Sloshing and seismic response of a floating roof in a cylindrical liquid storage tank

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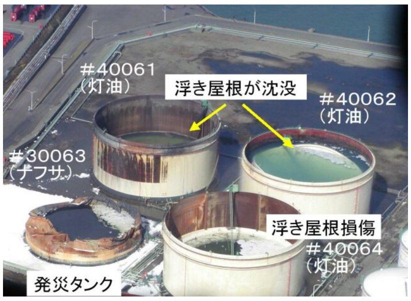
Summary: A response spectrum method is proposed to predict the sloshing response of a floating roof in a cylindrical liquid storage tank under seismic excitation. The liquid is assumed to be inviscid, incompressible, and irrotational, while the floating roof is considered as an orthotropic elastic plate of variable thickness. The dynamic interaction between the liquid and the floating roof is taken into account exactly within the framework of linear potential theory. The analysis is based on expanding the response of the floating roof into the free-vibration modes in liquid to derive the diagonalised equations of motion for the coupled liquid-floating roof system. The modal analysis based on the response spectrum is then carried out to predict the sloshing response. Numerical results are presented to illustrate the applicability of the proposed approach.

Background: During the 2003 Tokachi-oki earthquake, Japan, many oil-storage tanks of floating roof type located at Tomakomai area were seriously damaged. Damages are supposed to be caused by *sloshing*.



Sinking of floating roofs

Whole surface fire of tank

Buckling of pontoon

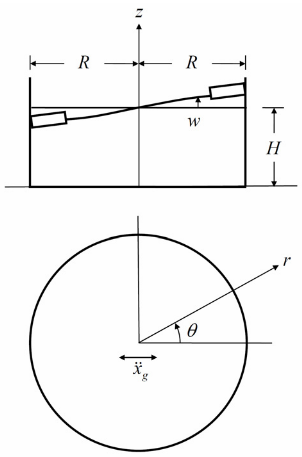
Objectives: To propose a response spectrum method to predict the sloshing response of a floating roof in a cylindrical liquid storage tank under seismic excitation.

Outline of analysis: (1) Derivation of analytical or numerical solution to the boundary-value problem for the coupled liquid-floating roof system, (2) Derivation of the *diagonalised* equations of motion based on expanding the response of the floating roof into the free-vibration modes *in liquid*, and (3) Modal analysis based on the response spectrum.

Basic assumptions: (1) The liquid is inviscid, incompressible and irrotational. (2) The tank wall is rigid. (3) The floating roof is idealized as an orthotropic elastic plate with arbitrary axisymmetric form. (4) The floating roof is always in contact with the liquid surface. (5) The wave elevation as well as the vertical displacement of the floating roof is so small that linear superposition principle may be valid. (6) The tank is subjected to a horizontal ground motion in one direction.

Analysis and results:

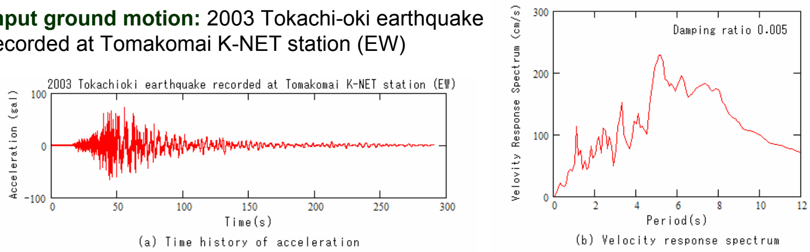
Tank model: Oil-storage tank with a single-deck type floating roof

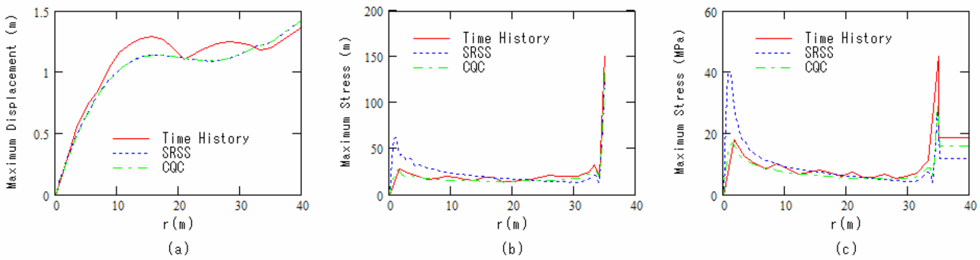


Tank sizes:
- Radius R=40m
- Liquid height H=20m

Tank geometry and coordinate system

Input ground motion: 2003 Tokachi-oki earthquake recorded at Tomakomai K-NET station (EW)





(a) Maximum roof displacement, (b) maximum radial bending stress, and (c) maximum circumferential bending stress along θ=0

Conclusions: (1) A response spectrum method has been proposed to predict the sloshing response of a floating roof in a cylindrical liquid storage tank under seismic excitation. (2) The validity of the proposed method has been confirmed by comparison with the results of time history analysis. (3) It can be concluded that the CQC method is preferable than the SRSS method because the former gives better predictions for both the roof displacement and the bending stresses, which are close to the results of time history analysis.