1.04%
T_3 (Torsion)	4.7916	4.6847	2.23%
Gravity (ton)	5.10738×10^5	5.10738×10^5	0%

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Shanghai Tower

- Time history analysis



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Thanks!

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