Fluid-Structure Interaction in Civil Engineering Structures

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1. Introduction

Motivation

- The design of civil engineering structures is often governed by hydrodynamic loads during earthquakes.
- The effects of the liquid are usually decomposed into an impulsive component (defining added masses) and a convective component (sloshing).
- Traditionally the pressure distributions are obtained solving the Laplace PDE, assuming water incompressibility and rigid boundaries.
1. Introduction

Methodology

- Some improvements are possible with structural-acoustic transient and steady-state analyses in Abaqus.
- The interface is modeled with a surface-based coupling procedure, where the master surface should be that with the higher impedance.
- The modal dynamics procedure is not applicable when implementing radiating boundary conditions, introduced with acoustic infinite elements or appropriate impedances.
2. Dams

Description of dam A

Height: 40.5 m

Concrete

Young’s modulus: 30 GPa
Poisson’s ratio: 0.2
Compressive strength: 20 MPa
Tensile strength: 2 MPa

Potential sliding with friction 0.7. The contribution of the dam toe to the sliding capacity is 2.5 MN/m
2. Dams

Description of dam B

Similar concrete

The intact rock has a Young’s modulus of 22 GPa and a strength of 120 MPa, but some lignite layers introducing potential weakness planes in the foundation.

Potential sliding with friction 0.8.
The contribution of the toe to the sliding capacity is 5 MN/m
2. Dams
Seismic input
2. Dams

Finite element model

- The model combines plane strain elements for the body of the dam, plane stress elements with the appropriate width for the spillway region and acoustic elements for the water.
2. Dams

Finite element model (cont.)

- The first frequency of each dam (without FSI) is near that of the reservoir. Thus, the compressibility of water plays an important role and a coupled analysis of the dam and the water is required.

- The problems are studied by direct integration of the fully coupled system using three accelerograms.

- Rayleigh damping is defined in concrete.

- Force histories are calculated to evaluate stability. Pore pressure distributions are known.
2. Dams

Resulting safety factors against sliding
3. Lock gates

Description of the locks

- Locks to be placed in the current expansion of the Panama Canal in the Pacific side.
- Their dimensions are 57.6 (width) x 32.6 (height) x 10.0 m (thickness).
- The mass of the steel structure is 3800 t and it encloses 13,190 t of water.
- The ground surrounding the lock gate is made of basalt rock with a wave propagation velocity of 1737 m/s.
3. Lock gates
Seismic input

Damping 2.5%
3. Lock gates
Finite element model

- The traditional method of added masses is applied first.
- The ulterior model accounts for the flexibility of the gate, the compressibility of the water and the radiation of energy through the ground.
- Rayleigh damping is defined in the lock.
3. Lock gates

First mode of the gate without interaction

First natural frequency: 6.9 Hz
3. Lock gates
First mode of the gate with interaction

First natural frequency: 2.5 Hz (from SSD)
3. Lock gates

Pressures at resonance for 1 m/s² (Pa)
3. Lock gates

Pressures for earthquake (Pa)

Response spectrum with added masses

Direct time integration of coupled problem
3. Lock gates

Summary of results

- Relaxing some of the traditional conservatisms (i.e. accounting for the deformability of the gate, the compressibility of the water and energy radiated through the ground) had relatively minor effects in the results.

- In contrast, the solution procedure (response spectrum with added masses or the fully coupled problem) did seem to have a more important effect on the values of the pressures.
4. LNG storage tanks

Description of the tank

- LNG is normally stored in full containment cylindrical tanks made of:
  - Prestressed concrete outer tank
  - Open top, self standing, cryogenic steel inner tank

- The inner tank studied here has 40 m radius, 33.65 m liquid level (normal operation), and wall thicknesses from 24.4 to 10.0 mm.
4. LNG storage tanks
Seismic input

Five accelerograms were constructed matching the design spectra

Durations:
32 s for OBE
36 s for SSE
4. LNG storage tanks
Finite element model

Tank discretized with 2,800 shell elements and stringer beams for stiffeners

25,000 acoustic elements for the liquid
4. LNG storage tanks

Procedures

- The hydrostatic pressure produced by the LNG at rest is applied first.
- Then natural modes and frequencies are extracted accounting for the structural-acoustic interaction.
- Finally a transient modal dynamics analysis is conducted.
4. LNG storage tanks

Results

Seismic vertical membrane forces along the bottom

Total membrane forces along the most unfavorable generator for SSE
5. Conclusions

- The use of acoustic elements provides a relatively simple and reliable procedure for dealing with the dynamic liquid-structure interactions that arise during seismic excitation of structures.

- More traditional procedures, such as the use of added masses appear to provide reasonably accurate results.