GPU-based high-performance computing for urban seismic damage prediction and visualization

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Outlines

- Introduction
- Program Framework
- Performance Benchmark
- Case Study
- Realistic Visualization
- Conclusions

Introduction

- China is subjected to most serious earthquake disaster threats in the world
- Earthquake occurs in cities will cause tremendous casualties and damage
- Scientific prediction of urban seismic damage is an important task

Beichuan City, 2008

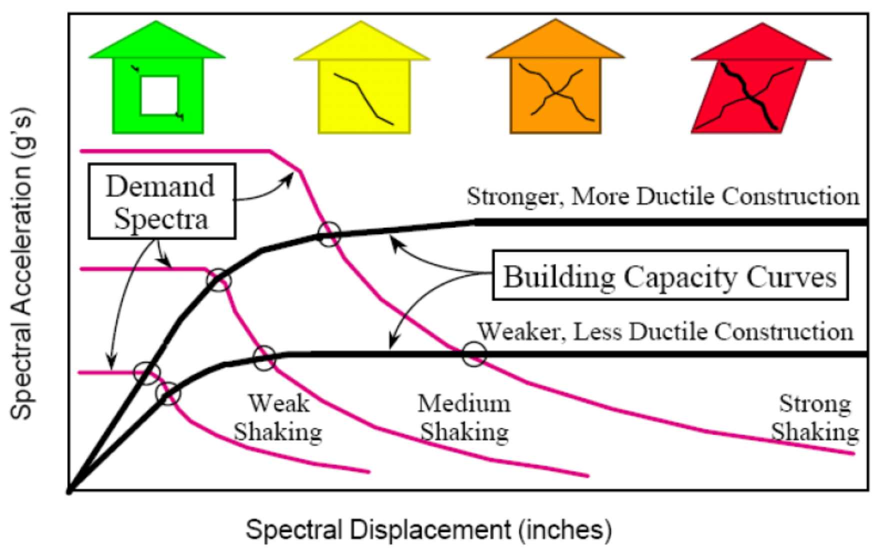
Tangshan City, 1976

Introduction

- Methods for urban seismic damage simulation
  - Based on probability matrices
    - ATC-13
  - Based on capacity curve and response spectrum
    - HAZUS, AEBM

ATC-13
Earthquake Damage Evaluation
Data for California

HAZUS MH
EARTHQUAKE • WIND • FLOOD

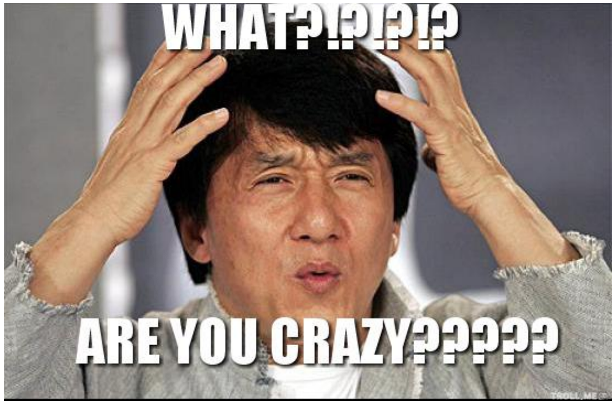


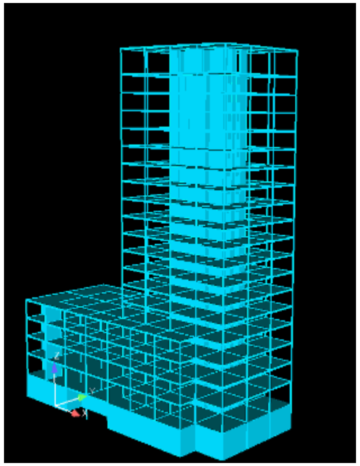
Problems:

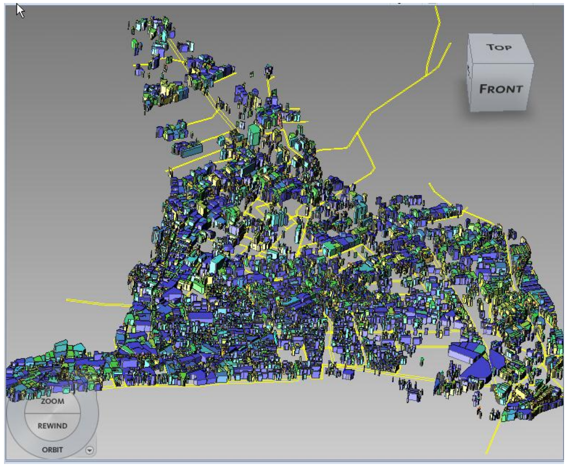
- SDOF model
- Pushover analysis
- Demand Spectra
- ….

Introduction

“Nonlinear Time History Analysis of a City!”







Single structure

- Detailed structural information
- One building

Urban region

- Limited structural information
- Hundreds of thousands of buildings

Introduction

清華大學 Tsinghua University

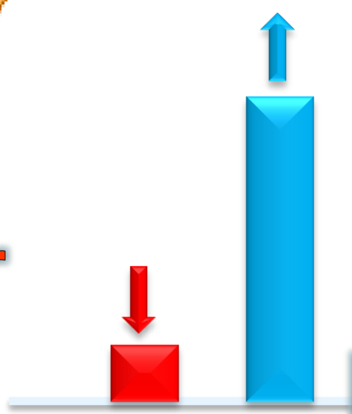
- University of Tokyo

Integrated Earthquake Simulation

- Supercomputer with traditional **CPU** platform
  - Expensive
  - Complex
  - High maintenance costs

How...

Lower cost

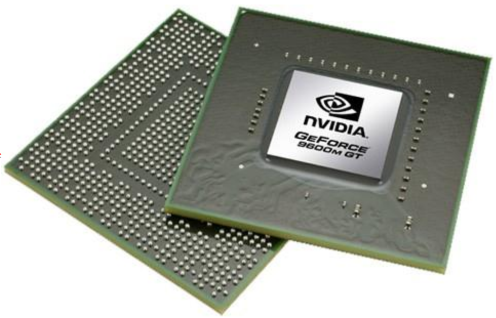


Higher performance

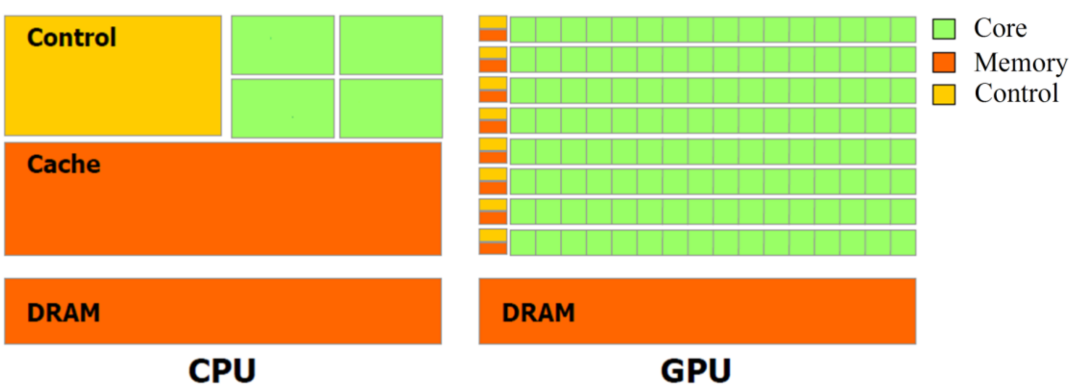
Introduction

- GPU (Graphic Processing Unit)

Video card



GPU



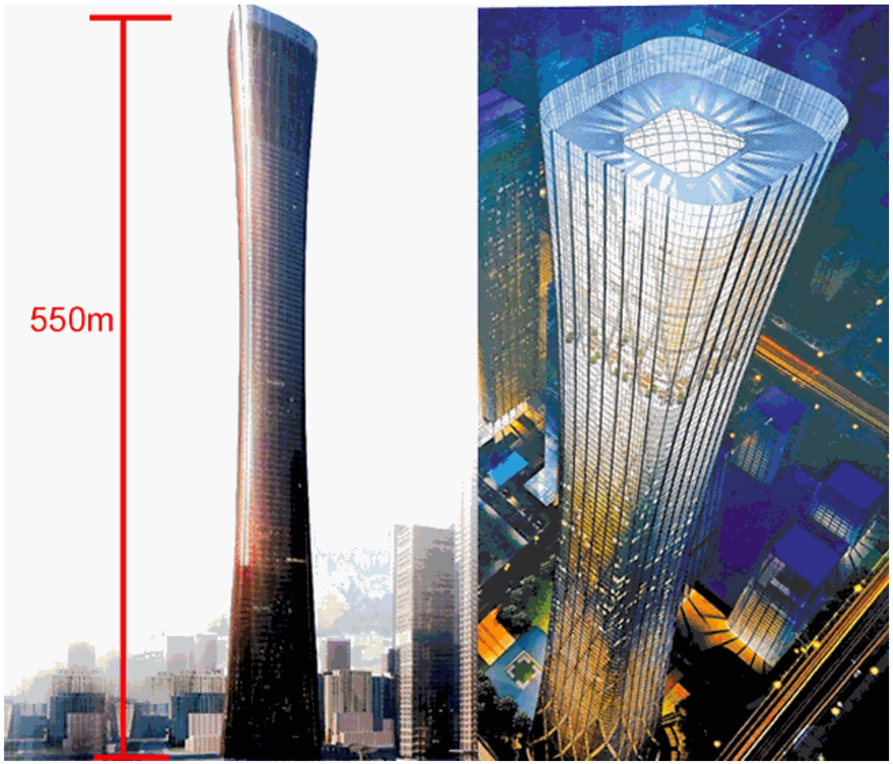
Comparison between the CPU and the GPU

CPU: 2~8 cores

GPU: hundreds/thousands of cores

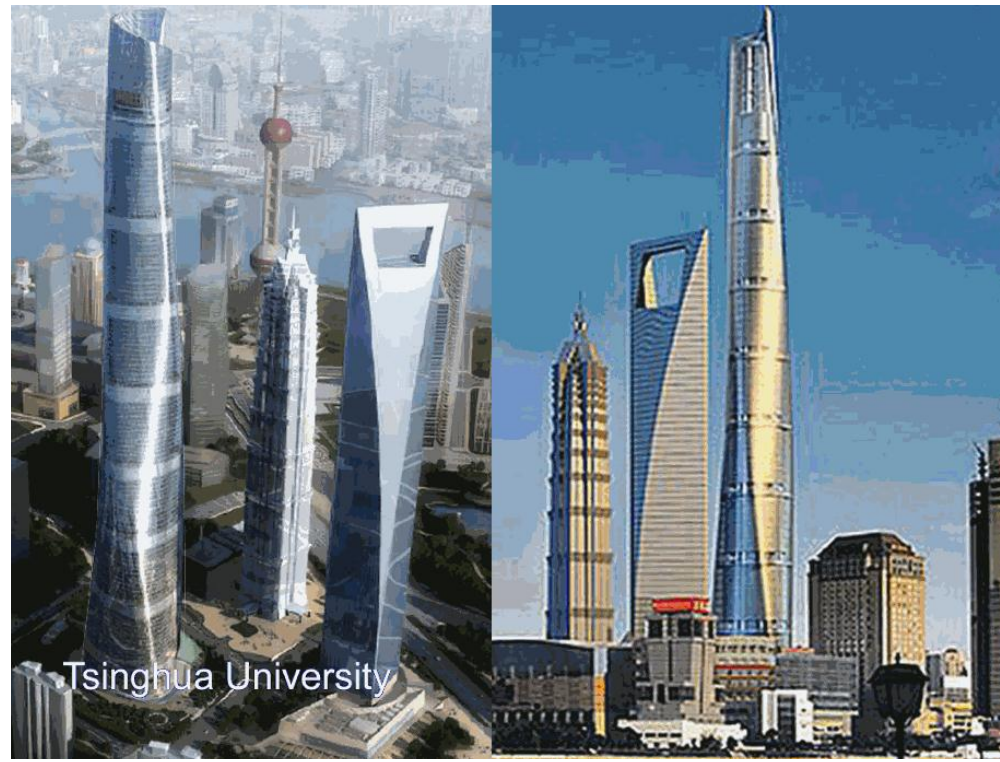
GPU-powered THA of Single Bld.

- Fiber beam element + Multi-layer shell element



Collapse simulation of Z15 in Beijing (H=550m)

Collapse simulation of reinforced concrete high-rise building induced by extreme earthquakes, *Earthquake Engineering & Structural Dynamics*, 2013, 42(5)

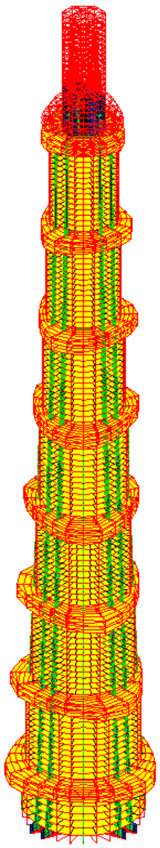


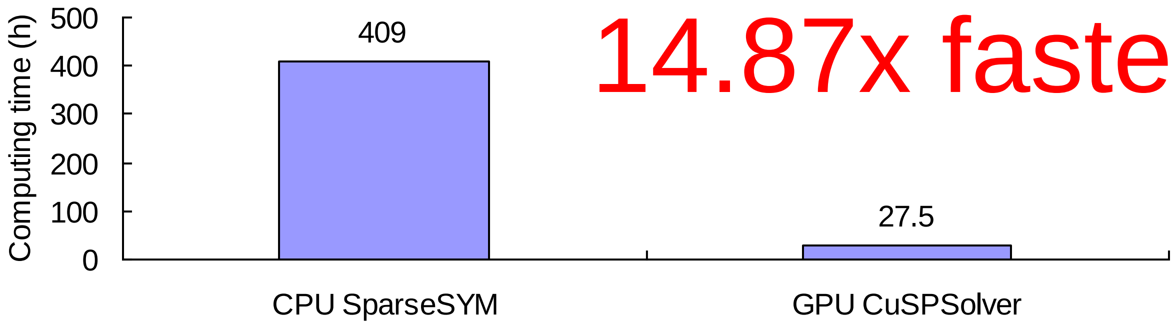
Collapse simulation of Shanghai Tower (H=630m)

Collapse simulation of a super high-rise building subjected to extremely strong earthquakes. *Science China Technological Sciences*, 2011, 54(10)

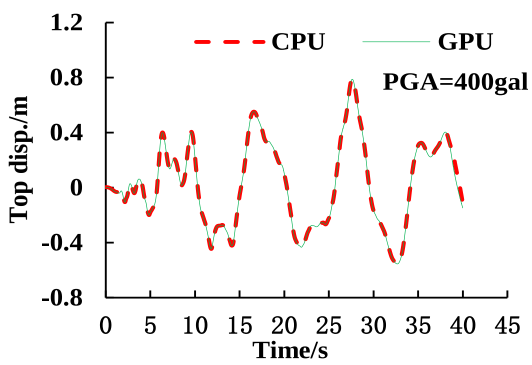
GPU-powered THA of Single Bld.

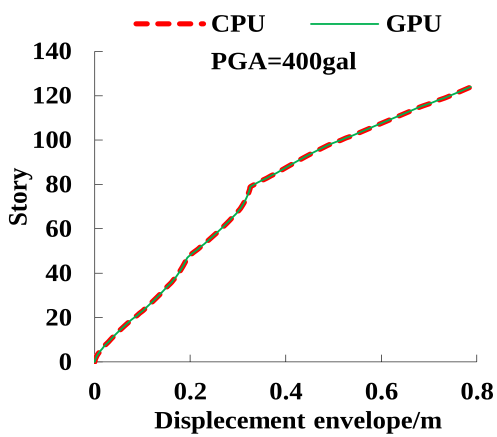
Platform	Hardware	Price	Solver
CPU	Intel Core i7-3970X 3.5GHz (Fastest CPU in the market)	US$2406	SparseSYM of OpenSees
GPU	Intel Core i7-4770X 3.4GHz &NVIDIA Geforce GTX Titan	US$2307	CuSPSolver of OpenSees





14.87x faster!





Region

清華大學 Tsinghua University

- The advantages for using GPU

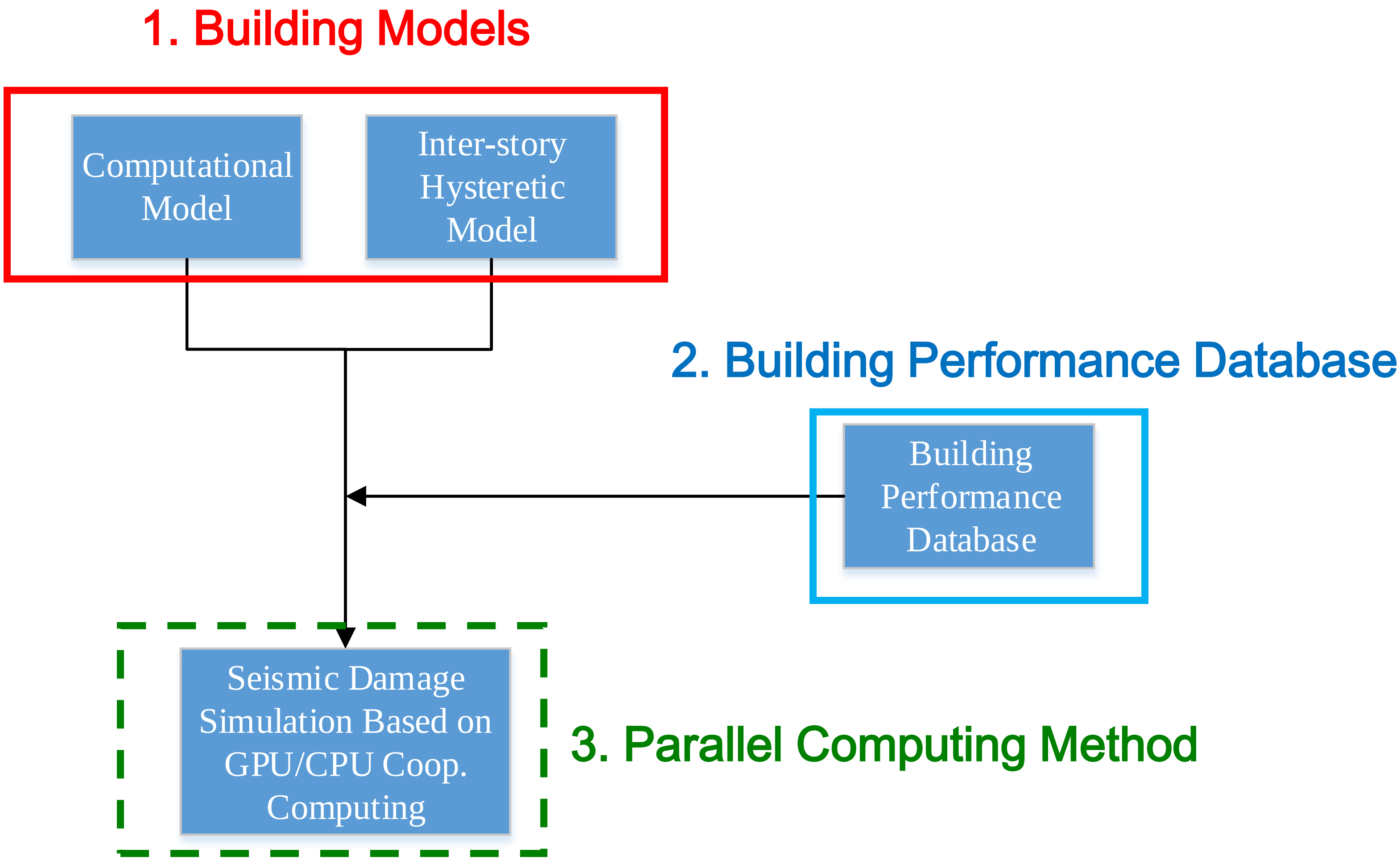
Seismic computing for normal buildings		Computing features of GPU
Simple model, few degree-of freedom in a single building	⟺	Relatively weak performance of a single core
No interaction between buildings	⟺	Fewer data exchange
A huge number of buildings	⟺	Suitable for parallel computing

Lower cost

Higher performance

A coarse-grained parallel approach for seismic damage simulations of urban areas based on refined models and GPU/CPU cooperative computing, *Advances in Engineering Software*, 2014

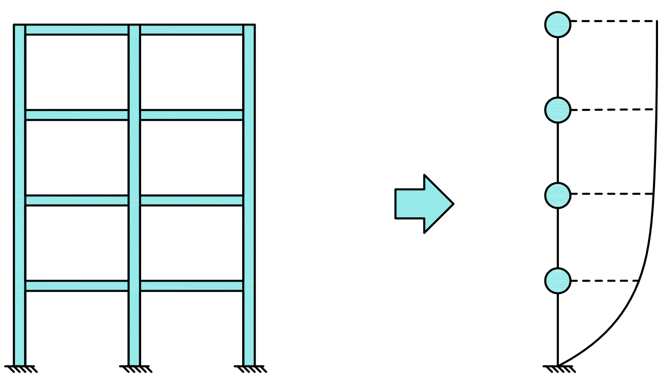
Program Framework



A coarse-grained parallel approach for seismic damage simulations of urban areas based on refined models and GPU/CPU cooperative computing, *Advances in Engineering Software*, 2014

Building Models

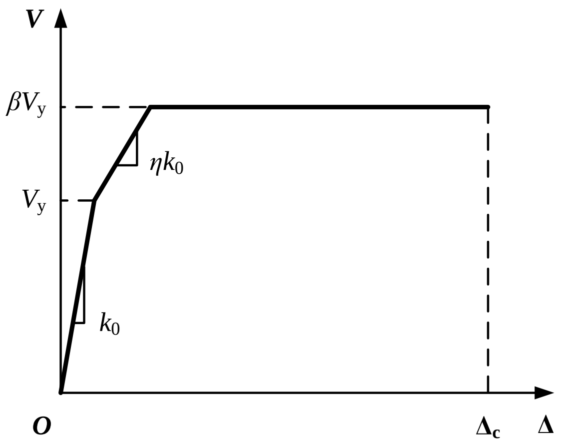
- Computational Model
  - Multi-story concentrated-mass shear (MCS) model
    - Moderate workload
    - Consider higher-order vibration modes & velocity pulses
    - Damage locations on different stories can be obtained
  - Suitable for GPU computing

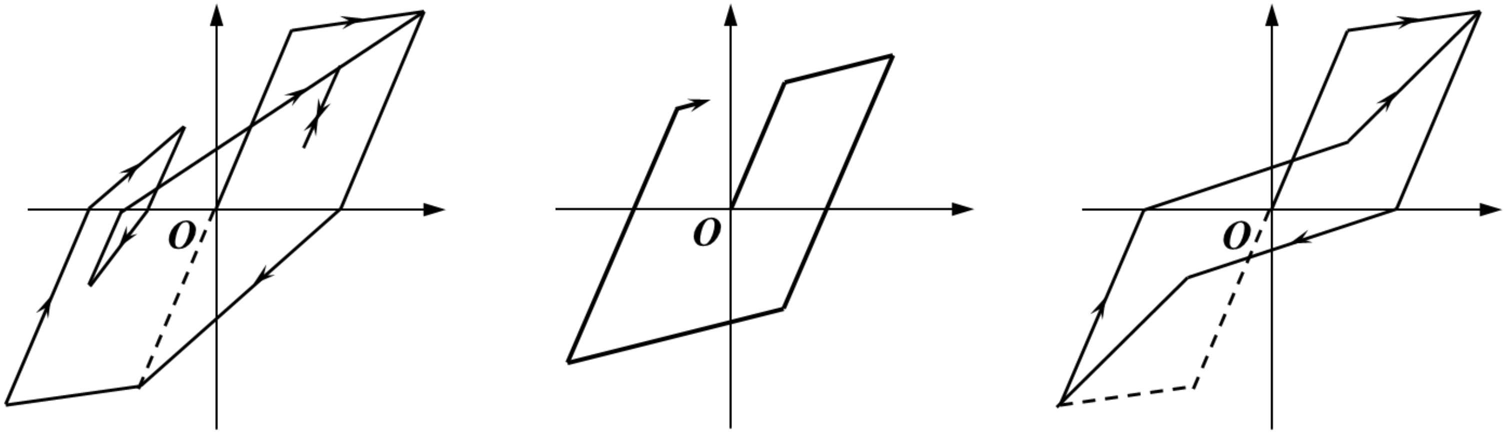


A coarse-grained parallel approach for seismic damage simulations of urban areas based on refined models and GPU/CPU cooperative computing, *Advances in Engineering Software*, 2014

Building Models

- Inter-story hysteretic model
  - Backbone curve
    - Trilinear, 5 parameters
  - Hysteretic model
    - Modified-Clough
    - Bilinear elasto-plastic
    - Pinching





A coarse-grained parallel approach for seismic damage simulations of urban areas based on refined models and GPU/CPU cooperative computing, *Advances in Engineering Software*, 2014

Building Performance Database

- For Regular Buildings
  - Based on the HAZUS performance database
  - Parameter Set Selection
    - According to building macro-parameters

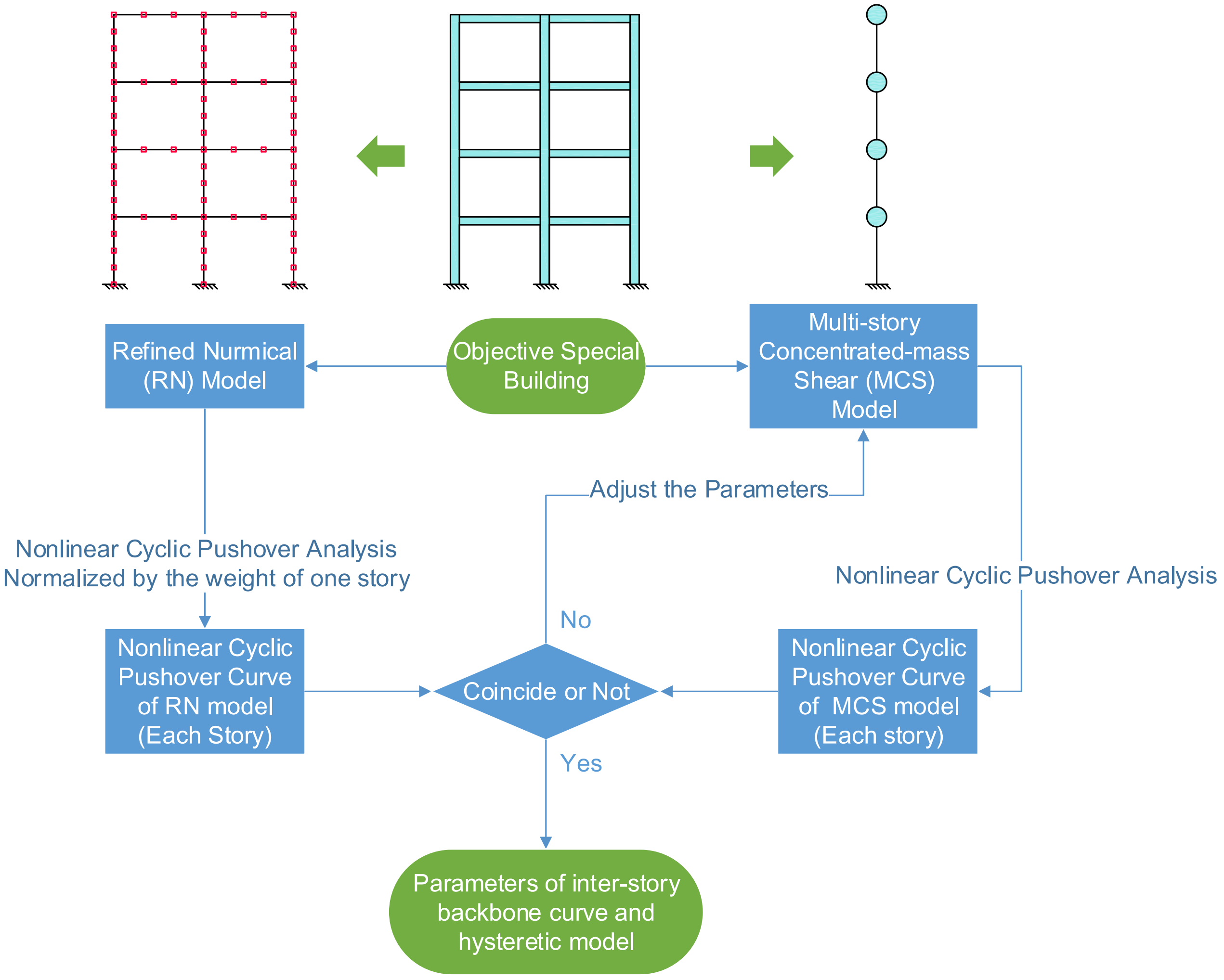
      Structural types, Numbers of stories, Construction Period

    - 19 building types proposed in HAZUS are adopted
  - HAZUS Parameters —convert→ MCS model Parameters

A coarse-grained parallel approach for seismic damage simulations of urban areas based on refined models and GPU/CPU cooperative computing, *Advances in Engineering Software*, 2014

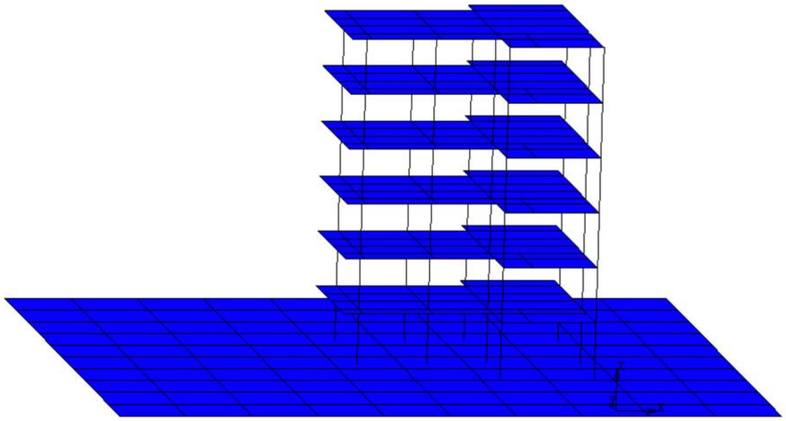
Building Performance Database

- For Special Buildings:

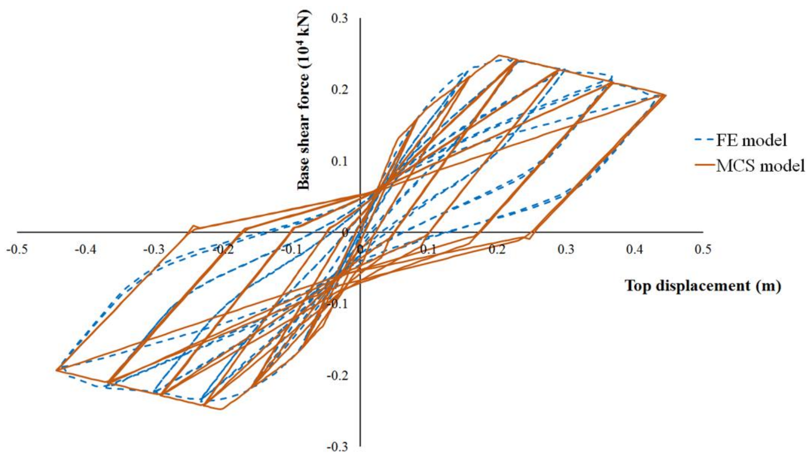


Building Performance Database

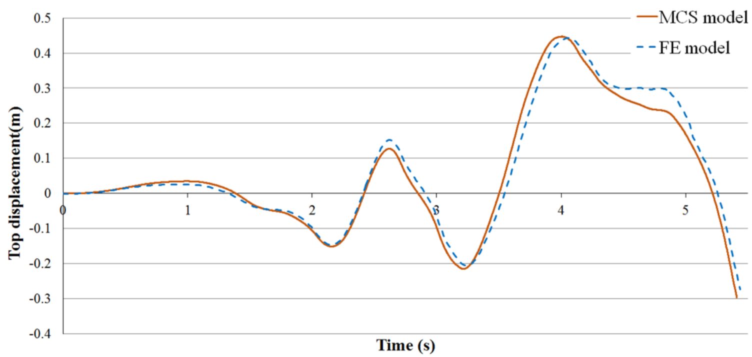
- Validation (six-story RC frame)



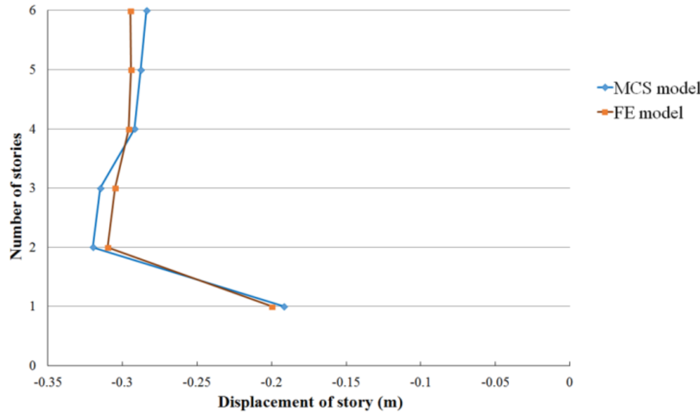
Refined FE model



Inter-story hysteretic model

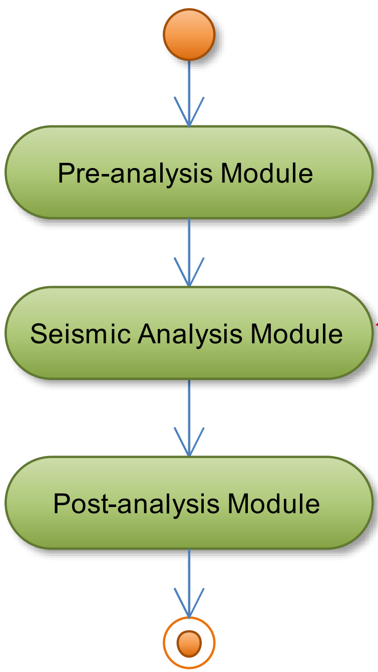


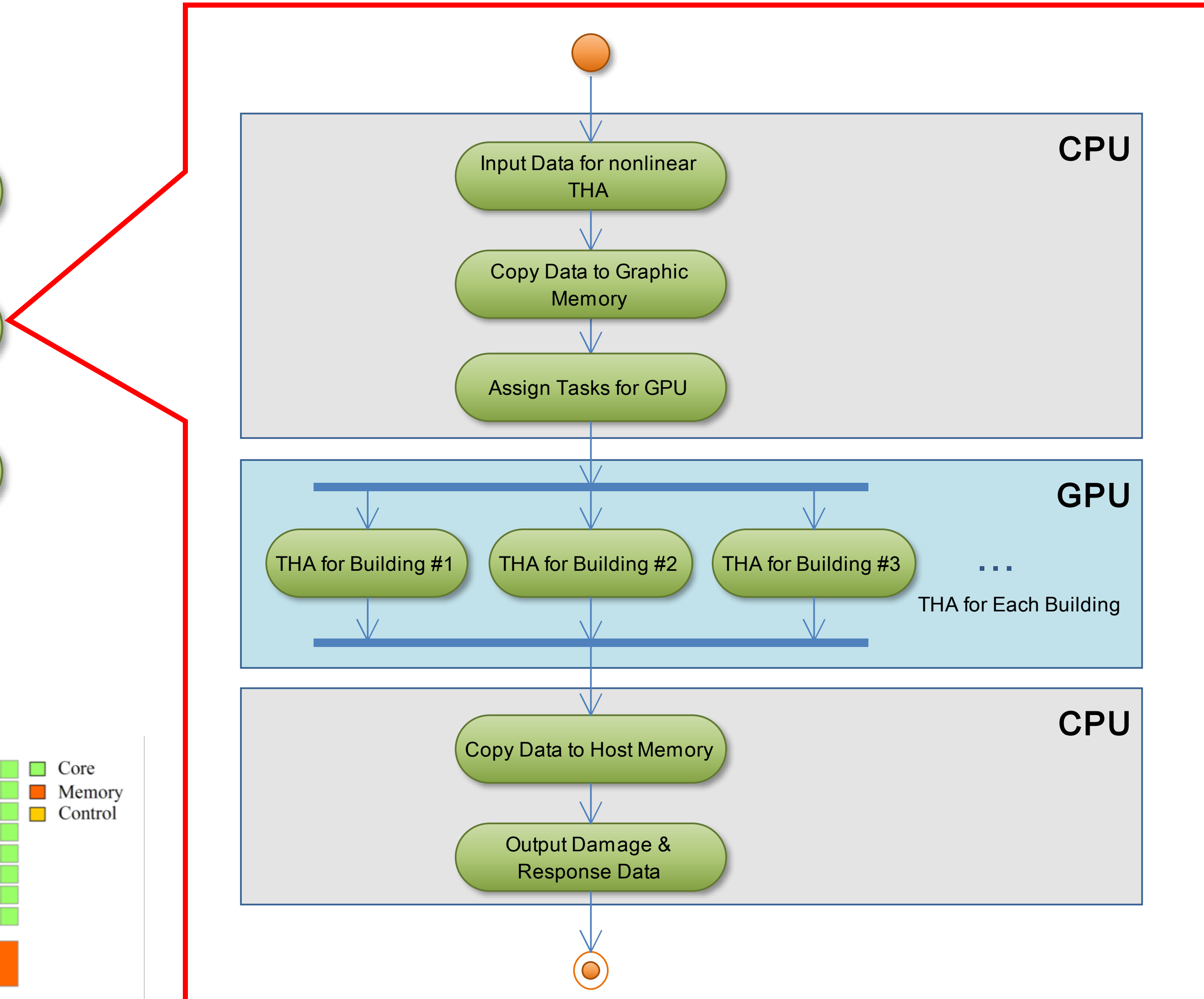
Top displacement

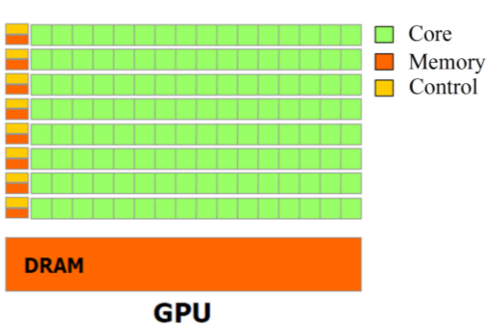


Inter-story drift

Parallel Computing Method







Performance Benchmark

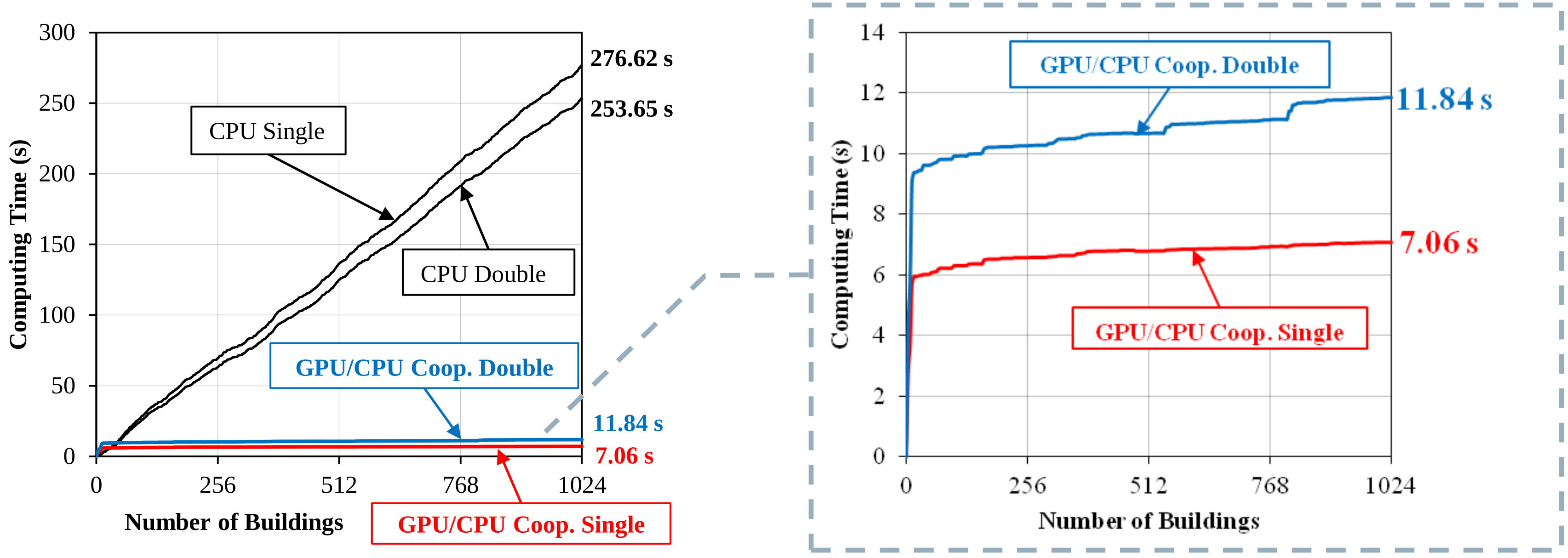
- CPU/GPU cooperative vs. CPU only
  - 1,024 buildings, numbers of stories and structural types are random generated
  - Earthquake record: El Centro, 40 s, PGA: 200 cm/s^2
  - Time of data input and output is not included

Platforms	Hardware	Compliers
CPU	Intel Core i3 530 @2.93GHz & DDR3 4G 1333MHz.	Microsoft Visual C++ 2008 SP1
GPU/CPU cooperative	Intel Celeron E3200 @ 2.4GHz & NVIDIA GeForce GTX 460 1GB.	Microsoft Visual C++ 2008 SP1 & CUDA 4.2

The two platforms have similar prices

Performance Benchmark

- Weak-scaling benchmarks for the two platforms
  - **39x** speedup when computing 1024 buildings



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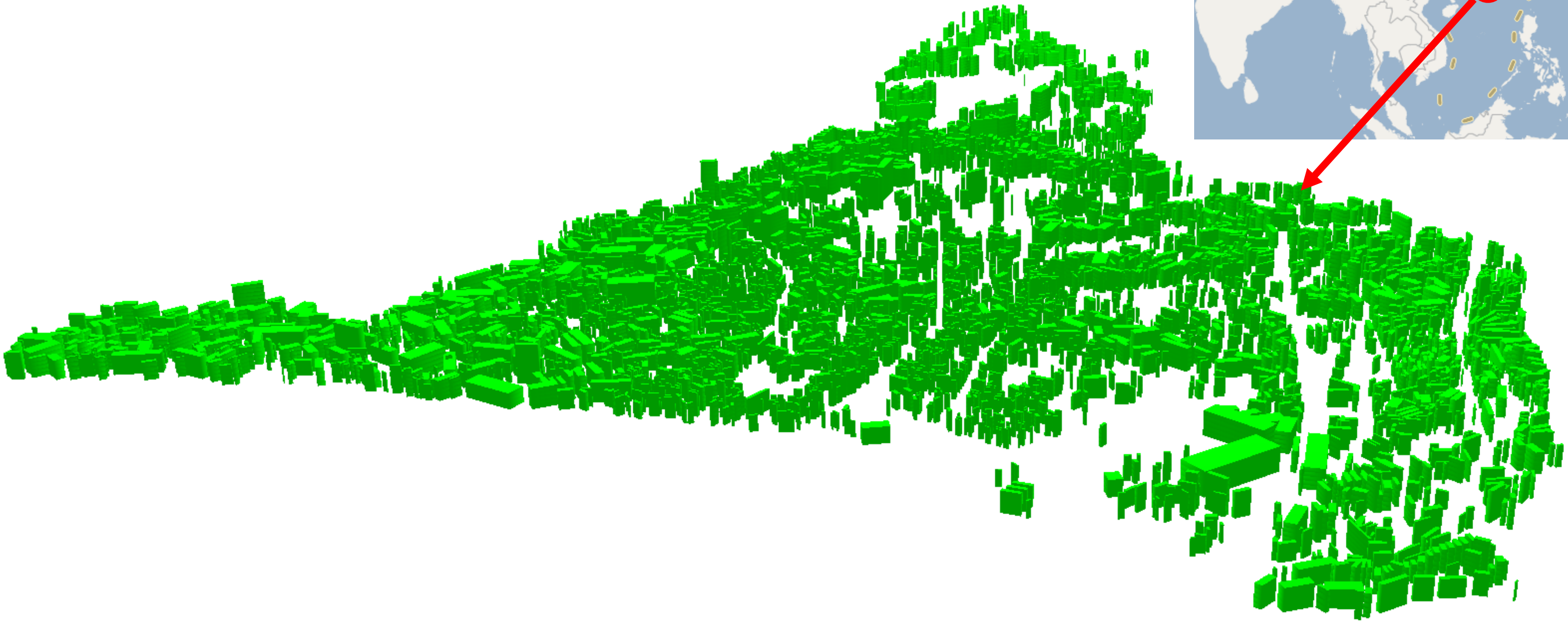
Case Study

- A medium-sized urban area in China
  4,225 buildings



Case Study

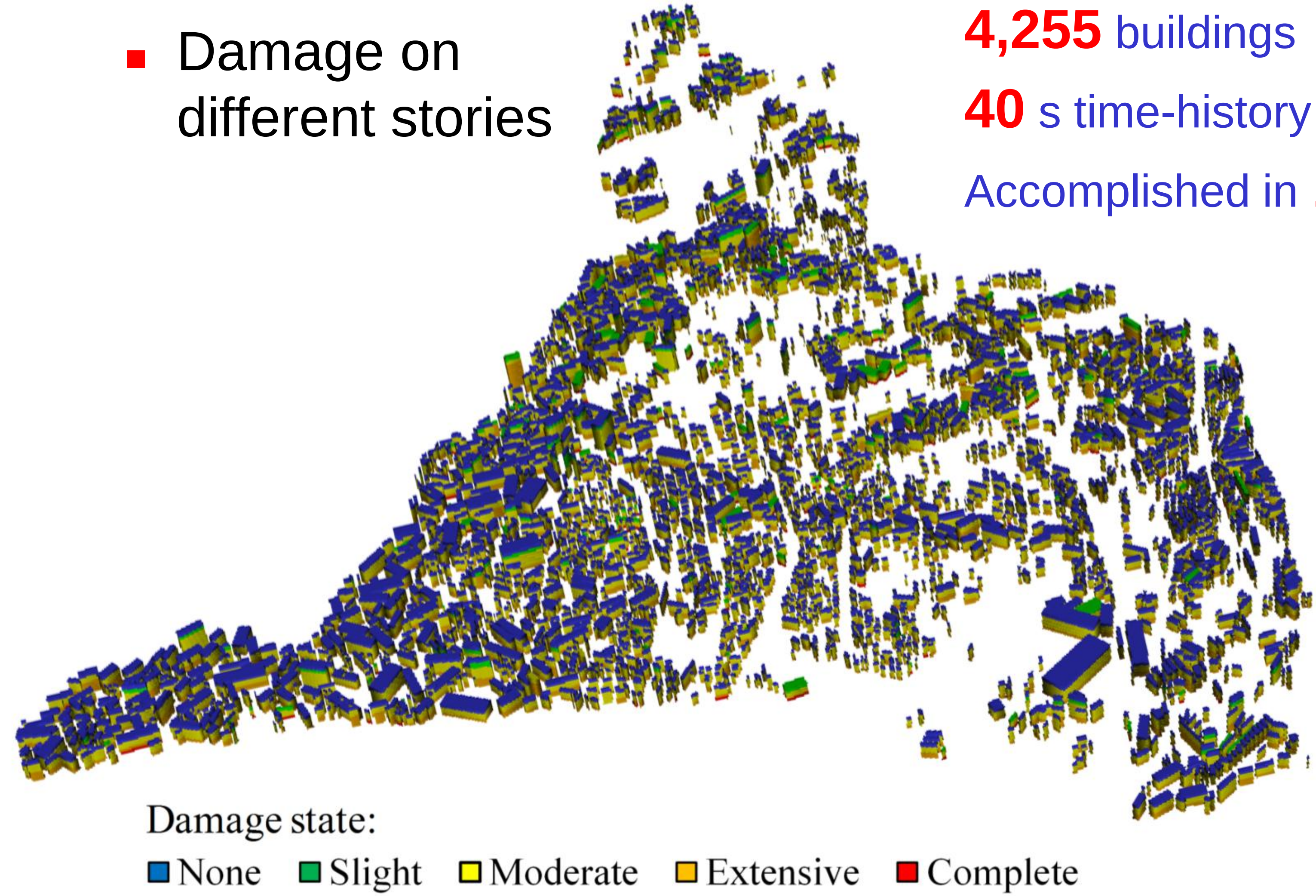
- Global view
  - Damage on different stories

Desktop Computer

4,255 buildings

40 s time-history analysis

Accomplished in **216** s



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Case Study

- Local view
  - Damage on different stories

Desktop Computer

4,255 buildings

40 s time-history analysis

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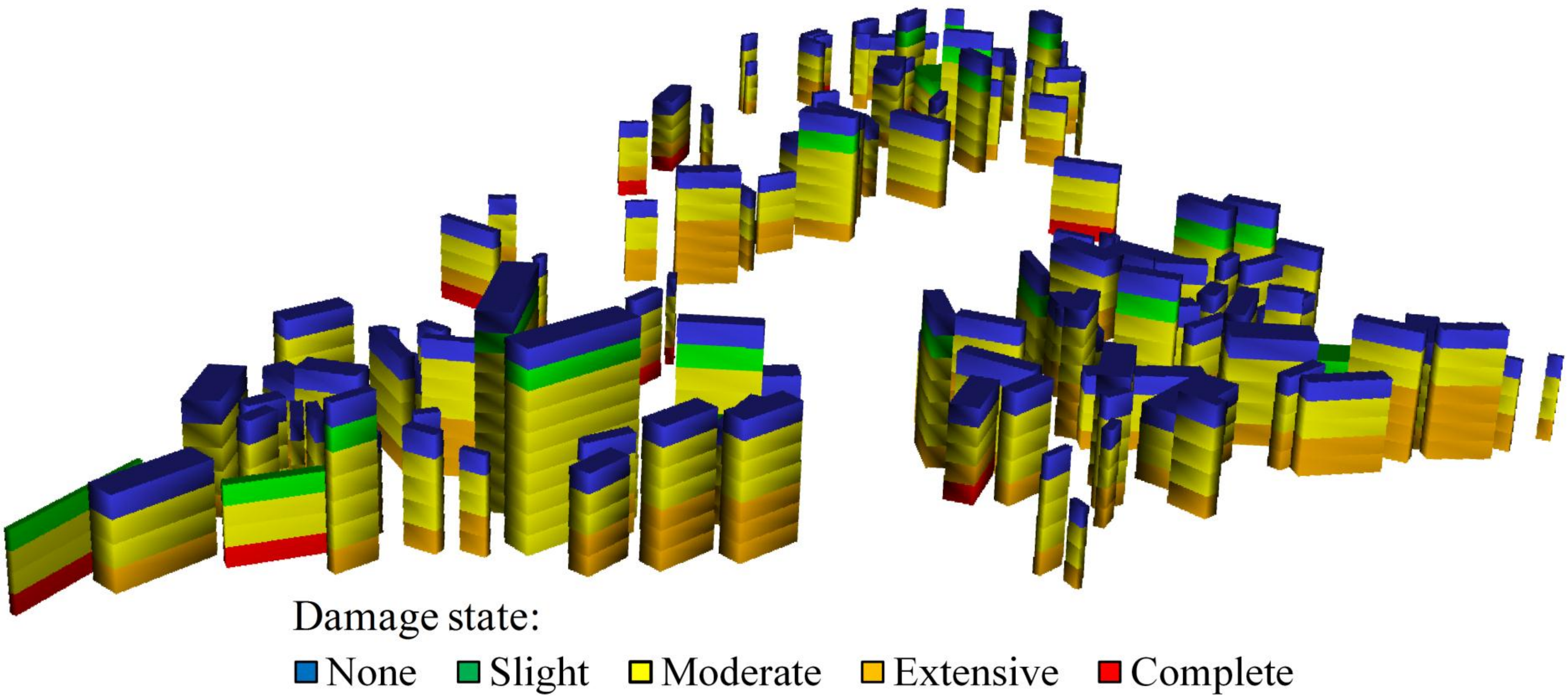
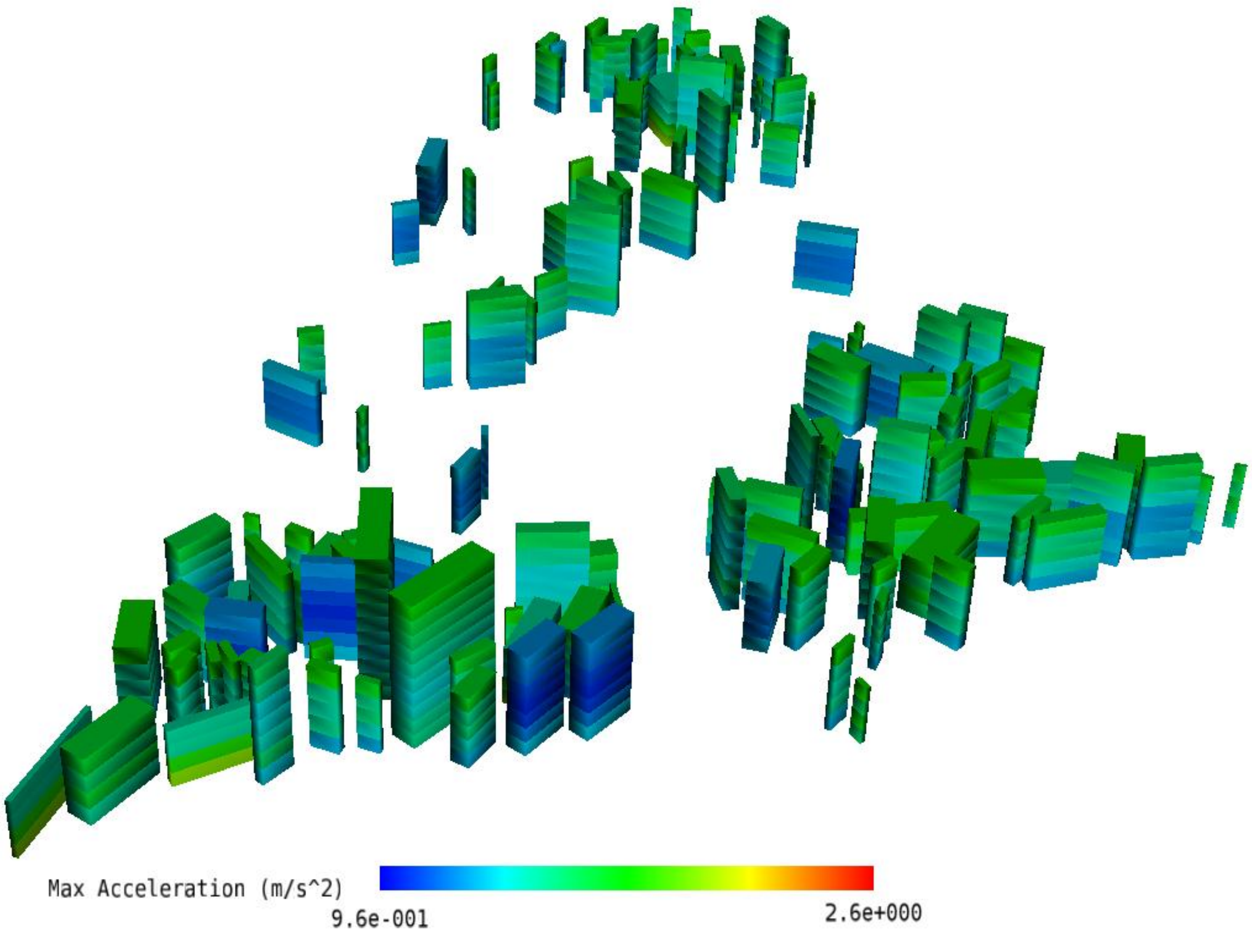


A coarse-grained parallel approach for seismic damage simulations of urban areas based on refined models and GPU/CPU cooperative computing, *Advances in Engineering Software*, 2014

Case Study

- Local view
  - Peak acceleration on different stories



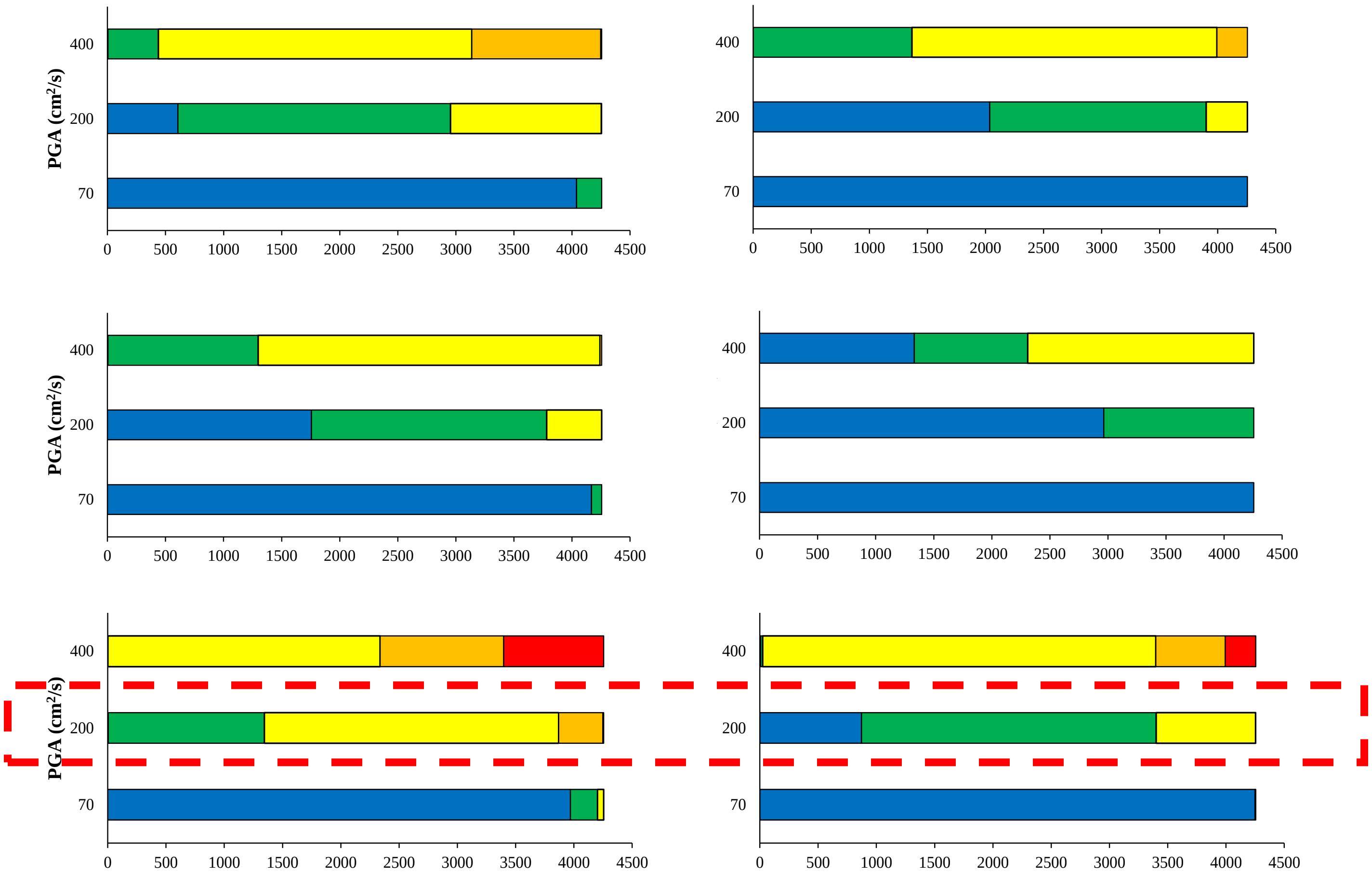
Case Study

MCS Model | **SDOF Model**

Far-field

Near-field without pulses

Near-field with pulses



Number of Buildings | **Number of Buildings**

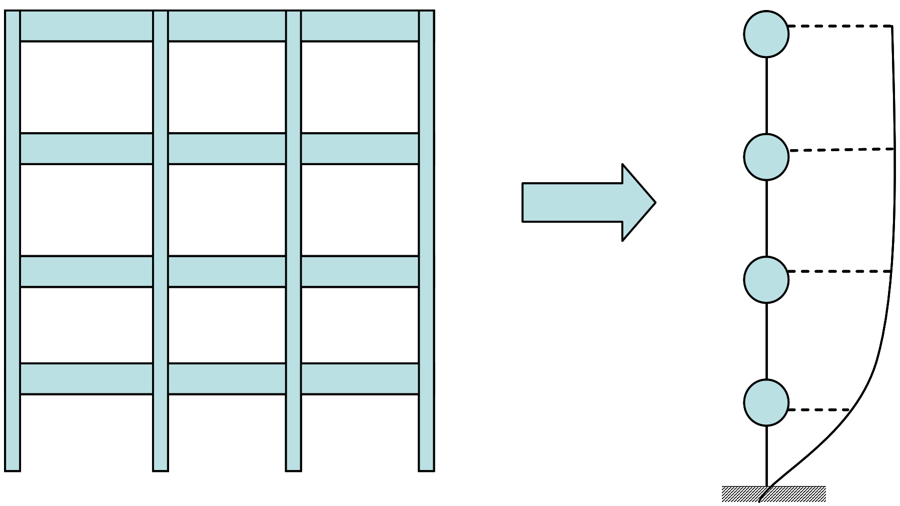
MCS model: velocity pulses can be considered

Visualization problem

- Realistic visualization
  Rescue and transportation planning

} Building collapse

- MCS model cannot simulate process of building collapse.

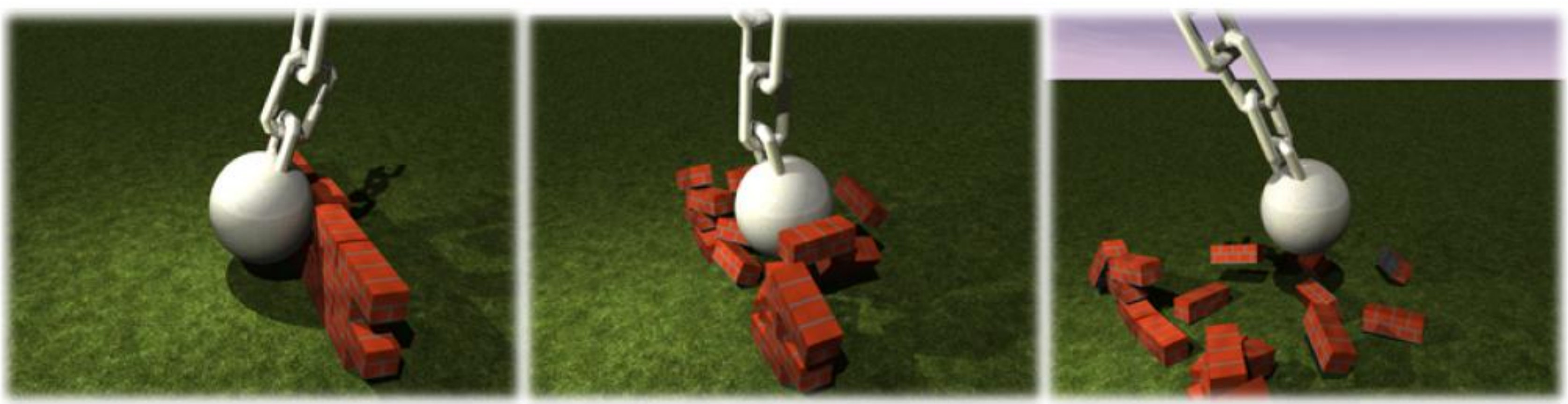


MCS model
(Criterion of collapse)

Real earthquake disaster
(Include building collapse)

Physics Engine Solutions

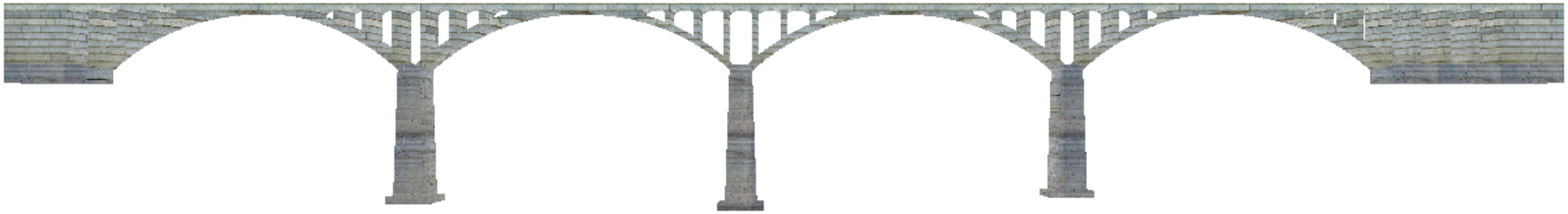
- Physics engine
  - A computer program for real-time dynamic calculation, good at multi-body dynamics.
  - Widely used in computer graphics, video games and film.



Example of physics engine

Seismic damage simulation in urban areas based on a high-fidelity structural model and a physics engine, *Natural Hazards*, 2014

Physics Engine Solutions



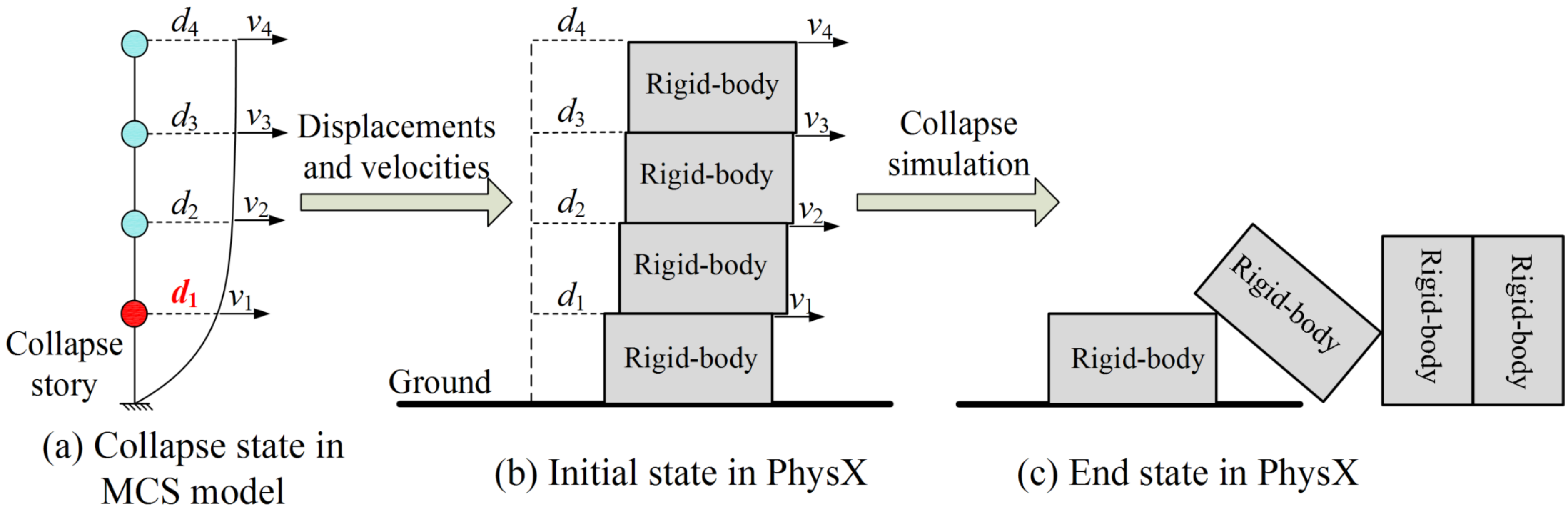
Finite element results

Finite element results + **physics engine based-debris**

Physics engine-driven visualization of deactivated elements and its application in bridge collapse simulation, *Automation in Construction*, 2013

Collapse simulation

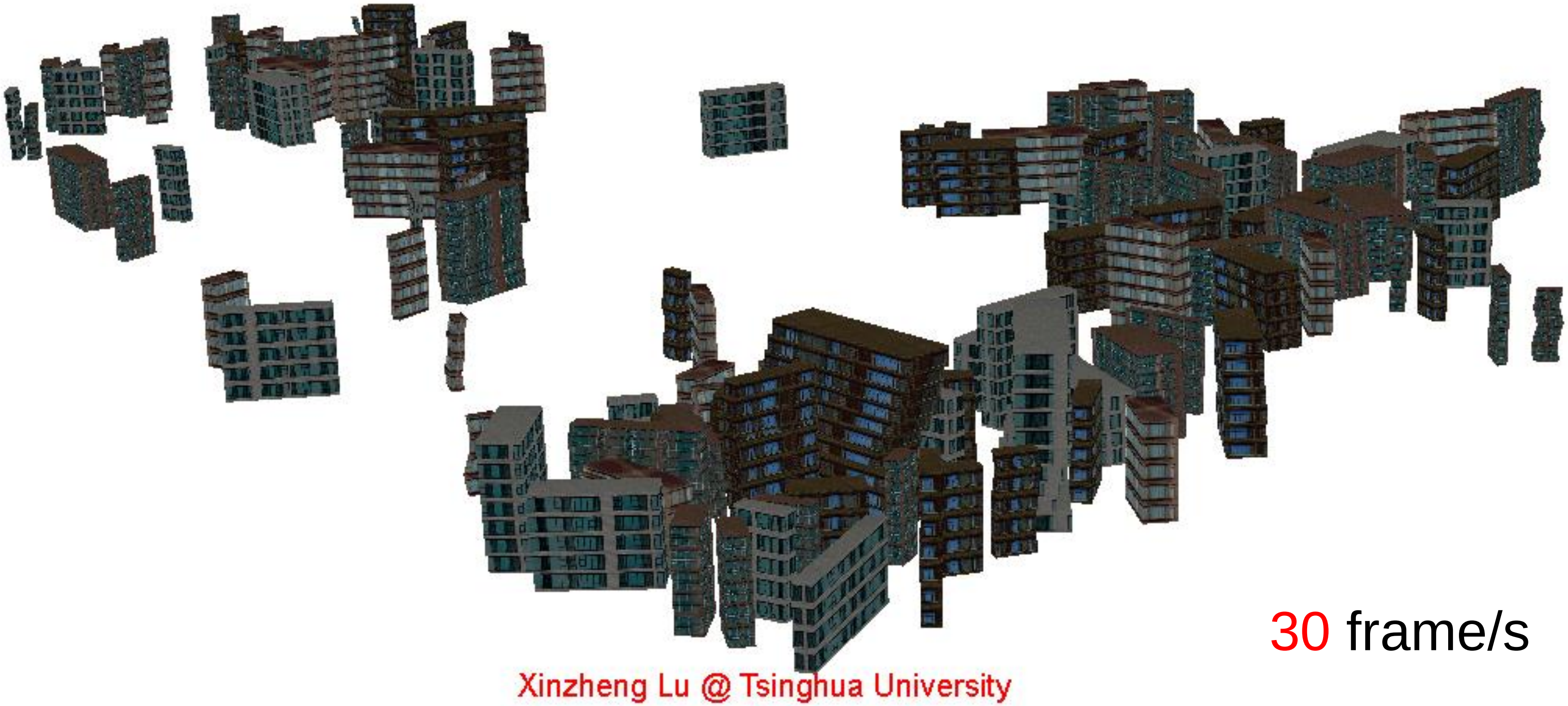
- Integrate MCS model and physics engine



The process of collapse simulation in physics engine

Seismic damage simulation in urban areas based on a high-fidelity structural model and a physics engine, *Natural Hazards*, 2014

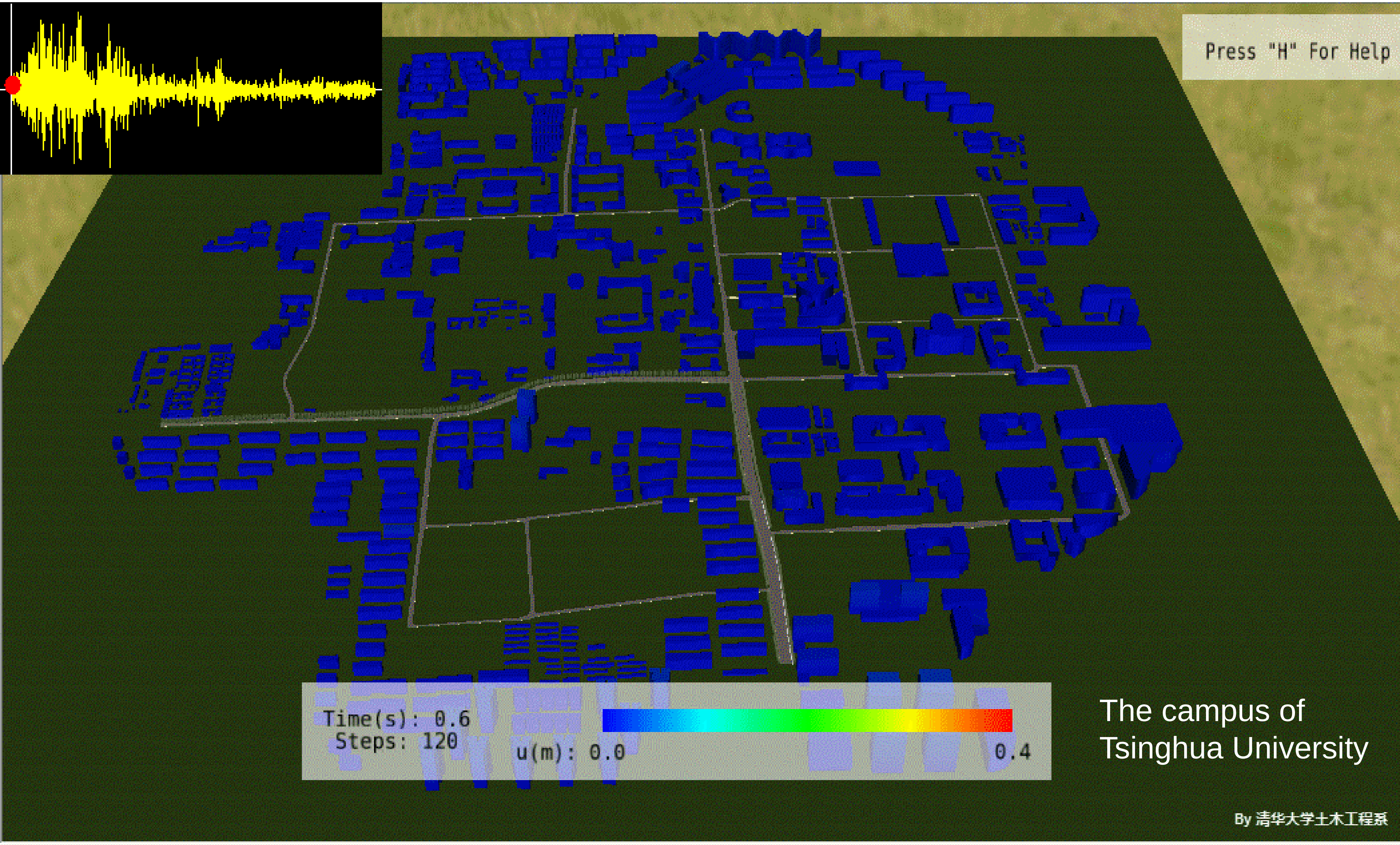
Collapse simulation



30 frame/s

High-efficient collapse simulation.

Application for Tsinghua Campus



The campus of Tsinghua University

By 清华大学土木工程系

Conclusions

Tsinghua University

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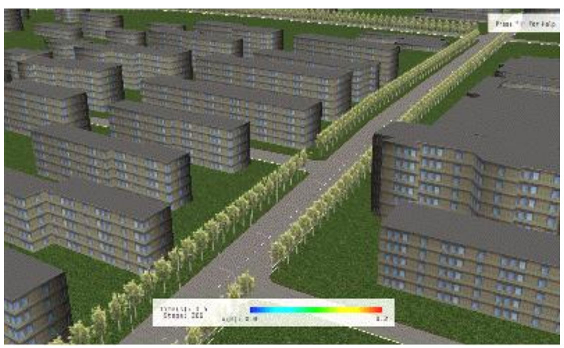
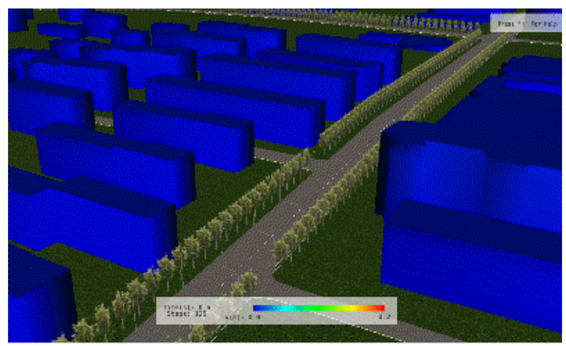
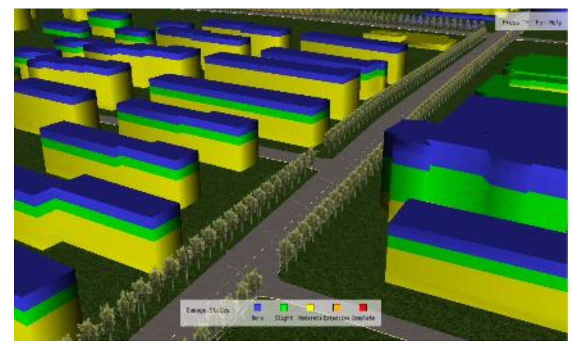


With Texture



Disp. Contour



Damage State

Fast	Cheap	High-fidelity	Realistic

Nonlinear time history analysis:

from mega-structures to cities?

Thank you for your attention!