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ASSESSMENT OF TANKS WITH FLUIDS SUBJECTED TO SEISMIC EXCITATION

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Abstract: *Checking analyses of large steel tanks with fluid have been carried out within the frame of the project of completion of Units 3 a 4 of the nuclear power plant Mochovce. The calculations have been carried out in accordance with the regulations NTD A.S.I. The calculations include the assessment of the tank resistance to seismic loads. The seismic analysis is based on the specified level of ground acceleration, for which the necessary floor response spectra have been generated. Problems have appeared with computation of responses of tanks with fluid. The applied ANSYS program package does not allow (for the time being) a correct response spectrum analysis with the use of FLUID30 finite elements. The application of FLUID80 elements is questionable, yet acceptable with cross-checking solution using FLUID30 elements. The paper contains procedure applied for the calculation of the convective mode frequency and the respective fluid pressure field. The resultant seismic responses of analyzed tanks have been combined with responses to static loads. Consequently, parameters of marginal seismic resistance of tanks have been computed.*

Keywords: ***Fluid structure interaction, ANSYS, steel tank, nuclear power plant, seismic analysis, acoustic-fluid element.***

1. Introduction

In order to complete the construction of Units 3 and 4 of the nuclear power plant in Mochovce the assessment of the seismic resistance is being carried out. Among the equipment assessed, there are also thin-walled steel tanks containing fluid. In seismic response calculations, fluid inertial effects must be taken into account. This paper deals with the application of the ANSYS program system (SAS IP, Inc., 2009) to determine the response of fluid filled tanks to seismic action. The response analysis of a tank must be correct so that it could serve as a reliable input to predict the tank behavior. The required response characteristic needed to assess the limit states of the tank bearing capacity and serviceability are displacements and stresses (Directive NTD ASI 2001). To evaluate the tank response to seismic loading, a rational method based on the analysis of hydrodynamic equations with corresponding boundary conditions must be used (ENEL, 2009, ASME QME-1-2007). The analysis must consider fluid movement as well as tank shell deformation due to interaction with fluid. Natural frequencies and vibration modes of the tank interacting with fluid must be determined. When using the finite element method, the structure and the modeled fluid region are discretized. When using the Lagrange approach, the fluid is modeled as a solid with negligible shear modulus and the movement of fluid particles is described using equations of motion. The disadvantage of this approach consists in the fact that within the range of significant lower natural frequencies are to be found very high numbers of frequencies of insignificant vibration of mostly fluid domain. When using the Euler method, the fluid particle movement is not considered. In the fluid domain the variables are pressures or velocities at nodes. The fluid structure interaction is characterized at the boundary by a normal component of the acceleration. In the ANSYS program system finite elements are implemented to solve the fluid structure interaction directly. The elements suitable for fluid modeling by the Lagrange approach are FLUID80 3–D Contained Fluid eight-node isoparametric finite elements. These elements are modified 3D elements for elastic solid analysis. The elements suitable for fluid modeling by Euler

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approach are FLUID30 3–D Acoustic Fluid eight-node isoparametric finite elements. The approach according to Euler is based on the Helmholtz acoustic (Kinsler, L. E. & Frey, A. R., 1962).

2. Testing computations

2.1. Computation models

Several computations have been carried out to test the optimum procedure of the modal analysis of the tank containing fluid. Two computation models have been used in order to analyze the effects of the choice of the type, shape and size of finite elements:

Model A - vertical cylindrical steel tank with fluid. The model has been used to analyze the effects of changing the following characteristics: tank diameter, tank height, shell thickness, element mesh density, type and formulation of elements, shape of elements.

Model B - vertical cylindrical thin-walled fluid containing steel tank with heavy roof supported by a central column. The model has been used to analyze the effects of changing the type and formulation of elements.

2.2. Convective type of the fluid vibration

The tank base seismic vibrations excite vibration of the fluid content. Vibration nodes characterized by fluid surface local level variations (fluid sloshing, convective mode vibrations) result in substantial increase of the fluid hydrodynamic pressure at the upper part of the tank shell. Using several alternatives of the model A, lowest natural frequencies of convective mode vibrations have been computed. Results have been compared with data given in Eurocode 8 (ČSN EN 1998-5, 2006). Differences up to 5 % have been found. Using FLUID30 elements, convective mode natural frequencies and corresponding pressure fields have been readily computed. No effects of shapes of elements have been observed. The application of FLUID80 element offers same advantages, e.g. direct computation of displacements. However, it has been concluded, that the only acceptable shape of the FLUID80 element for reliable computations is a shape close to cube. When computing the first sloshing vibration mode, shift of the frequency spectrum must be applied.

2.3. Impulsive type of vibration of fluid interacting with the structure

Impulsive type vibration of the fluid content interacting with the structure has been analyzed at the model A, using both FLUID30 and FLUID80 elements with various sizes and shapes. For a selected mode (e. q. tank first bending node), when decreasing the size of elements, the computed frequencies converge to the same frequency. The frequency value at FLUID30 elements converges smoothly and the rate of convergence is higher. Consequently, with a given mesh, FLUID30 elements provide natural frequencies with a higher accuracy, than FLUID80 elements. Modal analysis of two variants of the model B has been carried out, using formulations (settings) of both FLUID30 and FLUID80 elements available in the ANSYS program. The values of the first bending frequency of the tank have been computed and compared. However, no reliable conclusion about the optimum choice of the element setting have been obtained.

2.4. Impulsive mode response analysis of the tank with fluid

The response analysis in the time domain has been carried out, using model B variants described in par. 2.3, A third variant based on the added mass concept has been analyzed, too. The model has been tuned to the first bending frequency. The acceleration of the tank base has been described using a quasi harmonic function with frequency varying with time so, that during the considered time interval the dominant tank bending mode vibration has been excited. Using the same models, response spectrum analysis has been carried out. The response spectrum has been generated using the above mentioned excitation function. Maximum response displacements obtained by direct integration have been compared with those obtained using the response spectrum analysis. The model with FLUID80 elements has shown satisfactory coincidence. The model with added mass properly tuned to the dominant natural frequency has shown satisfactory results, too. The application of the model with FLUID30 elements has not shown generally reliable results.

3. Seismic response of a selected tank for the nuclear power plant Mochovce

3.1. Computation model of the tank with fluid

Seismic response analysis of the vertical cylindrical steel tank storing 550 m^3 of active concentrate in the NPP Mochovce has served as a case problem. The computation model of the tank (d = 10 m) is shown in Fig. 1. For modeling the tank structure, mostly SHELL43 elements have been used. Two variants of the fluid domain modeling have been applied. The response spectrum analysis has been carried out using FLUD80 elements. With respect to the complexity of the structure, the fluid domain mesh differs from the structure mesh the fluid-structure interaction ensure CONTA174 and TARGE170 elements. The model with FLUID30 elements has been used for the modal analysis verification.

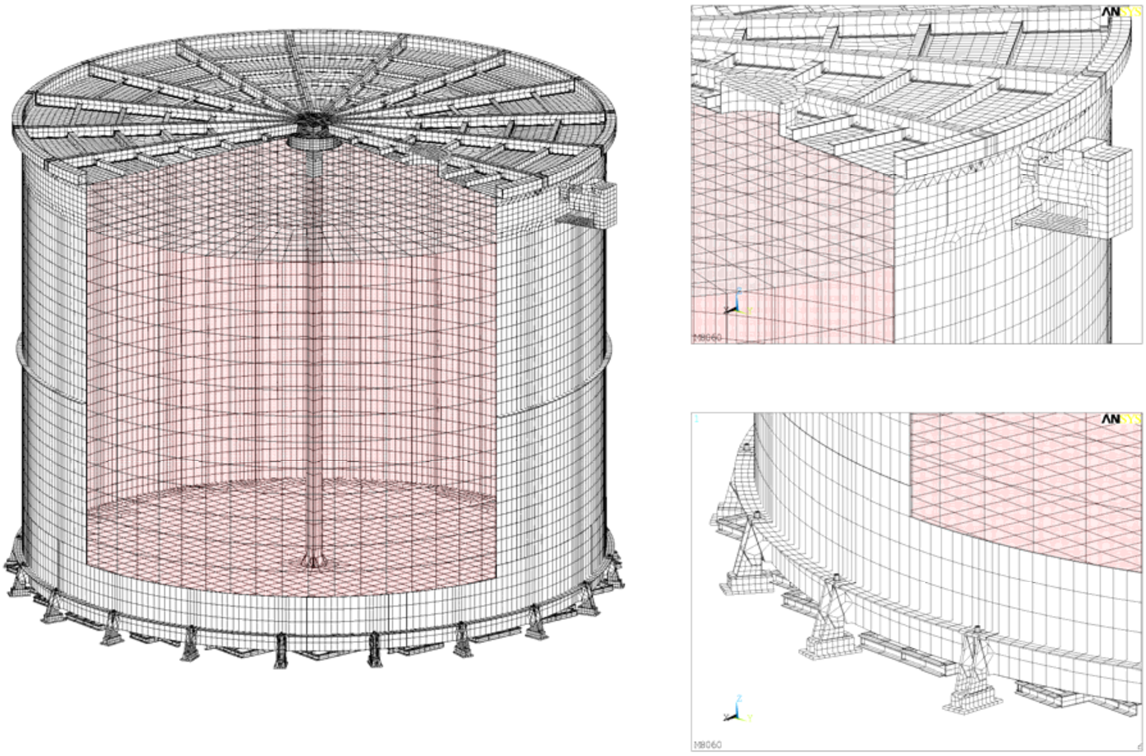
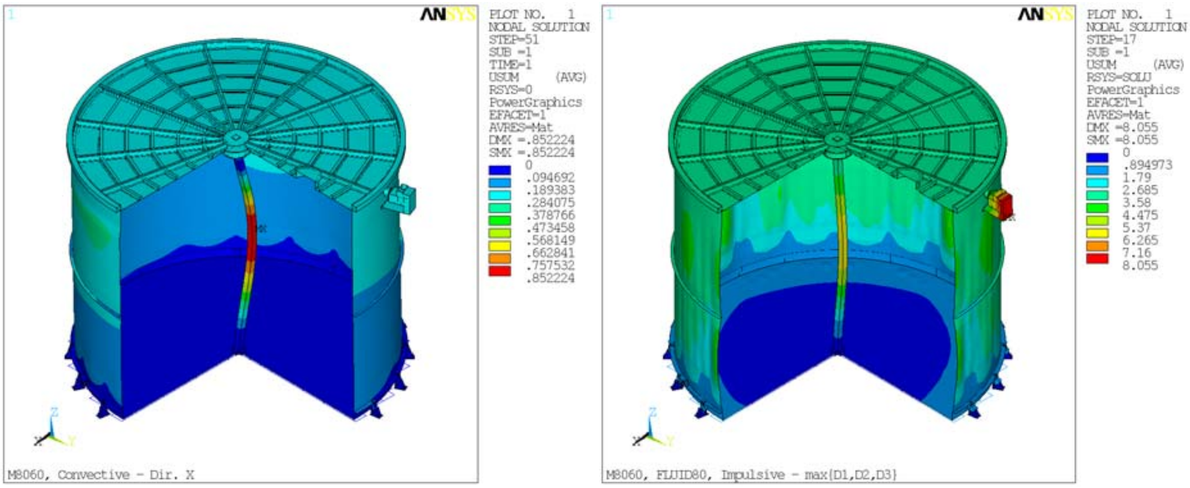


Fig. 1: Tank computational model.

3.2. Seismic response analysis

Seismic response analysis has been performed using the elastic response spectrum method. Design spectra f or two earthquake levels have been used. For the design earthquake level (SL-1), damping ratio 2 % has been considered, whereas for the maximum computational earthquake (SL-2) damping ratio of 3 % has been used (with impulsive fluid vibration modes). For convective fluid vibration modes damping ratio 0.5 % has been used. Seismic responses in both displacements and stresses have been computed for three orthogonal directions (x, y and z). Modal responses have been combined using Complete Quadratic Combination rule (except simply added convective mode responses). Subsequently, directional response effects have been combined using factored addition rule. For the final limit state assessments, addition rule has been applied to combine the maximum seismic effects with static loads at current operation conditions. For illustration, separated resultant responses to convective and impulsive excitation are shown in Fig. 2a and Fig. 2b, respectively.



a) Response of convective fluid motion *b) Response of impulsive fluid/structure motion*

Fig. 2: Resultant responses.

4. Conclusions

Verification seismic analyses of several tanks with fluid designed for the Nuclear Power Plant Mochovce have been carried out using the finite element method implemented in the ANSYS program. Particular attention has been devoted to assess correctly the seismic resistance level of tanks sensitive to fluid-structure interactions. The applications of fluid elements of the ANSYS program have been thoroughly tested. It can be stated, that for the time being, direct response analysis of the tank with fluid using elements based on the Euler approach (FLUIF30 elements) cannot be performed. The analysis using elements based on the Lagrange approach (FLUIF80 elements) can be carried out, however with great caution. Modal analyses using fluid elements can be routinely performed.

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