Simulation of Damage of a Wide Coastal Area due to the Huge Tsunami

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Tsunami simulations are carried out by the integrated numerical model named STOC which includes a non-hydrostatic and three-dimensional model of STOC-IC. Applying STOC to the area suffering damages by the 2004 Indian Ocean Tsunami, the effect of coastal buildings is discussed. To investigate the mechanism of destruction of land structures due to the tsunami force, the large experiments were conducted with the wooden wall of a wooden house.

Keywords: Tsunami, Numerical Models, Multi Scale Modeling, Large Experiments, Indian Ocean Tsunami

1. Introduction

Many people recognized again that tsunamis had devastating forces and caused various damages such as destruction of structures, beach erosion, etc. after the 2004 Indian Ocean Tsunami. However, many people do not evacuate immediately even when they feel earthquake motion in a tsunami prone area, because they misunderstand characteristics of tsunami and vulnerability against tsunamis in their living-areas.

On the other hand, many people evacuated in Indonesia at the tsunami event on March 28, 2005, because they had the experience of tsunami disaster caused by the Indian Ocean Tsunami on December 26, 2004. This suggests that we need to predict and understand disasters realistically which will be caused by tsunamis in the future.

In this project, numerical and physical simulation has been investigated. Macro-Micro scale interlocked tsunami simulator named STOC (Storm surge and Tsunami simulator in Oceans and Coastal areas) has been developed. For the validity of numerical models, large physical tests were conducted. This paper described the briefly explanation of numerical simulation system and results of large physical tests.

2. Numerical simulation system

2.1 Outline of tsunami propagation analysis

The tsunami propagation simulation system, named STOC, is composed of three different sub-models: STOC-ML, STOC-IC and STOC-VF, in order to calculate the tsunamis interacting with structures as well as propagating in the oceans (see Fig. 1, Tomita et al., (2006) [1]).

STOC-ML is a multi-level model in which water bodies

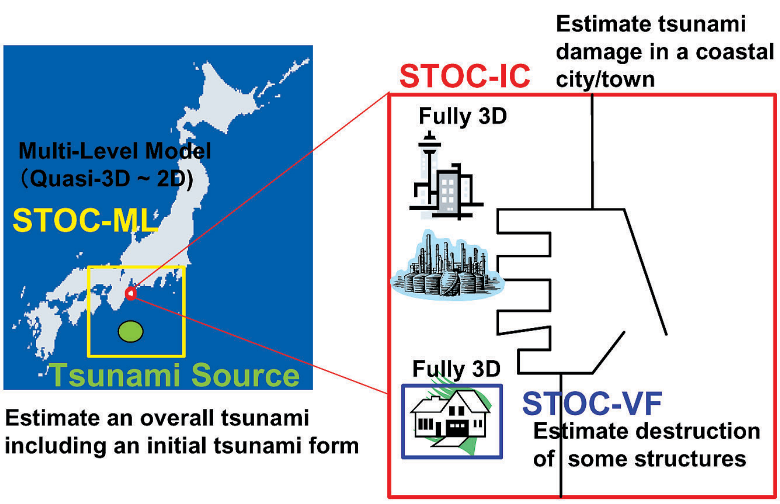

Fig. 1 Outline of STOC simulator.

are divided vertically into some horizontal layers. The governing equations are Reynolds-Averaged Navier-Stokes equations, although the assumption of hydrostatic pressure is applied in each layer. No calculation of Poisson equation of water pressure results in reduction of computational effort and then STOC-ML is applied to wide areas such as the oceans.

The governing equations of STOC-IC are Reynolds-Averaged Navier-Stokes equations and continuity equation for incompressible fluid in three dimensions. Free water surfaces are detected by the vertically-integrated continuity equation to reduce computational effort. The governing equations are solved by the finite difference method with SMAC algorithm.

The governing equations of STOC-VF are Navier-Stokes (Reynolds) equations and the continuity equation for three-dimensional incompressible fluid modified by the porous-body method. The VOF method is adopted to analyze the free surface boundary.

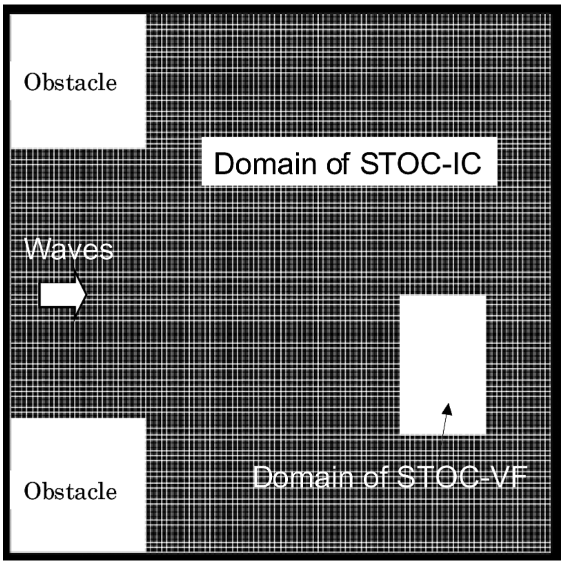

Fig. 2 Calculation domain.

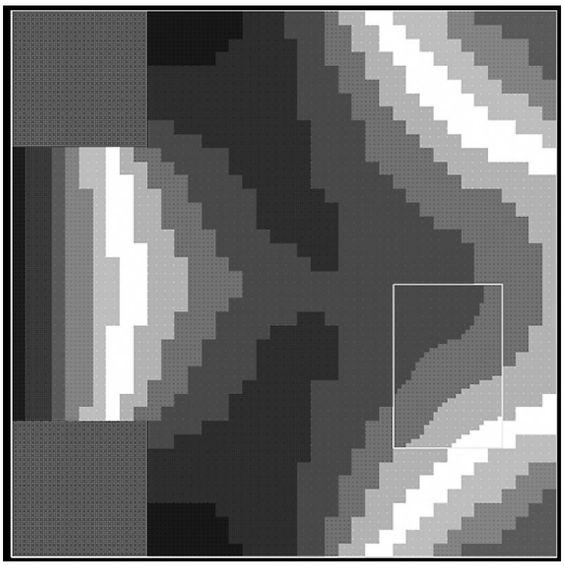

Fig. 3 Snap shot of the water profile.

2.2 Coupling system

The connection between STOC-ML and STOC-IC is made in overlapping zones in which the physical quantities such as the water surface displacement, velocities, pressure, etc. in each computational area of STOC-ML and STOC-IC are adjusted using the interpolation technique.

STOC-VF is made weak connection with STOC-IC, that means data of velocities and water surface displacement is send to each other. Figure 2 shows the area of test calculation and small waves are given. The snap shot of the water profile is shown in Fig. 3. It shows that waves are smoothly transported in the area of STOC-VF, though there is a slight difference between water profile in the STOC-IC domain and that in the STOC-VF domain.

2.3 Outline of structure destruction analysis

Distinct element method, called DEM, is applied to the structure destruction analysis. DEM can calculate large deformation and destruction. The DEM domain is set in the STOC-VF domain (see Fig. 4). Wave pressure is given to DEM from STOC-VF and the porosity is given to STOC-VF if the structures are deformed. Figure 5 shows the test results of wall destruction due to waves.

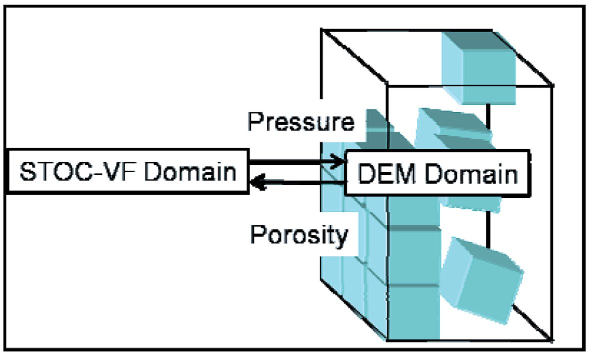

Fig. 4 Relation between DEM and STOC-VF.

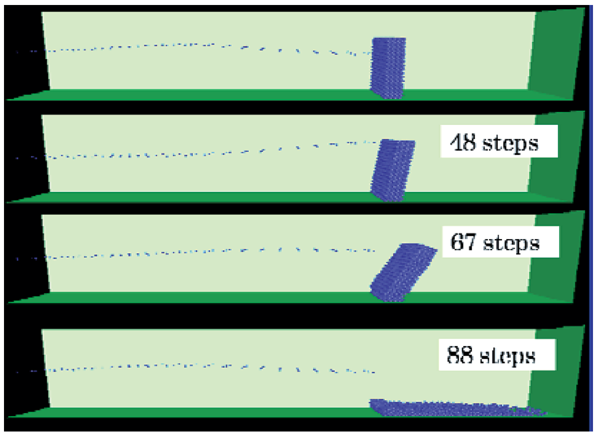

Fig. 5 Result of destruction due to waves.

3. Large Model Tests

3.1 Physical experimental setup

The size of the Large Hydro Geo Flume is 184 m long, 3.5 m wide and 12 m deep at the maximum. This wave flume has the 14 m stroke and can generate the 2.5 m height tsunami. The concrete walls are set up from the edge to the position in 1.8 m (Fig. 6). The size of walls is 2.5 m high and 2.5 m wide. The thickness of walls is changed from 6 cm to 12.5 cm. Figure 7 shows a plan of reinforced concrete wall of 2 rigid sides. In the figure, G means the position of the strain gauge and P means the position of the pressure gauge.

3.2 State of tsunami attack

Maximum height of tsunami above the still water level is 2.5 m and inundation depth in front of wall is 1.8 m. Figure 8 shows the time history of pressures at P1 and P2, which position is shown in Fig. 7. It indicates that the impulsive load, that exceeds 10 ton at P1, is attacking fast and the sustainable pressure is attacking next. The state of tsunami attack is shown in Photo 1. The very big splash is occurred in a moment of attacking tsunami.

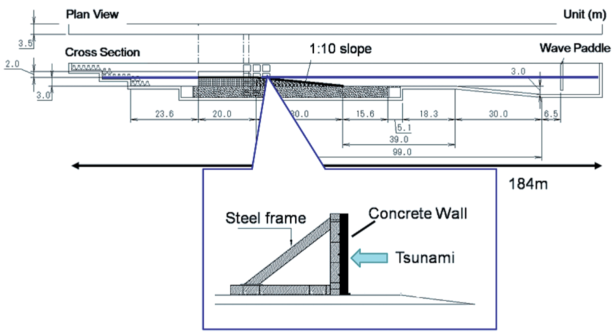

Fig. 6 experimental set up.

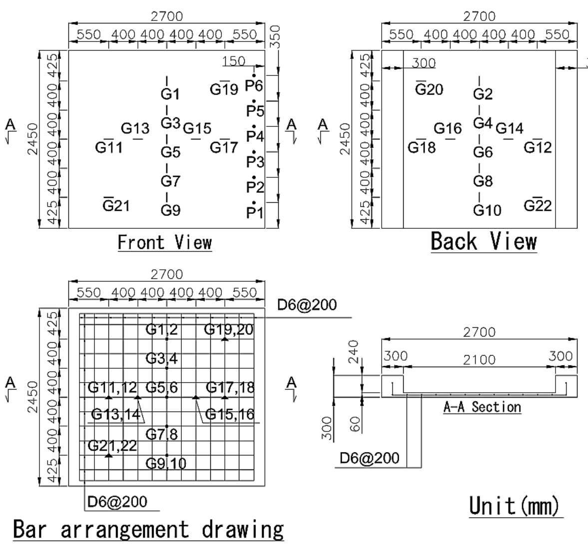

Fig. 7 Plan of reinforced concrete wall.

3.3 State of destruction

Photo 2 shows the failure of the reinforced concrete wall with 6 cm and 10 cm thickness from the front. It is found that the concrete wall is broken in the instance of tsunami attacking at the lower part of wall.

3.4 Result of numerical simulation

The wall destruction simulation is calculated by using coupling system of STOC-VF and DEM. Figure 9 shows the results of simulation of weak wall. It is found that the walls are broken in punching shear mode similar to physical experiment results.

4. Conclusion

The coupling system from tsunami propagation to structure destruction is developed. The validity of this model is verified by using the large physical model tests. To apply this system to the field data is the final step.

References

[1] T. Tomita, K. Honda and T. Kakinuma, "Application of Three-Dimensional Tsunami Simulator to Estimation of Tsunami Behavior around Structures," Proc. 30th Int. Conf. on Coastal Eng., 2006.

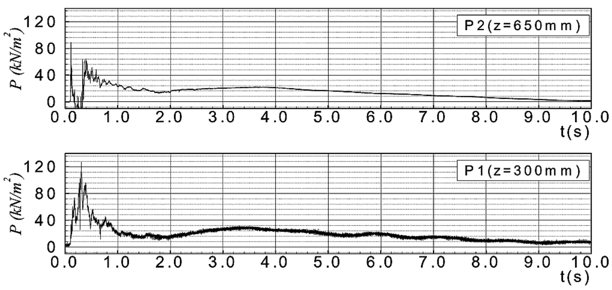

Fig. 8 Time history of tsunami pressure on the wall.

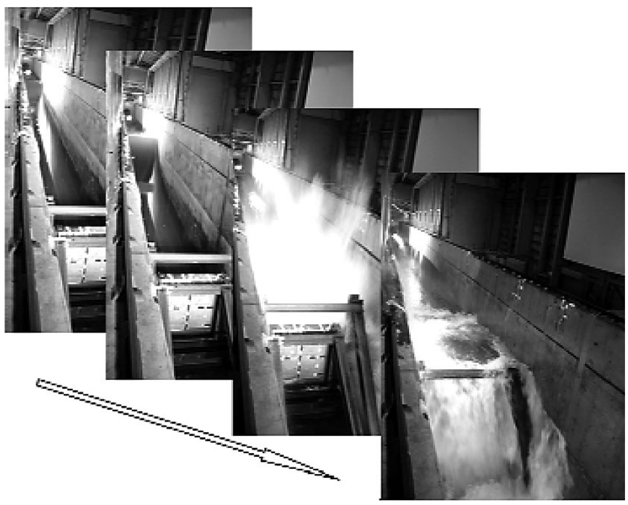

Photo 1 State of tsunami attack.

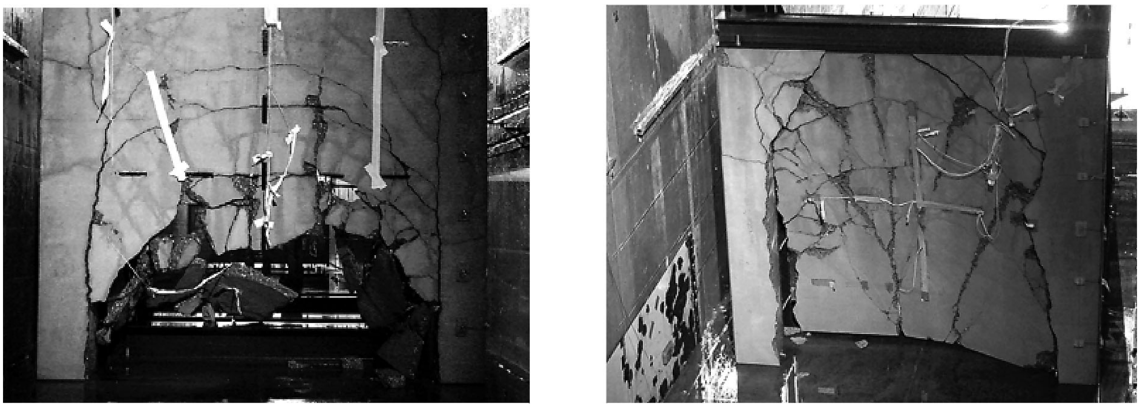

Photo 2 Failure of concrete wall with 6 cm (left) and 10 cm (right) thickness.

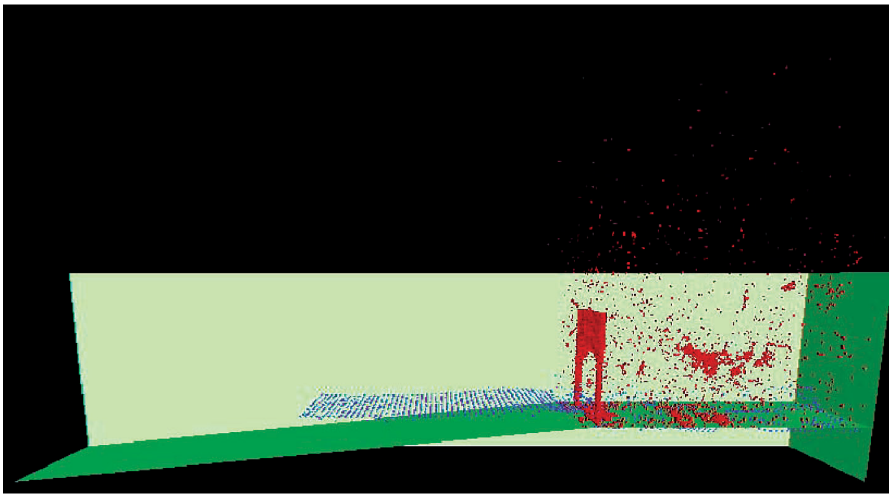

Fig. 9 Calculation result of wall destruction.

巨大津波による広域沿岸被害シミュレーション

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津波による災害をより深く理解し、さらに、市民への避難喚起、啓蒙の促進を図ることを目的として、その現象を再現する数値シミュレータの開発、大規模実験を行っている。

数値シミュレータは、これまで開発を続けてきたSTOC (Storm surge and Tsunami simulator in Oceans and Coastal areas) を基本として、大洋を伝播する津波から構造物を破壊する局所的な津波までを数値計算により解析するために、マルチスケールを対象にしたマルチモデルからなる階層型連携シミュレーションモデルの開発を行っている。

本モデルの妥当性を検証するために、大規模な模型実験を行った。長さ184m、深さ12m、幅3.5mの水槽の中に、幅2.7m、高さ2.5m、厚さ (6cm～10cm) のコンクリート壁面を設置し、そこに高さ2.5mの津波に相当する衝撃波力を作用させる実験である。その状態と同じ状態を数値計算で行い、その妥当性を確認する。

図1にその結果を示す。左図はSTOCを用いて、波を作用させて壁面が破壊する様子を計算したものであり、右図は模型実験によりコンクリート壁 (厚さ6.0cm) の破壊の様子である。模型実験の結果を見ると、壁面の下部の方が津波力が強いため、その付近を中心として押抜きせん断破壊され、穴が空いている様子がよくわかる。数値計算においても、その様子が再現されており、定性的には、本計算システムの結果が実験結果と整合していることがわかる。今後、本システムを現地に適用し、定量的に再現できるかどうかを確認するとともに、今後の大規模津波に対して破壊・変形まで含めた予測手法の構築を行う。

キーワード：階層型連携シミュレーションモデル, マルチスケール, マルチモデル, 津波, 被害シミュレーション

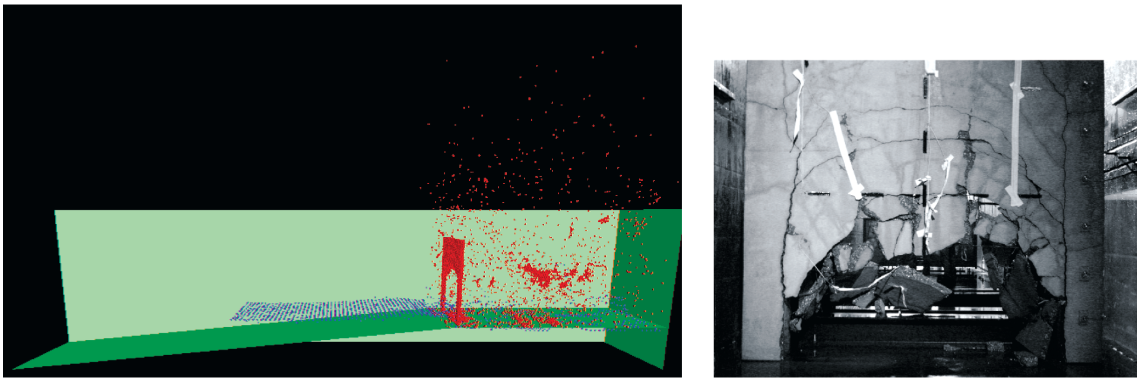

図1　壁面破壊の様子 (左：STOCにより計算、右：コンクリート壁面破壊実験結果)