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Boundary element analysis of liquid sloshing in baffled tanks

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ABSTRACT

The paper concerns the natural frequencies and mode shapes of liquid sloshing in three dimensional baffled tanks with arbitrary geometries. The liquid is considered to be inviscid and incompressible and amplitudes of oscillations are assumed to be small. The tank bottom and the baffle are treated as rigid. The boundary element method is used to solve the considered problem. Triangular curvilinear 6-node boundary elements are applied. In the present formulation is not necessary to introduce the zoning method, because the baffles are treated as double layers immersed in liquid. After discretization the problem is formulated as the standard eigenvalue problem, which is limited to free surface degrees of freedom only. Several examples are given to verify the proposed method.

1. Introduction

The liquid sloshing phenomenon in tanks is an important field of the fluid dynamic research. Liquid tanks are considered as important elements of municipal facilities systems, oil industry, naval and aerospace systems. Hydrodynamic forces acting on tank walls as a result of the liquid sloshing may damage the whole structure. Baffles in tanks are used to increase the damping of the liquid sloshing. They usually cause changes of sloshing frequencies and can be treated as a passive control system. The liquid sloshing in tanks with arbitrary geometries can be analysed by numerical methods. Among these methods the finite element method and the boundary element method are most frequently used. In the FEM the whole volume of liquid is discretized by 3D elements (see, for example [1,2]), but in the BEM the liquid boundary is discretized by surface elements. During the last years many papers were published, where the BEM was used to solve the considered problem.

Seismic response of liquid in a rigid cylindrical tank with a rigid baffle was considered by Gedikli and Ergüven [3]. The boundary element method was used to evaluate the natural modes of liquid and the method of superposition of modes was implemented to compute the seismic response. The same authors also used the non-singular symmetric variational boundary element formulation for the liquid sloshing problem in a cylindrical container with a rigid baffle [4]. The effect of the baffle on the natural frequencies was examined. The formulation presented in these papers concerned axi-symmetric geometry only.

Firouz-Abadi et al. [5] used BEM to determine the natural frequencies and mode shapes of a liquid sloshing in 3D baffled tanks with arbitrary geometries. The fluid boundary was discretised by quadrilateral elements with bilinear shape functions. The zoning method was introduced to model arbitrary arrangements of baffles. The effect of the baffles on the sloshing frequencies was investigated. In the paper [6] the same authors examined free surface motion of liquid sloshing in tanks under angular and lateral kinematic excitation of the tank. The reduced order modelling technique was introduced.

Dutte and Laha [7] investigated the problem of liquid sloshing in a rigid container of arbitrary geometry. The low-order boundary element method was used to analyse both free and forced oscillation cases.

This paper presents an application of the boundary element method to determine the natural frequencies and mode shapes of a liquid sloshing in three dimensional baffled tanks with arbitrary geometries. The liquid is treated as incompressible and inviscid. The amplitudes of oscillations are assumed to be small. The tank bottom and the baffles are rigid. The discretization of the liquid boundary is performed using six-node isoparametric curvilinear triangular elements. In the present formulation the baffles are treated as double layers immersed in liquid. The double layer concept was earlier introduced for calculations of the aerodynamic forces acting on oscillating thin surfaces in a subsonic flow [8,9]. A similar problem of liquid sloshing in tanks with baffles was considered in the papers [3–5], in which the zoning method was introduced. The domain of the liquid was divided into zones. The baffles were then located at the boundaries of the zones and compatibility conditions between the zones were applied. In the present formulation such an approach is not necessary.

2. Problem formulation

Let us consider a tank of an arbitrary shape with a liquid free surface S_1, a bottom surface S_2 and a baffle S' (Fig. 1). It is assumed

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