Chapter 12

Disaster Simulation

Field of expertise: Computational Mechanics and Computational Disaster Science

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Summary

One of the essential words to describe the Great East Japan Earthquake is "unexpected" and there is nothing more vulnerable to this unexpectedness than numerical simulations. In this chapter, I will review the role and challenges of disaster simulations, which consist of setting conditions such as the type and scale of disaster, calculation tools, prediction (output) results, and how to improve them.

Keywords: numerical simulation, earthquake/tsunami, destructive phenomena, surrogate model

Introduction

Numerical simulations are expected to provide useful preliminary information for disaster preparedness within a set of assumed conditions. On the other hand, an essential word to describe the Great East Japan Earthquake is "unexpected". In this chapter, I reaffirm the utmost importance of assumptions in disaster simulation, and present my personal views on the current issues and developments.

1: Problems Revealed by the Great East Japan Earthquake

What happened?

Simulation is a means of predicting what will happen in the event of a disaster, but it is not possible to predict what has not been anticipated. This obvious fact was exposed and the enormous damage that occurred could not have been foreseen. From the standpoint of a specialist in numerical simulations, this is all I can say, but it is necessary to consider what role simulations played or should have played in the Great East Japan Earthquake, and what lessons we can learn for the future.

The reality is still unclear

I will leave the figures on the various types of damage to other chapters, but I will mention that the energy of the earthquake far exceeded the performance ability of structures, regions and cities. This resulted in destruction over a wide area and over a long period of time. It was so severe that it made us think that our prior countermeasures were meaningless. However, there must have been some meaning to our precautionary measures. In fact, thanks to the measures taken after the Great Hanshin-Awaji Earthquake, the damage to buildings caused by the Great East Japan Earthquake was within expectations, except for the problem of them interacting with the ground. It is also true that the structural measures taken in advance did not provide complete protection against the tremendous destructive power of the tsunami, but they must have contributed in some small way to mitigating the damage by absorbing the energy. However, as will be explained later, the actual situation cannot be clarified because the current simulation technology is unable to properly reproduce this type of destruction. Here, I focus mainly on the predictive function of disaster simulations, although the scientific verification function of the effectiveness of these proactive measures is also important, and we hope for the advancement of this technology.

2: Recognizing Unchanging Common Sense

In general, a simulation has an object for that simulation and tools are designed specifically for that object. A tool is a box, so to speak. When certain conditions (data) are put into the box, the result (prediction) is the output. Therefore, for a simulation, the assumptions are the input, and they are in one-to-one correspondence with the prediction results. However, even if the conditions are not prepared, it is possible to foresee possible events within the range of accuracy, as long as the range of conditions is determined. In other words, if multiple predictions are made in advance within the assumed range of conditions, interpolation will provide useful advance information for disaster preparedness. This is the conventional wisdom and it will continue to be.

While we naturally conclude that if the input to the assumed box is different from the actual situation, the predictions will not match reality. This does not mean that everything is OK if the input is correct. Whether the box works as expected and whether it provides reliable predictions is always in question. The simulation tool (i.e., the box) is a computational program, but it is also a mathematical model (i.e., an equation) that is designed to simulate a certain type of disaster. In fact, we should not forget that there are assumptions here as well. We must verify whether the model is trustworthy, whether it can adequately represent the phenomenon to be predicted, and whether the input information, such as physical properties, is reliable.

3: Requirements for Improvement and Delineation

If the simulation is limited to the prediction and reproduction of physical phenomena such as natural disasters, our purpose is to derive useful information that contributes to disaster prevention and mitigation through expressing physical phenomena in the language of mathematics, then replacing it with a language that computers can understand, and then reproducing it. Figure 12-1 summarizes numerical simulations of earthquake and tsunami disasters and the changes in hardware and software. As time passes, the high performance of hardware (represented by supercomputers) and the sophistication of software have progressed in step with each other, but with these changes, demands for more complex and large-scale (i.e., in the actual target area) disaster reproduction and predictions have increased as well. In parallel with the review of design standards and legal systems triggered by major disasters, computational disaster science has also been required to improve accuracy and adapt to new calculation targets.

In particular, after the Great Hanshin-Awaji Earthquake, it became necessary to reproduce phenomena that were not taken into account in the design calculations, such as the destruction and collapse of buildings, and this is still one of the important research topics in the field of computational science. On the other hand, even if the huge tsunami that occurred at the time of the Great East Japan Earthquake could be predicted, the damage to cities and structures caused by the fluid force was far beyond the complexity and scale that the simulation technology of the time could handle. In fact, the phenomenon of tsunamis destroying structures, engulfing debris, and hitting people and buildings cannot be reproduced even today, and many researchers are working hard to improve numerical simulations. Thus, the problems of destruction and the interaction between the ground, structures, and liquids should be continuously challenged.

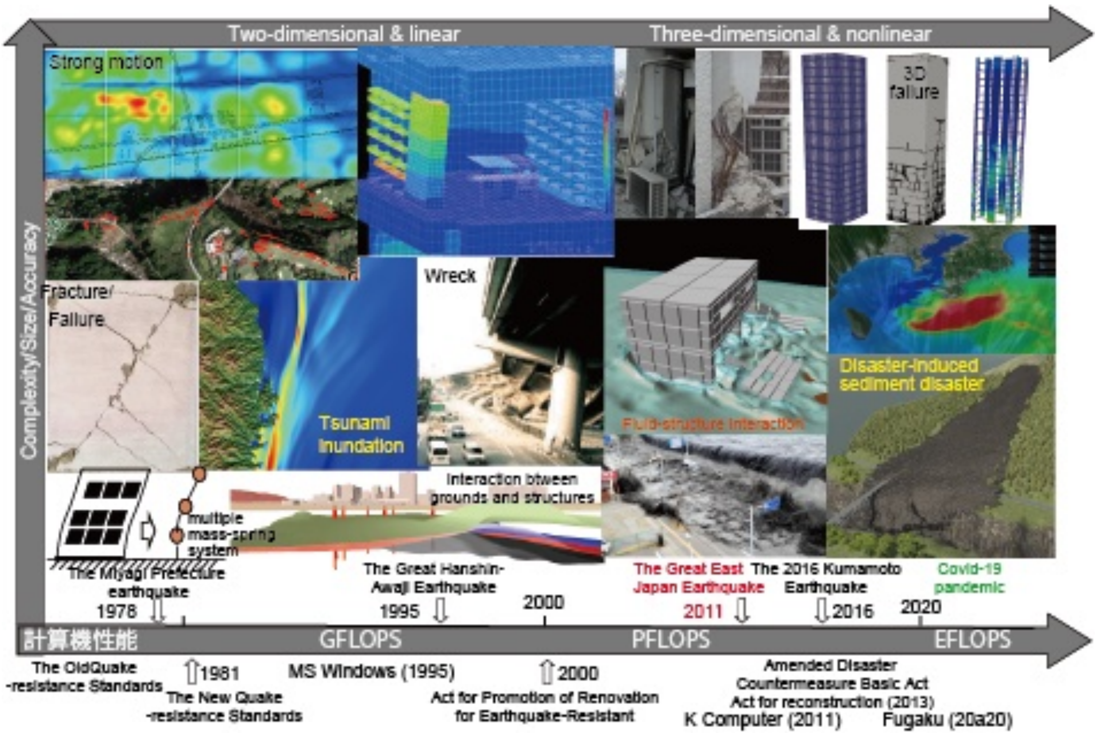

Figure 12-1. Disaster simulation and the changes in hardware and software

4: Demands for Efficiency and Certainty

There are several simulation tools that have a good track record and are currently used with a certain degree of reliability. These include tsunami arrival time and inundation predictions. The method of estimating the generation and size of a tsunami at the same time as an earthquake occurs, and making the most reliable prediction based on the results of calculations for many scenarios (cases) in advance, has proven to be sufficiently accurate for practical use (although there is no limit to what we can ask for). Once the tool is complete, the issues to be addressed are to reduce the computational cost by introducing model reduction and surrogate models, to pursue real-time performance, and to establish probabilistic risk assessment.

Figure 12-2 shows an example of calculating the tsunami that would hit Sendai Bay, Miyagi Prefecture, by changing the fault slip angle (rake) and the amount of slip (explanatory variables) of the fault. By expressing the maximum wave height as a function of the explanatory variables, as shown in Figure 12-3, we can estimate the real-time damage. We can also show the probability of other scenarios using the results of the most likely scenario as the expected value (Figure 12-4) (Kotani et al., 2020). Results of each scenario show the probability of occurrence for each.

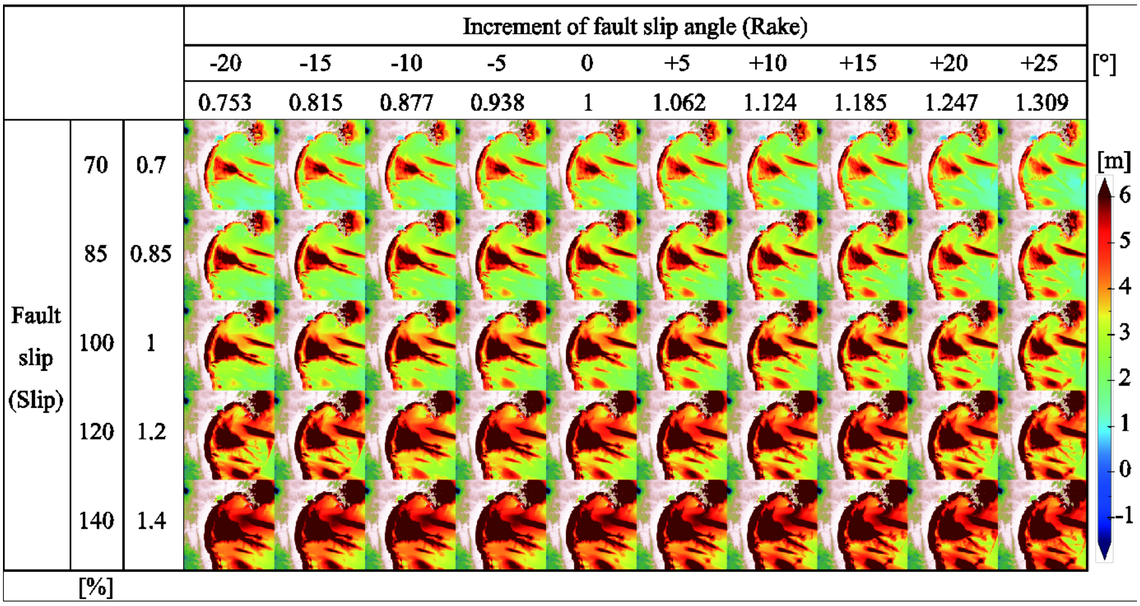

Figure 12-2. Variation in the maximum wave height of a tsunami reaching Sendai Bay resulting from a simulation assuming variation in the slip amount and slip angle of the fault that generates the tsunami

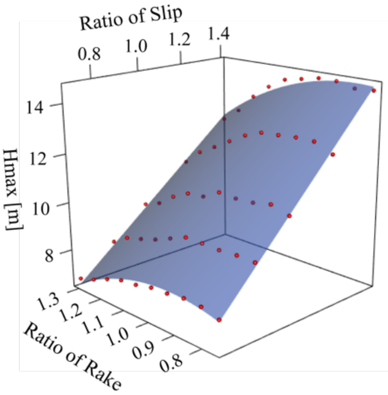

Figure 12-3. Expression of the maximum wave height as a function of the amount of fault slip and slip angle (rake) as explanatory variables

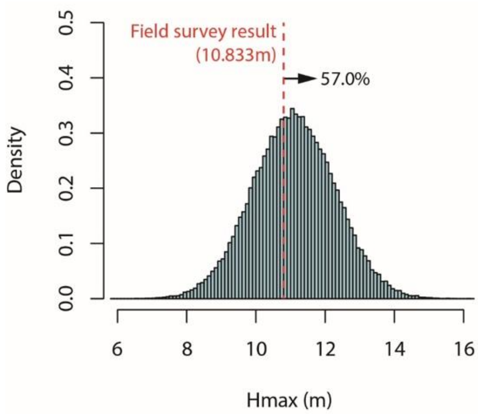

Figure 12-4 Density distribution of probable tsunamis with the maximum wave height in the assumed scenario

It is essential to conduct research so that we can solve problems that have so far been unsolvable, and continue practical research to improve efficiency and certainty of these solvable problems.

Conclusion - from the authors

We would like to develop numerical simulations as a disaster prevention technology that can answer with certainty the questions of whether or not a region, city, or structure has the most important function of protecting human lives from disasters, and if not, what measures should be taken.

References

Kotani, T., Tozato, K., Takase, S., Moriguchi, S., Terada, K., Fukutani, Y., Otake, Y., Nojima, K., Sakuraba, M., & Choe, Y. (2020). Probabilistic tsunami hazard assessment with simulation-based response surfaces. *Coastal Engineering*, *160*, [103719]. https://doi.org/10.1016/j.coastaleng.2020.103719