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FLUID-STRUCTURE INTERACTION APPLIED TO OVALLING OSCILLATIONS OF A SILO

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ABSTRACT

Circular cylindrical shells are susceptible to wind induced ovalling oscillations, an aeroelastic phenomenon, where the cross section deforms as a shell without bending deformation of the longitudinal axis of symmetry [1]. Resonance occurs when the negative aerodynamic damping cancels the structural modal damping.

During a storm in October 2002, ovalling was observed on several empty silos of a group of forty silos in the port of Antwerp. The silos are placed in five rows of eight silos with gaps of $30\,\mathrm{cm}$ between two neighbouring silos. The final aim of the study is to describe the wind-silo interaction phenomenon. Currently, a coupled numerical analysis of the wind flow around one silo is performed.

A three-dimensional finite element model of the silo structure is validated using experimental modal analysis [2]. The eigenmodes with the lowest eigenfrequencies, around $4\,\mathrm{Hz}$, have a circumferential wavenumber $n = 3$ and 4. For the fluid-structure interaction computation, a coarser finite element model without the local refinements near the boundaries is used. The finite element model of the structure is advanced in time using the Newmark method. Rayleigh damping is added with a modal damping ratio of 0.25% at $3.93\,\mathrm{Hz}$ and of 0.50% at $20\,\mathrm{Hz}$.

The three-dimensional wind flow around a single cylinder is modelled at a Reynolds number of $12.4 \cdot 10^6$. An unsteady incompressible RANS simulation using the Shear Stress Transport turbulence model is performed. The transient solution is integrated by the three-point backward difference scheme. The vortex shedding frequency is equal to $2.16\,\mathrm{Hz}$.

Between the silo and a cylindrical surface with a diameter equal to twice the silo diameter, the three-dimensional fluid flow is computed on a deforming mesh, using the Arbitrary Lagrangian Eulerian formulation. The grid point displacements of the fluid mesh are obtained by diffusing the displacements of the structure through this domain. As to preserve the quality of the mesh in refined regions, the diffusivity of a finite volume is equal to the inverse of its volume. A globally conservative interpolation is used for the load transfer between the non-matching grids, while a profile preserving interpolation is used for the displacement transfer. The structure and the fluid are sequentially coupled. First, a staggered

calculation is performed, which means that every field is computed once at each time t. In a second computation interfield iterations ensure the equilibrium between the two fields at each time t. No relaxation factor is used. Maximum four interfield iterations are needed to obtain a relative change of the transferred quantities smaller than 0.001. The differences between the results of both computations increase in time which indicates that the computation using interfield iterations is more accurate.

The response of the silo is dominated by the eigenmodes with circumferential wavenumber $n = 3$ and 4. The structural deformations influence the pressure field near the wall: the pressure fluctuations at the vortex shedding frequency have clearly increased and due to the interaction pressure fluctuations are present as well at the lowest eigenfrequencies of the structure. All eigenmodes which contribute to the response, are positioned roughly with an antinode facing the flow.

The coupling procedure with interfield iterations enables to simulate the response of the silo under wind loading, but more time steps should be computed to determine if the ovalling oscillations persist in time.

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