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COLLAPSE ANALYSIS OF A STEEL FRAME BUILDING UNDER TSUNAMI FLOW

Daigoro Isobe[*] and Seizo Tanaka[*]

[*]University of Tsukuba
1-1-1, Tennodai, Tsukuba-shi, Ibaraki, 305-8573, Japan
e-mail: <isobe@kz.tsukuba.ac.jp>
webpage: http://www.kz.tsukuba.ac.jp/~isobe/index.html

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Abstract. *The Great East Japan Earthquake and the following tsunami that occurred on March 11, 2011 caused a significant disaster along the ocean-side of the Tohoku area. The big tsunami carried different kinds of debris such as ships and cars up the stream, which caused additional damage to the buildings in the area. In this paper, a finite element approach for the damage estimation of a steel-framed building under tsunami flow is described. A seismic wave recorded during the earthquake was first applied to the model, followed by an input of fluid forces owing to the tsunami wave. A three-dimensional free-surface flow analysis code based on the volume of fluid (VOF) method was adopted to simulate wave propagation problems and compare the obtained wave forces between several inflow conditions and building shapes. Then, a debris model with a velocity was collided, and the collapse behavior of the building was simulated using the adaptively shifted integration (ASI)-Gauss code.*

1 INTRODUCTION

A huge disaster occurred after the Great East Japan Earthquake on March 11, 2011, when the following big tsunami washed away most of the manmade structures in its way. The design and construction of tsunami evacuation buildings started soon after the event, particularly in areas where no other natural evacuation points were in the vicinity.

In this paper, the wave forces owing to a tsunami acting on the surface of a building were evaluated by fluid analysis using the finite element method (FEM). Then, a one-way coupling analysis of a steel-framed building by continuously applying a seismic excitation, buoyant force, and tsunami force in a single simulation was conducted.

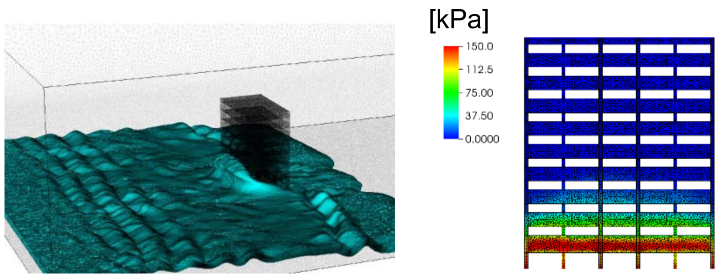
There were also some possibilities that the flow of debris such as ships, cars, and containers may had caused some destructive impact and additional damage to buildings[1]. Therefore, evacuation buildings should be designed not only to withstand seismic excitations and tsunami waves but also to cope with impacts caused by debris. A continuous simulation with some debris collided after the application of wave forces is also conducted in this research.

2 FLUID ANALYSIS USING STABILIZED FEM

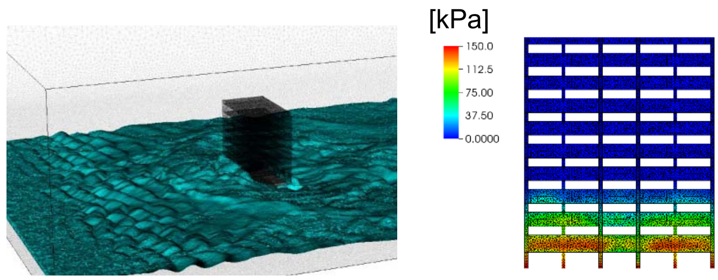
A numerical code[2] using stabilized FEM based upon the volume of fluid (VOF) method, which indirectly expresses a free-surface shape by function values, was adopted for the fluid analysis. A hybrid parallel computing method was implemented in this code to drastically reduce the computational time and memory resources to cope with large-scale simulations.

A numerical model with a region of 240 m in length, 180 m in width, and 80 m in height was constructed. Two types of building models without any openings and with openings were constructed and the pressure distributions at front of the models were compared. The building with openings was designed for evacuation uses[3] and was 10 stories high, with 40.15 m of height and 32.00 m of width. The buildings were modeled as rigid bodies that allowed no deformation, and the openings were assumed to be located at the window parts. These models were all subdivided with tetrahedron elements, with the distances between nodes fixed at approximately 0.5 m under the waterline and around the building. The total number of nodes and elements were approximately 3.7 million and 21 million for the model with openings.

The shape of the flow surface and the pressure distribution computed at the front of the building are shown in Figure 1 for the model with openings. The upstream depth was set to 8.0 m and the tsunami wave velocity to 12.0 m/s in this case. One can observe the inflow and propagation of the tsunami wave, and the impact to the front of the building. The complex free-surface shape owing to amplification of the wave height by short reflected waves, for example, appears to be well simulated. The seawater flowing in and out of the openings can also be observed.



(a) 10 s



(b) 20 s

Figure 1: Shape of flow surface (left) and pressure distribution at front of building (right) [model with openings]

3 DEBRIS IMPACT ANALYSIS OF TSUNAMI EVACUATION BUILDING

A one-way coupling analysis of the fluid and structure was conducted using the simulated wave force obtained from the fluid analysis. Then, the behavior of the building was simulated using the adaptively shifted integration (ASI)-Gauss code[4] when an initial velocity was applied to some container boxes that mimicked the debris owing to the tsunami (Figure 2). The container boxes collide near the beam-column joint sections of the second and third floors, causing ultimate material failures to columns and beams around the impact point. The shock wave rapidly propagating from the impact point can also be observed. The relative velocity between the debris and tsunami flow increases when the debris reduces its velocity in front of the building. Then, a much larger drag force is applied to the debris, and thereby to the building itself. Member fractures initiate at the front columns of the first floor and propagate progressively to the inside. Finally, the building collapses and is washed away.

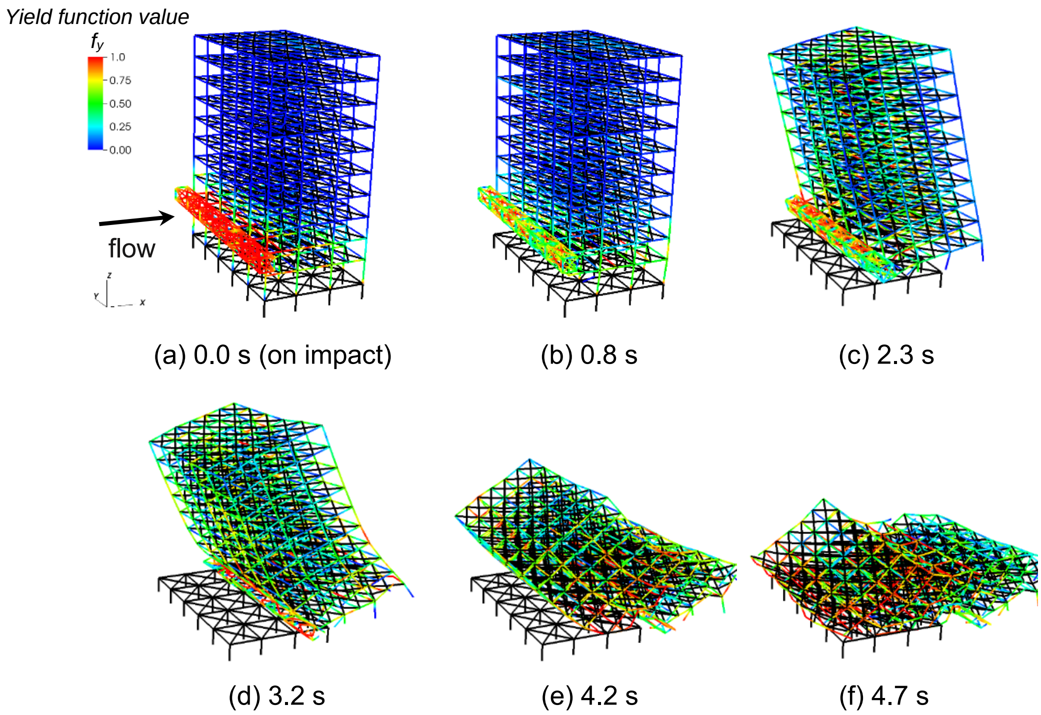


Figure 2: Behavior of building during debris collision

4 CONCLUSIONS

In this paper, a fluid analysis using a stabilized FEM was described. The differences of the free-surface shapes and tsunami wave forces between models with and without openings are to be shown in the presentation. A wide area at the lower part of the building was highly pressurized for the model without openings, but the pressure was significantly reduced for the model with openings as the seawater flowed into the building. These results clearly showed the effect of wave force reduction by making large openings at lower parts of buildings.

Furthermore, a debris model constructed of six container boxes was introduced, and an impact analysis of the building was conducted. The impact phenomena and damage to the building were practically simulated. However, a change in the flow channel geometry according to current changes near the openings should be simulated in future investigations to consider a more precise flow path of tsunami debris. The demand for a more advanced, two-way coupling analysis between the fluid and structure is now growing.

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