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

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The large tsunami has often the large impulsive tsunami force. It is possible that this type of force has three times or more force compared with usual tsunami force. So, to develop the estimation tool for the impulsive tsunami force is important for the prediction of failures due to the large tsunamis. In this report, the mechanism of destruction of concrete walls due to tsunami force was investigated with large hydraulic experiments and numerical simulations.

Keywords: Tsunami, Numerical Models, DEM, Large Experiments

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. Especially, in the area where the more than 10m tsunami was attacking, many houses in a place away from coastline by about 1 km were broken.

In the case of large tsunami attacking, the type of tsunami force in the inundated is the surge front tsunami force. Surge front tsunami force may qualitatively divide into the following types (see Fig. 1) from past researches and the experiments conducted so far.

It seems to be classified according to the speed and wave profile of inundated tsunami. Type 1 shows the case where the overflow with slow speed acts on the structures. Suppose that such a situation is called overflow type in this paper. Type 2 shows the case where overflow with quick speed acts. When the inundated tsunami carries out soliton fission or becomes bore, it may be accompanied by the flow quick in this way. It is called bore type in this paper. Type 3 shows the case where tsunami breaks in front of structures. This type may cause when the structures are near the coast

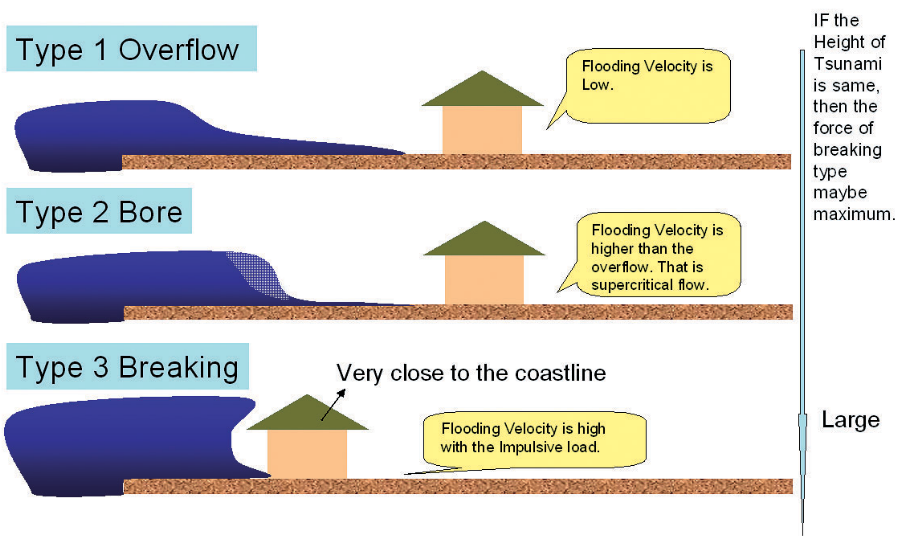

Fig. 1 Type of surge front tsunami force.

line and slope of seabed is steep, which is called breaking type. If the inundated height of tsunami is same, then it is thought that the maximum force becomes large as it becomes breaking type from overflow type. However, it is not clear how large the force is and where a boundary line of type is.

So, to develop the estimation tool for the impulsive tsunami force is important for the prediction of failures due to the large tsunamis. In this report, the mechanism of destruction of concrete walls due to tsunami force was investigated with large hydraulic experiments and numerical simulations.

2. Large Hydraulic Experiments

2.1 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. 2). Figure 3 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.

The size of walls is 2.5 m high and 2.7 m wide. The thickness of walls is changed from 6 cm to 10.0 cm. Specifications of concrete walls are shown in Table 1.

2.2 The relationship between state of destruction and tsunami force

The time histories of tsunami pressure of case 2 are shown in Fig. 4. The large impulsive tsunami force was attacking at P1 to P3 around 43.9s. The state of destruction at the time of point A and B in Fig. 4 is shown in Photo 1. Photo 1 took from behind by hi-speed camera. The cracks were occurred from bottom to top at the time of point A. It was found that the concrete wall was broken in the instance of tsunami attacking at the lower part of wall.

Table 1 Specifications of concrete walls.

Case No.	Thickness of wall (mm)	Compressive strength (N/mm^2)
1	60	21
2	60	33
3	75	21
4	75	33
5	80	32.7
6	90	32.7
7	100	21
8	100	32.7

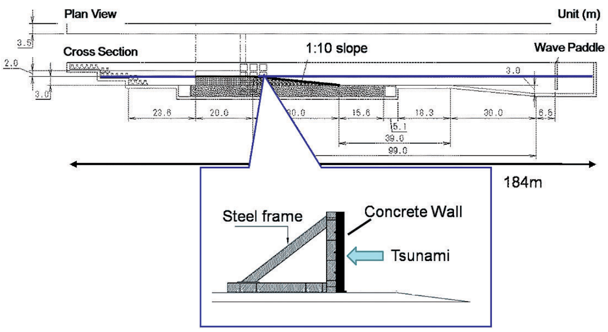

Fig. 2 Experimental set up.

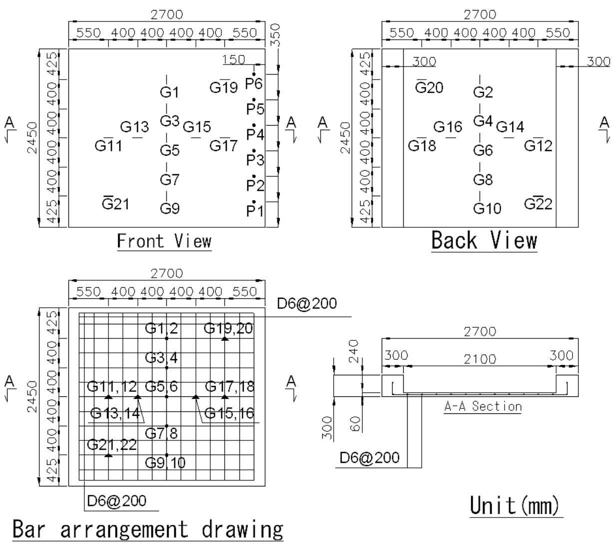

Fig. 3 Plan of reinforced concrete wall.

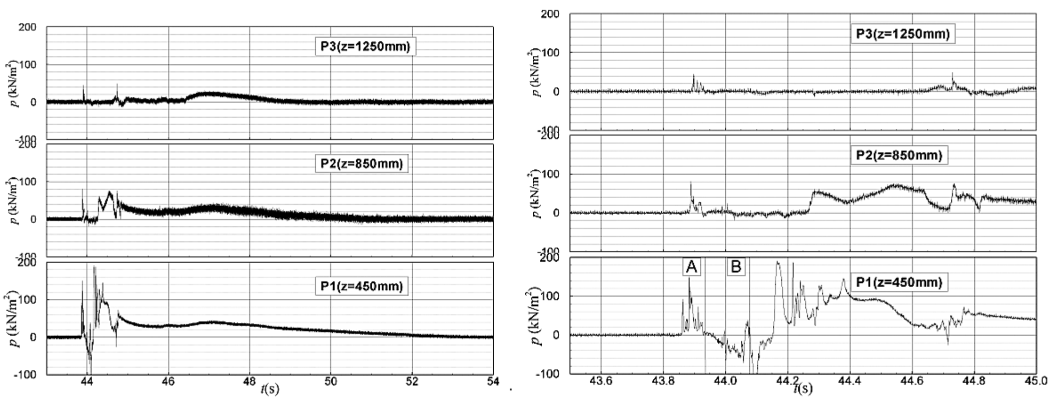

Fig. 4 Time histories of tsunami pressure. (left figure: wide range, right figure: detailed)

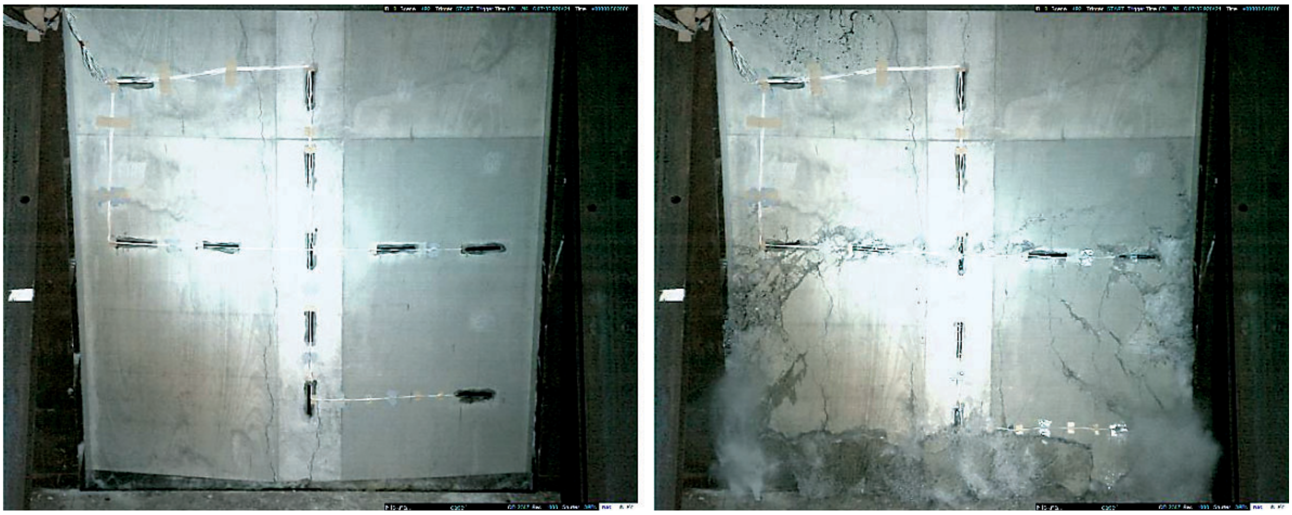

Photo 1 The state of destruction at the time of A and B. (left: A, right: B)

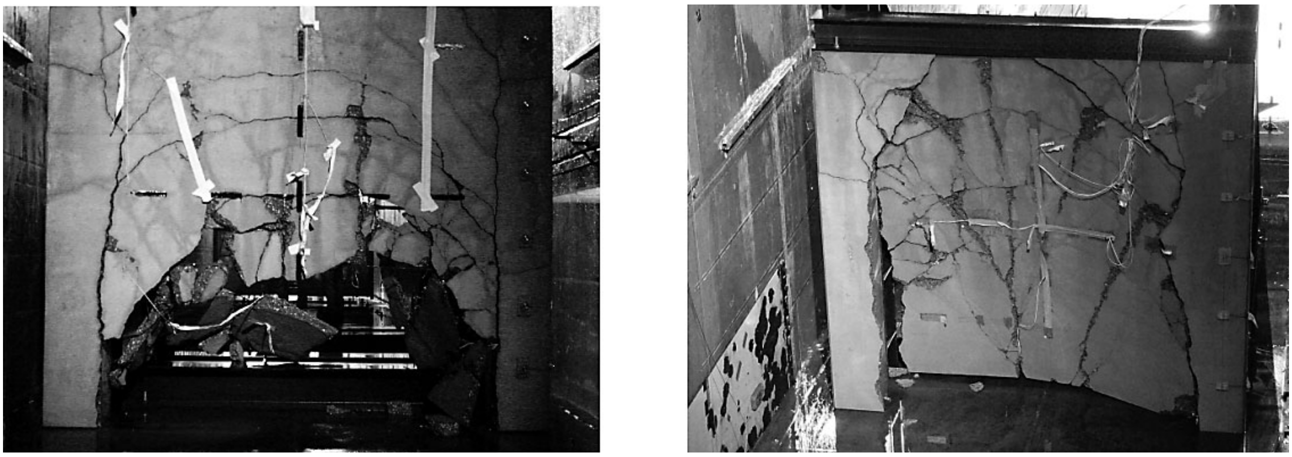

Photo 2 Failure of concrete wall with 6 cm (left) and 10 cm (right) thickness.

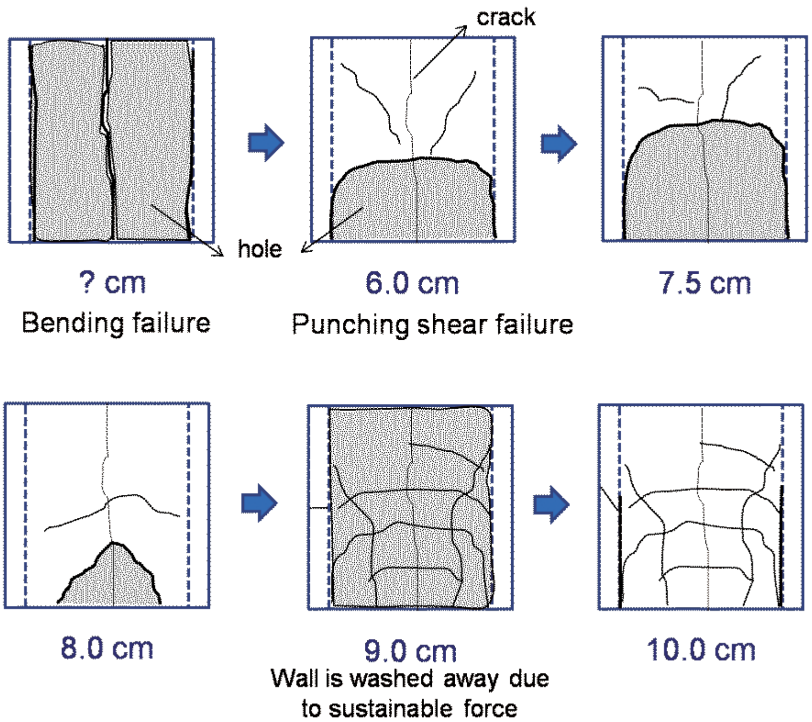

Fig. 5 Difference of the state of concrete wall destruction.

Photo 2 shows the failure of the reinforced concrete wall with 6 cm and 10 cm thickness from the front view. Figure 5 explains the difference of the state of destruction according to the thickness of wall. Under this tsunami condition, if the thickness of wall is more than 10 cm, the column is probably broken.

3. Numerical Simulations

3.1 Numerical scheme

The destruction of concrete walls was analyzed by numerical simulations. The scheme of the numerical simulation is PDS-FEM, which is essentially FEM with Particle Discretization Scheme. This method is the fusion of FEM and DEM. In this scheme, displacement filed has the same accuracy of FEM with linear interpolation functions at nodal points. Characteristic functions of conjugate geometries are used to discretize conjugate variables, function and derivative. Numerous discontinuities in the discretized displacement filed can be used to model cracks, efficiently

3.2 Model

Figure 6 shows the concrete wall model of numerical simulations. Material properties of concrete are the followings; Young's modulus is 30 GPa, Poisson's ratio is 0.2, density is 2400 kg/m^3. Number of elements is 4.5 million, and number of nodes is 1 million. Pressure distribution measured during the real experiment is used as the input load. So, the pressure between measuring points is interpolated.

3.3 Results of numerical simulations

Figure 7 shows the result of the cracking progress in the case of 6cm thickness. Comparing with photo 2, the small cracks are not so accurate, but the final broken area is almost same. The result of 10 cm thickness is shown in Fig. 8. The crack progress of the back side is different with that of the front side. Radial cracking is shown stronger than the 6 cm case. Photo 2 indicates that the punching sheer failure is not so remarkable in the case of 10 cm. So, the material properties or the composite coefficient needs to be modified. The

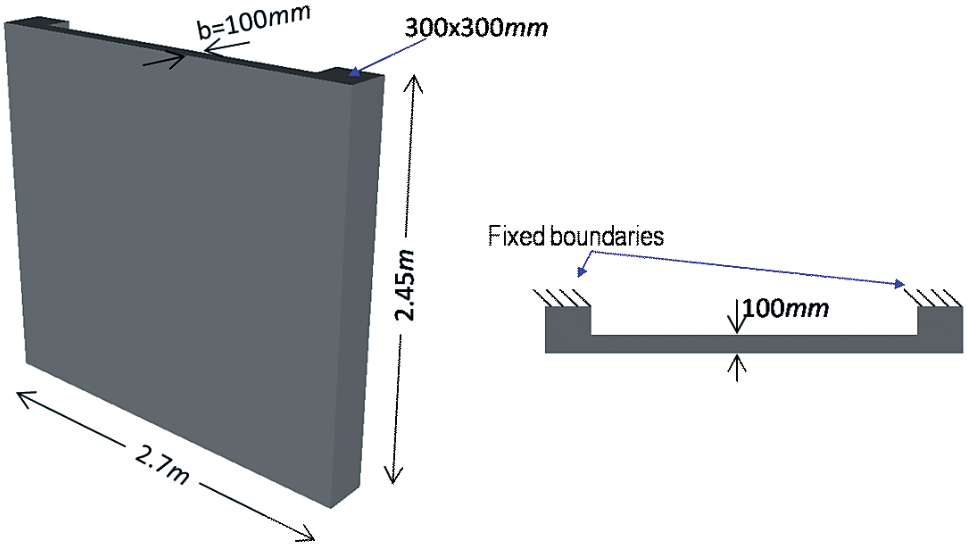

Fig. 6 The numerical concrete wall model.

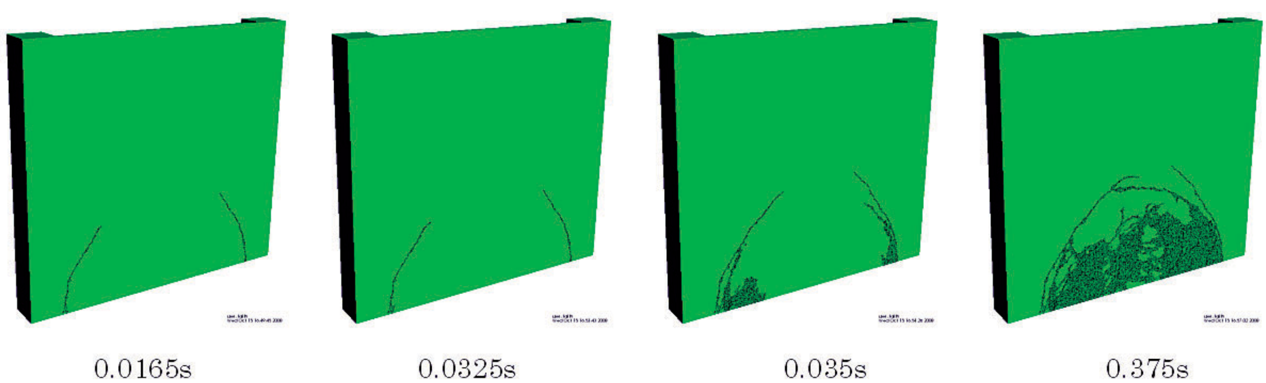

Fig. 7 The result of cracking patters with 6 cm thickness. (front view)

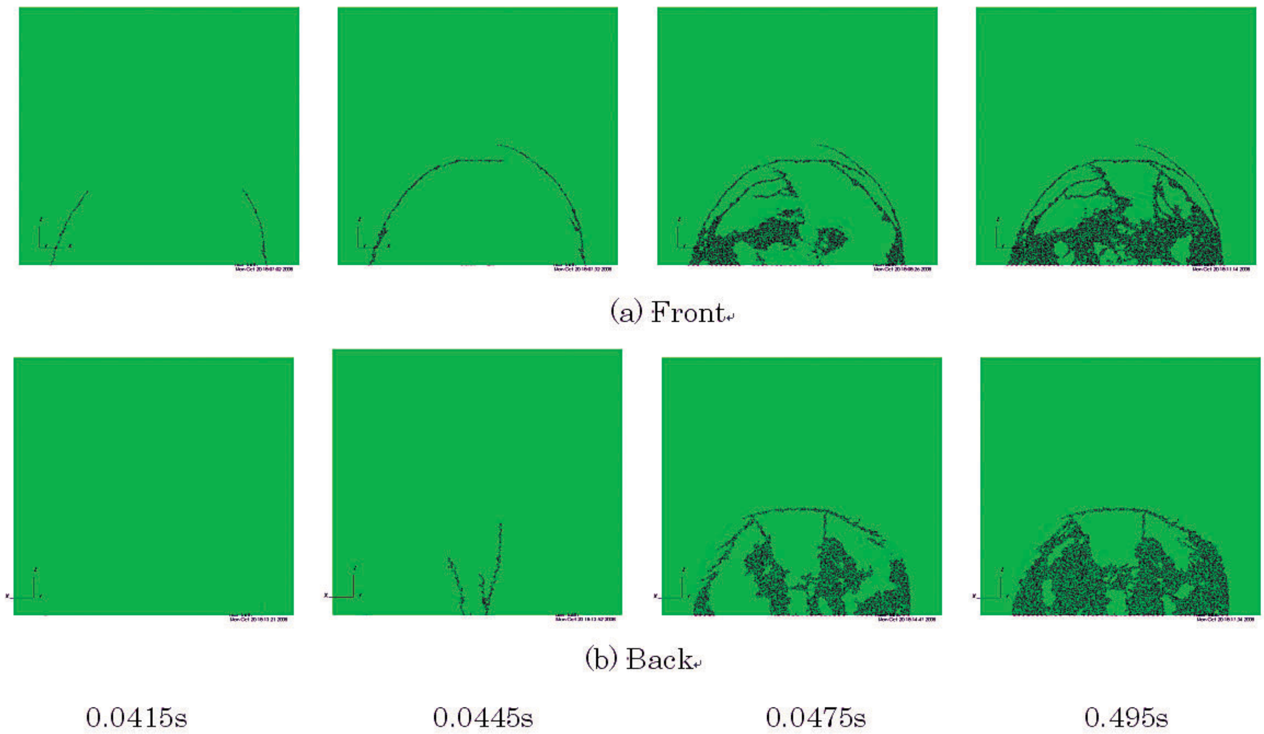

Fig. 8 The result of cracking progress with 10 cm thickness.

comparison with photo 2 describes that the numerical concrete wall is weaker than the hydraulic concrete wall. So, this is the future subject. However, potential in this numerical model can be able to predict the destruction of structures due to impulsive tsunami force.

4. Conclusion

The mechanism of destruction of concrete walls due to tsunami force was investigated with large hydraulic experiments and numerical simulations. The comparison with experimental results indicates that potential in this development numerical model can be able to predict the destruction of structures due to impulsive tsunami force.

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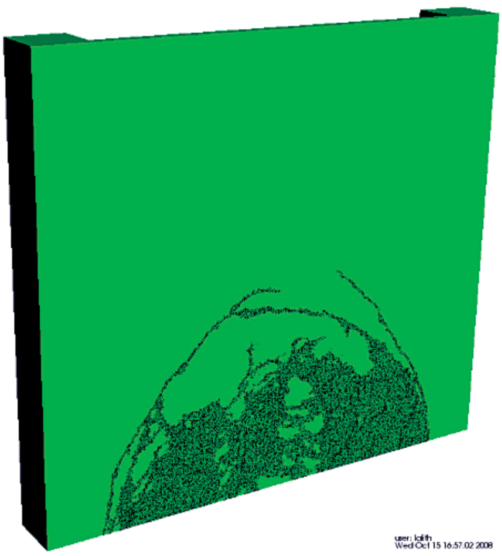
津波による災害をより深く理解し、さらに、市民への避難喚起、啓蒙の促進を図ることを目的として、その現象を再現する数値シミュレータの開発、大規模実験を行っている。

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。

本研究では、津波による構造物の破壊に焦点を絞り、コンクリート壁面を用いた大規模破壊実験と、PSD-FEM法を用いた詳細はクラック進展に関する数値シミュレーションとを比較検討した。その結果、より強度の強い壁面の計算においては、数値シミュレーションのほうが弱い板として表現される傾向になったため、構成係数などの見直しが必要であるものの、最終的な押し抜き剪断破壊域に関しては、おおよその予測が可能であることがわかり、本モデルを用いた津波による構造物の破壊予測手法が、構築できる可能性を秘めていることが確認された。

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



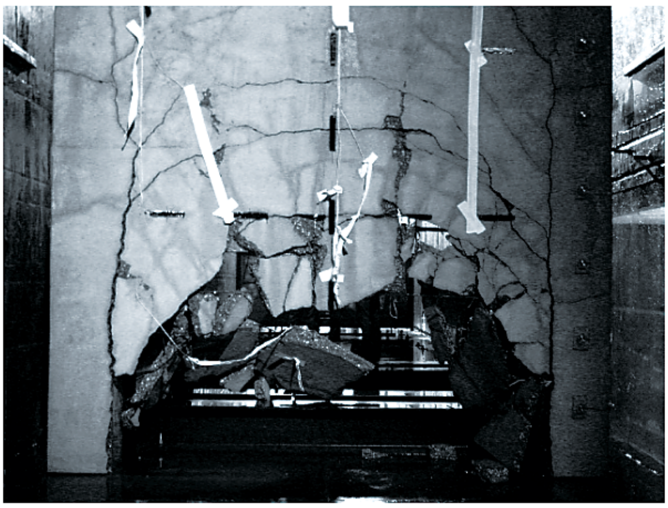


図1　壁面破壊の様子(左：PSD-FEMによる計算、右：壁面破壊実験結果)