Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 198 (2017) 836 – 844

Procedia Engineering

www.elsevier.com/locate/procedia

Urban Transitions Conference, Shanghai, September 2016

High performance computing for regional building seismic damage simulation

Xinzheng Lu[a,]*, Zhen Xu[b], Chen Xiong[c], Xiang Zeng[d]

[a]Key Laboratory of Civil Engineering Safety and Durability of China Education Ministry, Department of Civil Engineering, Tsinghua University, Beijing 100084, P.R. China

[b]School of Civil and Environmental Engineering, University of Science and Technology Beijing, Beijing 100084, P.R. China

[c] Department of Civil Engineering, Shenzhen University, Shenzhen 518060, P.R. China

[d]Beijing Engineering Research Center of Steel and Concrete Composite Structures, Department of Civil Engineering, Tsinghua University, Beijing 100084, P.R. China

Abstract

Modern cities are becoming integrated systems that consist of a high density of population and buildings. Once they are hit by earthquakes, the damage or collapse of buildings will result in huge economic losses and casualties. For the three key problems (i.e. modeling, computing and visualization) in regional building seismic damage simulation, a high-fidelity modeling method, a high-performance computing approach and a realistic visualization technique are proposed in this study, respectively. With respect to the modeling problem, a multi-degree-of-freedom (MDOF) shear model for multi-story buildings and a MDOF flexural-shear model for tall buildings are proposed. Also, the corresponding parameter determination methods are proposed. For the computing problem, a parallel computing method based on GPU (graphics processing unit) for regional building seismic damage simulation is proposed, leading to a speedup ratio of approximately 54 times. In regard to the visualization problem, a 3D-GIS data generation method using the widely accessible 3D urban polygonal model and a realistic visualization method are proposed for displaying the simulated urban earthquake disaster scenario. The above proposed methods have been used in a large-sized city and Beijing central business district (CBD). Accurate, efficient, and realistic simulations for regional building seismic damage have been achieved with these methods. The outcome of this study provides important technology for regional building seismic damage simulation, which can improve the ability of urban disaster prevention and mitigation.

Peer-review under responsibility of the organizing committee of the Urban Transitions Conference

* Corresponding author. Tel.: +86-10-62795364; fax: +86-10-62795364.
E-mail address: luxz@tsinghua.edu.cn

1877-7058 © 2017 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the organizing committee of the Urban Transitions Conference
doi:10.1016/j.proeng.2017.07.134

Keywords: Building damage simulation; regional simulation; high-fidelity model; high performance computing

1. Introduction

Many modern cities are transforming into more sophisticated and integrated infrastructure systems, which significantly increases the risk of earthquake-induced damages in these cities. For example, the 2008 Wenchuan earthquake in China [1,2] and the 2011 Christchurch earthquake in New Zealand [3] have led to massive loss of life and property. The resulting significant social, psychological and economic consequences have promoted the research on urban seismic damage simulation for improving the emergency preparedness and mitigating the possible earthquake-induced losses of high seismic regions and populous modern cities.

The well-known methods of regional building seismic damage simulation like the damage probability matrix method [4] and the Hazus method [5] can give a reasonable prediction of regional seismic damage. However, with the advances of computing power, regional building seismic damage simulation based on higher fidelity building models and nonlinear time-history analysis (THA) becomes possible, which can fully represent the characteristics of various buildings and different ground motions. For example, an important cutting-edge advance of using nonlinear THA for urban region is proposed by Hori [6] that is named as "integrated earthquake simulation (IES)". It has been applied to simulate the seismic damage of Tokyo city [6].

IES method still has three key challenges (i.e. modeling, computing and visualization) for regional building seismic damage simulation. (1) There are many different kinds of buildings in an urban area. Further studies are need to determine which type of building model should be used and how to determine the corresponding parameters. (2) The number of buildings in an urban area is huge. The IES method utilizes a super computer system to meet the computing requirements, which leads to the high cost of purchase and maintenance. An efficient and affordable computational solution should be proposed. (3) Regional building seismic damage simulation based on THA yields a huge volume of building response data, how to realistically visualize them is also an important issue.

In correspond to these three demands, a high-fidelity modeling method, a high-performance computing approach and a realistic visualization technique are proposed in this study, respectively. With respect to the modeling problem, a multi-degree-of-freedom (MDOF) shear model for multi-story buildings [7] and a MDOF flexural-shear model for tall buildings [8] are proposed. For the computing problem, a parallel computing method based on GPU (graphics processing unit) for regional building seismic damage simulation is proposed, leading to a speed up of approximately 54 times [9,10]. In regard to the visualization problem, a 3D-GIS data generation method using the widely accessible 3D urban polygonal model and a realistic visualization method are proposed for displaying the simulated urban earthquake disaster scenario [11]. The above proposed methods have been used in a large-sized city and Beijing CBD. Accurate, efficient, and realistic simulations for regional building seismic damage have been achieved with these methods. The outcome of this study provides important technology for regional building seismic damage simulation, which can improve the ability of urban disaster prevention and mitigation.

2. Methodology

2.1. High-fidelity building model

The seismic responses of multi-story buildings are dominated by the inter-story shear deformation. Thus, each building can be represented by a MDOF shear model [7]. The concept of the MDOF shear model is shown in Figure 1a. The model assumes that the mass of each story is concentrated on its elevation and represented by a mass point. The mass points of different stories are connected by nonlinear shear springs. The MDOF shear model can well capture the nonlinear properties of multi-story buildings, predict the engineering demand parameters (EDPs) on each story and consider the damage concentration on different stories [10]. A tri-linear backbone curve (Figure 1c) and a single-parameter hysteretic model (Figure 1d) are used to represent the inter-story behavior of each shear spring [5, 10, 12].

Different from the multi-story buildings, tall buildings exhibits a more complex flexural-shear coupled deformation mode. Therefore, a nonlinear MDOF flexural-shear model is proposed to fulfill such requirement [8].