# Chapter 17

# Computational Disaster Mitigation and Reduction Research Team

## 17.1 Members

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## 17.2 Overview of Research Activities

Computational Disaster Mitigation and Reduction Research Team is aimed at developing advanced large-scale numerical simulation of natural disasters such as earthquake, tsunami, flood and inundation, for Kobe City and other urban areas in Hyogo Prefecture. Besides for the construction of a sophisticated urban area model and the development of new numerical codes, the team seeks to be a bridge between Science and Local Government for the disaster mitigation and reduction.

Computational Disaster Mitigation and Reduction Research Team is also conducting to integrate all kinds of geo hazards, water hazards and related hazards. Demand for natural disaster simulations increased related to growing number of disasters in recent years. Therefore, we are developing appropriate sets of programs which meet the demand of calculations. Computational Disaster Mitigation and Reduction Research Team is dealing with the following three kinds of research topics.

Urban model development: Research for urban hazards requires urban models which represent structure and shape of cities in numerical form. However, it takes very long time to create urban models consisting of buildings, foundations and infrastructures like bridges, ports and roads with ordinary way. Therefore, it is indispensable to invent methods which automatically construct urban models from exiting data that is basically

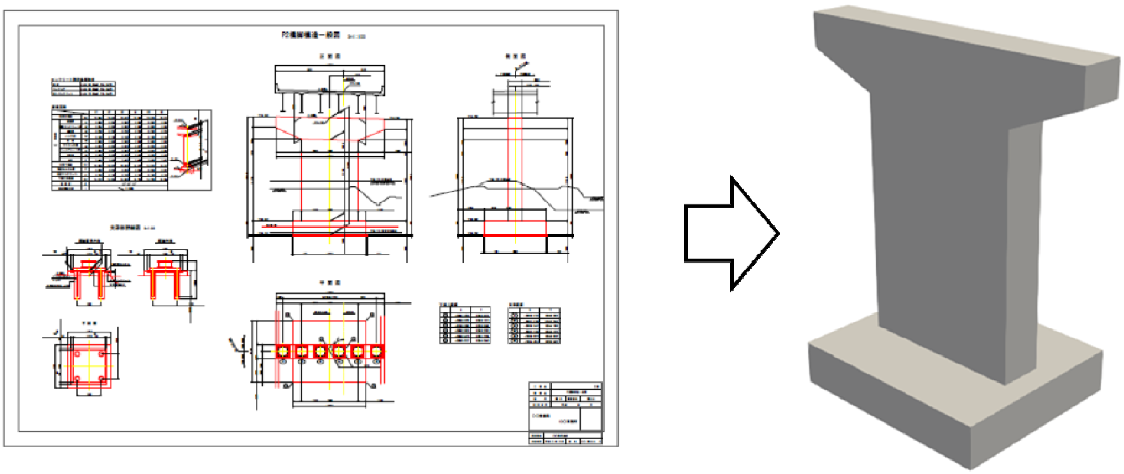

Figure 17.1: Automatically created three dimensional model of bridge pier.

ill-structured. Computational Disaster Mitigation and Reduction Research Team developed Data Processing Platform (DPP) for such purpose. By using DPP, construction of a national-wide urban model and 3D model construction from engineering drawings are achieved.

Performance enhancement of finite-element seismic ground motion simulation for many-core wide-SIMD architecture: We have been developing high-performance finite-element methods for the K computer and other CPU-based computational resources. In order to adapt the existing code to the Supercomputer Fugaku , we developed solver methods suitable for many-core wide SIMD architecture. An example of urban earthquake simulation using the developed finite-element method is conducted on the Intel Xeon Phi (Knights Landing)-based Oakforest PACS system.

Development of simulation-based assessment for debris-flow: To enable predictive simulation for debris-flow, we combined a 2D FVM simulation of debris flow and statistically-based landslide prediction. By using the numerous landslide data that was randomly generated based on the possibility distribution of landslides, 60 cases of the predictive simulations were simultaneously conducted on K computer. By this method, we numerically indicated that the variation of the estimated damage of debris-flow decreases in the downstream area of catchment topography. Additionally, we also started to use the debris-flow simulation as a generator of artificial damage map for machine learning training data.

## 17.3 Research Results and Achievements

### 17.3.1 Urban model development

In this year, we re-developed sets of programs for creating three dimensional urban model automatically. Those programs, namely Data Processing Platform (DPP) has been re-designed and implemented as Data Processing Platform Version 2 (DPP2). This program gives thematic elements on two dimensional computer aided design data (2D-CAD data) according to their levels of recognition, contexts of 2D-CAD data which come from arrangement of lines, figures and types of 2D-CAD data. Fig. 17.1 shows the result of three dimensional model of bridge pier from 2D-CAD data. The programs utilize rule-base processes for recognizing elements on the drawings in order to adopting the contexts and levels of recognition. However, the programs also utilize other kinds of process for recognizing elements, then it is possible to develop each software for many kinds of drawings using division of programming the software.

### 17.3.2 Performance enhancement of finite-element seismic ground motion simulation for many-core wide-SIMD architecture

We have been developing high-performance finite-element methods for the K computer and other CPU-based computational resources. Recent CPU systems such as the Arm SVE-based Fugaku system often equip many cores with wide-SIMD units; thus, changes in the algorithm and tuning designed for previous systems with lower

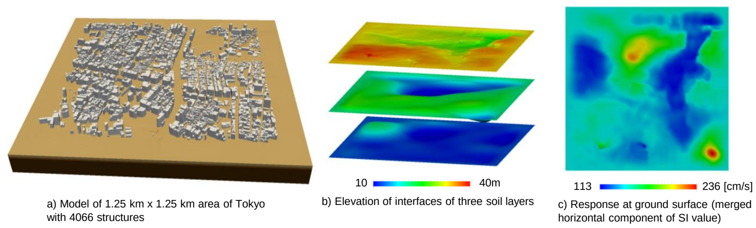


Figure 17.2: Application problem setting and results of finite-element seismic ground motion simulation. The ground is modeled with 252,738,195 second-order tetrahedral elements and 340,873,512 nodes.

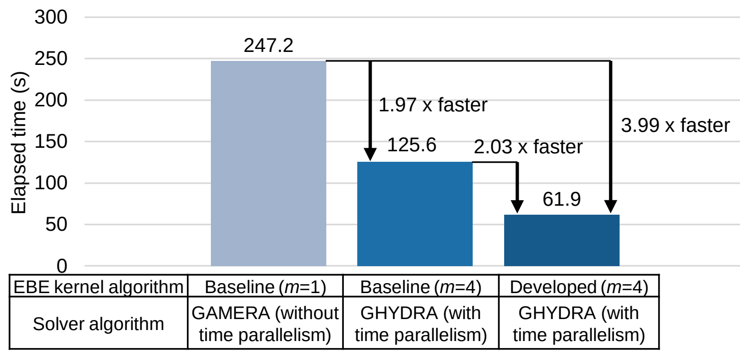


Figure 17.3: Performance of the developed finite-element solver on the application problem measured using 144 nodes of Oakforest-PACS.

core counts and narrower SIMD units are required to attain performance on recent systems. Indeed, when using the SC14 Gordon Bell Prize finalist solver, which attained high performance of 11.1% of peak FLOPS on the K computer, attained only 2.26% of peak FLOPS on the many-core wide-SIMD CPU-based Oakforest-PACS system at JCAHPC (Joint Center for Advanced High Performance Computing). Thus, we introduced a time-parallel solver algorithm and Element-by-Element kernel algorithms which can exploit performance of many-core wide-SIMD systems [1]. Here, based on the fact that the finite-element mesh is constant in time, the time-parallel solver algorithm rearranges the iterative solver such that random access is converted to sequential access in the matrix-vector product kernel. Cache-aware thread partitioning methods and SIMD-friendly blocking and loop splitting methods are introduced to accelerate the Element-by-Element based matrix-vector product kernel.

As an application example of the developed finite-element solver, we computed a 1.25 x 1.25 km area of Tokyo with a three-layered ground structure, discretized with 1 m sized elements (Fig. 17.2). Fig. 17.3 shows the elapsed time for solving the first 25 time steps of the input 1995 Kobe Earthquake wave with $dt = 0.001$ s using 144 nodes of Oakforest-PACS. We can see that by using the time-parallel algorithm, the baseline solver (GAMERA: SC14 Gordon Bell Prize finalist solver) was accelerated by 1.97-fold. Combination with the developed Element-by-Element kernel algorithm leads to a further 2.03-fold speedup, leading to application performance of 11.6% of FP64 peak and a total of 3.99-fold speedup from the baseline solver. We can see that suitable algorithms and tuning for the many-core wide-SIMD CPU architecture has led to high-performance for the random access-dominated unstructured finite-element application. The developed method is expected to be effective for other many-core wide-SIMD CPU-based systems such as the Supercomputer Fugaku.

### 17.3.3 Debris flow simulation

Debris flow is a phenomenon that develops from landslide and is a catastrophic hazard that can cause human damages. To establish a widely-applicable debris-flow assessing scheme, firstly, we developed a parallelized numerical code based on the MacCoamack scheme, one of a scheme in finite difference method. To validate the simulation, we applied it to the heavy rainfall disaster that happened in Asakura city, Fukuoka prefecture, in 2017. In the simulation that uses actual landslide data as initiate locations of the debris flow, the damaged

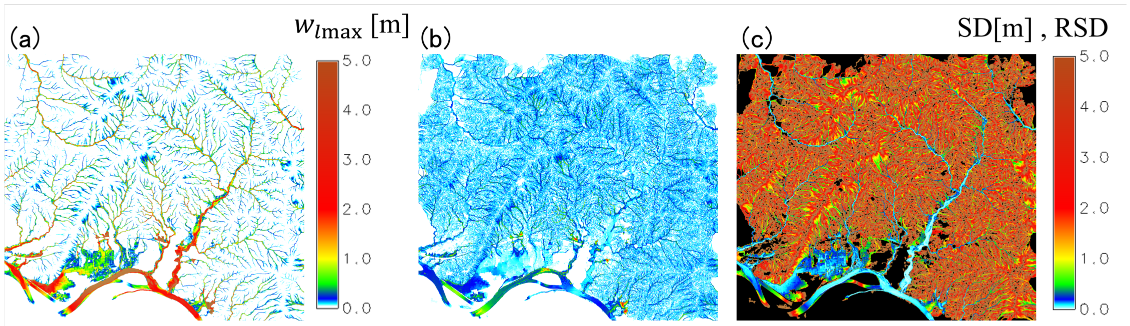


Figure 17.4: Average value, standard deviation, and relative standard deviation for maximum water level ampong 60 the simulation cases. [2].

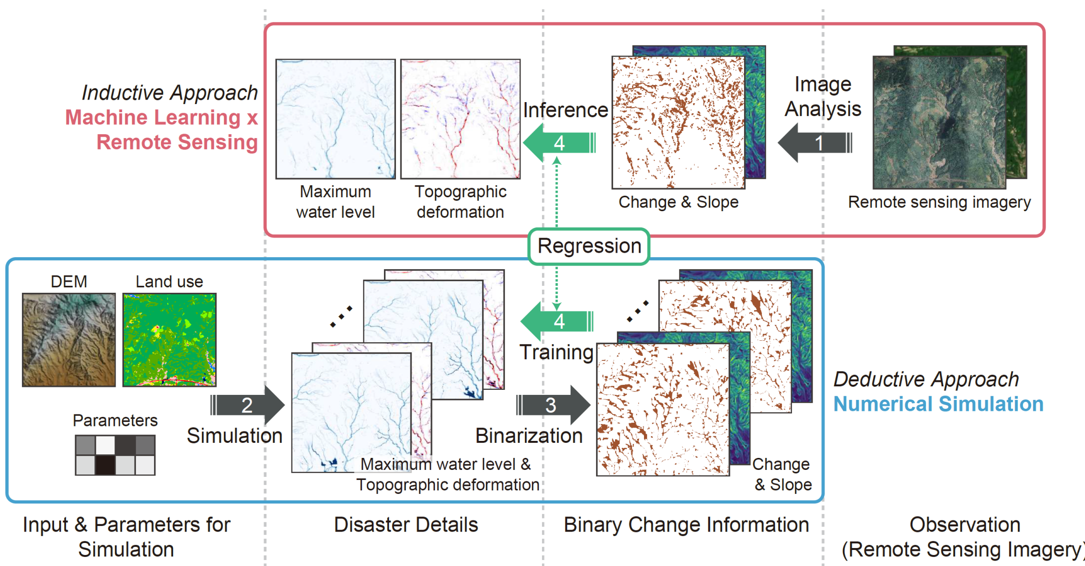


Figure 17.5: The overview concept of the proposed framework combining numerical simulation and machine learning [3].

area in the disaster was successfully reproduced. However, the landslide data can be obtained only in the post-disaster term; therefore, it was difficult to use the simulation for the prediction. To solve this problem, we generated the numerous artificial landslide data by applying the statistical landslide prediction method using logistic regression. We applied 60 cases of simulations using different artificial landslide data simultaneously using K computer. By summarizing all simulation outputs, we found that the variation of the maximum water levels and terrain deformation decreases as it flows to downstream in the catchment topography [2], see Fig 17.4. In other words, we numerically showed that the predictability of the debris-flow damages increases in the downstream area.

Another advantage of the proposed method is that it can generate numerous artificial damage maps for sediment-related disasters. To estimate the damage of disaster from the satellite imagery at an immediately following phase, AI trained with the actual disaster data seems to be very effective. However, the amount of training data is very limited because of the rarity of disasters. On the other hand, the proposed simulation can be used as a data generator to increase the amount of data. From this viewpoint, we started to collaborative work with the Geoinformatics Unit, RIKEN Center for Advanced Intelligence Project, to employ the simulation for the data generator. In this fiscal year, we succeeded in estimating the inundation depth and terrain deformation from remote sensing images by combining deep learning and numerical simulation[3], see Fig 17.5..

## 17.4 Schedule and Future Plan

1. Developing a national-wide real-time disaster simulation: We will enhance the automation of DPP2 to collect real-time seismic information and to perform an automated disaster simulation in a certain target area. This will reveal the extent to which speeding up is required for real-time characteristics.

2. Construction of templates for high fidelity models of highway network: In the template-based methodology, we need to ready the templates in beforehand, and the quality and quantity of templates will be critical to the output model.

3. Developing an algorism for resolving the topographic error to improve the quality of the simulation and establish efficient data preparation on the large-scale simulation.

4. Testing the rapid extraction from SAR observation employing AI based method using the multiple simulation results as learning data.

5. Damage estimation of the sediment and water-related disasters in urban area considering the ground condition change due to an earthquake.

## 17.5 Publications

### 17.5.1 Articles/Journal

[1] Fujita, K., Horikoshi, M., Ichimura, T., Meadows, L., Nakajima, K., Hori, M., Maddegedara, L., "Development of Element-by-Element Kernel Algorithms in Unstructured Implicit Low-Order Finite-Element Earthquake Simulation for Many-Core Wide-SIMD CPUs." Computational Science - ICCS 2019, Lecture Notes in Computer Science, vol 11536, 2019.
[2] Yamanoi, K., Oishi, S., Kawaike, K., Nakagawa, H., "Predictive Simulation of Concurrent Debris Flow: How Slope Failure Locations Affect Predicted Damage", Preprints (2020),
(doi: 10.20944/preprints202004.0118.v1).
[3] Yokoya, N., Yamanoi K., He, W., Baier, G., Adriano, B., Miura, H., Oishi, S., "Breaking the Limits of Remote Sensing by Simulation and Deep Learning for Flood and Debris Flow Mapping", Arxiv (2020),
(doi: arXiv:2006.05180)

### 17.5.2 Conference Papers

[4] O-tani, H., Oishi, S., Hori, M., "FLEXIBLE AND ROBUST METHOD OF AUTOMATED DIGITAL BRIDGE CONSTRUCTION CORESPONDING TO THE QUANTITY AND QUALITY OF INFORMATION FROM ENGENEERING DRAWINGS", First i-Construction Symposium proceeding, (2019).

### 17.5.3 Invited Talks

[5] Oishi, S., "Large scale numerical simulation of earthquake, tsunami, weather, flood and sediment disaster", Advanced sensor symposium 2019, (Osaka, July 24, 2019).

### 17.5.4 Oral Talks

[6] Oishi, S., "Digital-Ensemble Concept for Making Resilient Society against Natural Hazard", JpGU Meeting 2019, (Chiba, May 26, 2019).
[7] O-tani, H., "A Study on Automated Type Definition in the System for Utilization of Heterogeneous Datasets Based on Automatic Conversions of Data formats", 28th congress of GIS Association of Japan, (Tokushima, October 20, 2019).
[8] O-tani, H., Oishi, S. Hori, M., "FLEXIBLE AND ROBUST METHOD OF AUTOMATED DIGITAL BRIDGE CONSTRUCTION CORESPONDING TO THE QUANTITY AND QUALITY OF INFORMATION FROM ENGENEERING DRAWINGS", First i-Construction Symposium, (Tokyo, July 30, 2019).

### 17.5.5 Software

[9] O-tani, H., ""Data Processing Platform", (2019).

### 17.5.6 Patents

[10] O-tani, H., (2019) “Data interpretation device, method and program, data unification device, method and program and system to transform cites into digital twins”, 2019-139150. (2019).