Numerical Simulation for Overflow Behavior of Water from Spent Fuel Pool with Sloshing in the 2007 Niigata-ken Chuetsu-oki Earthquake

Background

In order to evaluate overflow behavior of water from liquid-storage tank with nonlinear sloshing, CRIEPI has developed and validated two-dimensional computational fluid dynamics code, SLOSH-2D, and its three-dimensional version, SLOSH-3D, using the volume-of-fluid (VOF) technique, following the 2003 Tokachi-oki Earthquake. The VOF technique is one of the simulation methods for liquid surface behavior. Since it is very simple and specific to simulate the separation and combination of liquid mass as well as to conserve the mass volume, the VOF technique is adopted in our codes. On the other hand, it was reported that, due to the 2007 Niigata-ken Chuetsu-oki Earthquake, the water of spent fuel pool (referred to as "SFP") overflowed onto the operation floor in the Unit-1 to Unit-7 reactor buildings at the Kashiwazaki-Kariwa Nuclear Power Plants (referred to as "NNPs") of Tokyo Electric Power Company, Inc. A video record of the incident at Unit-3, showing overflow behavior and complex water free surface phenomena, was made public. Therefore, in order to contribute to the evaluation of seismic safety of the NPPs, it became necessary to clarify the overflow behavior of the SFP water with nonlinear sloshing.

Objectives

The purpose of this study is to validate the applicability of the newly developed three-dimensional computational fluid dynamics code, SLOSH-3D, and clarify the overflow behavior of the SFP water with nonlinear sloshing.

Principal Results

1. Validation of the applicability of the computer program

The video record indicated that the triangular waves with conical shape were generated on the water free surface, and the SFP water overflowed from the curb of the pool, with the seismic-induced sloshing (Fig. 1). Time-history response analyses were performed using the three components of the observed seismic motions on the operation floor (tri-axial excitation in north-south, east-west and vertical directions), in order to simulate the overflow behavior of the SFP water with nonlinear sloshing. Based on the analysis results, the time-dependent sloshing behavior was investigated by three-dimensional free surface profiles at various time steps (Fig. 2). Consequently, it was found that the newly developed computer program, SLOSH-3D, could simulate the observed complex water free surface phenomena with acceptable accuracy.

2. Overflow behavior of the SFP water with nonlinear sloshing

(1) Sloshing response

The analysis results indicate that the dominant frequency components in the free surface oscillations correspond to the natural frequencies of the first and second sloshing mode, calculated by assuming the SFP to be a rectangular container. As a result, it is found that the first sloshing mode is generally the dominant mode of the oscillations, and the complex free surface shape of SFP water, such as the triangular waves, are superimposed on the first sloshing mode shape.

(2) Overflow onto the operation floor

The SFP water began to overflow onto the operation floor in the latter half of a principal shock of the input seismic motion, and covered nearly the entire floor area of the analytical model in about 10 seconds. Subsequently, the cumulative amount of overflowed water volume became almost constant (Fig. 4).

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Reference

M. Sakai, et al, 2007, "Nonlinear sloshing response evaluation method for rectangular tank with overflowing water," CRIEPI Report N06031 (in Japanese).

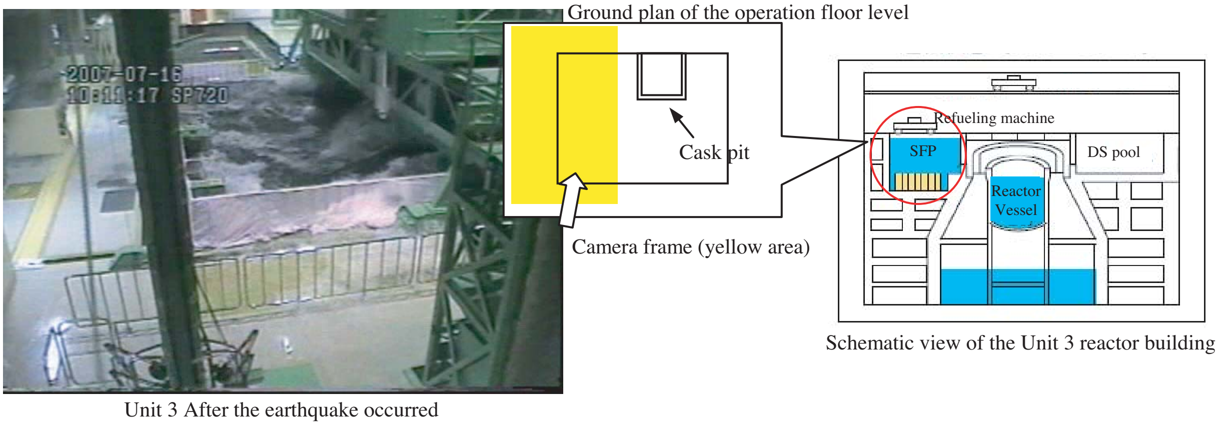

Fig.1 Snap Shot of the video record (by courtesy of The Tokyo Electric Power Company, Inc.)

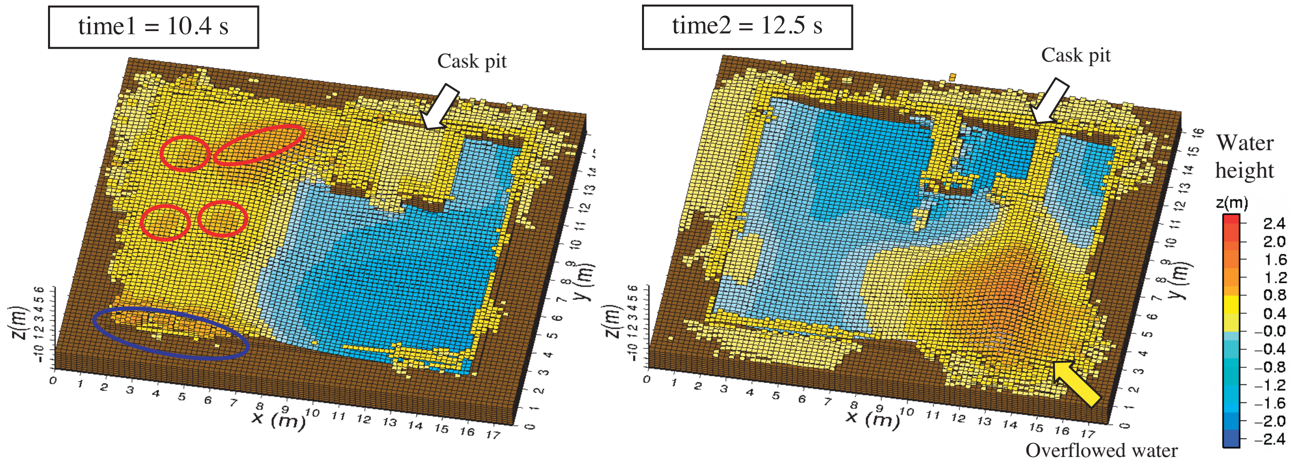

Fig.2 Computed free surface profiles of the SFP water at two time steps

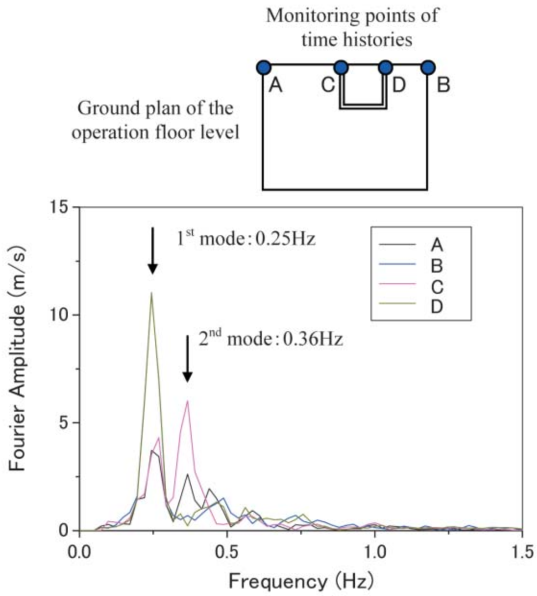

Fig.3 Fourier spectrum of the water height responses

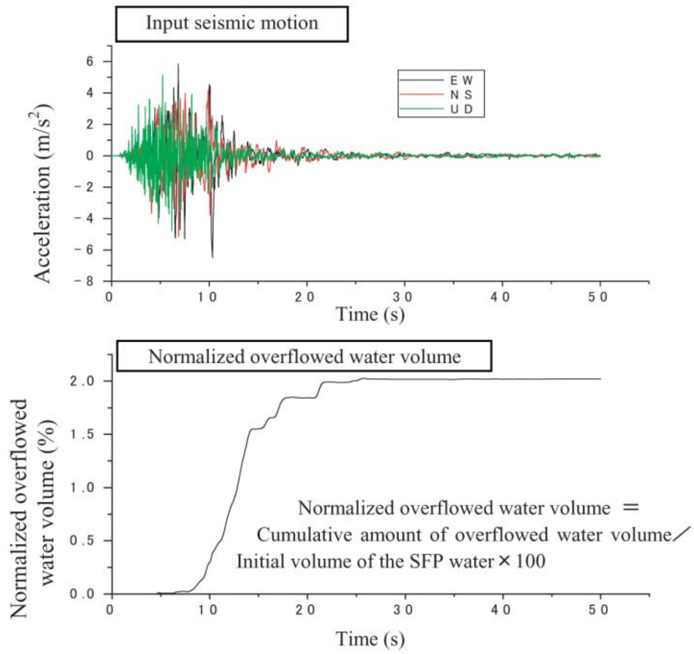

Fig.4 Time history of relative overflowed water volume