

Rectangular tank under the seismic load

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Abstract. Tanks have been currently used for the storage of various substances, in particular as drinking water storage tanks and for storage of various technical fluids. Rectangular tanks have advantages over cylindrical tanks, such as: lower sensitivity to unilateral loads and better use of space when used in a system of tanks. The rectangular tank analyzed in this article is filled with water. During the dynamic analysis of the tank, it was loaded by an accelerogram of a natural earthquake. In the calculation, the method of direct integration over time was used, considering damping. From the accelerogram a response spectrum was generated and applied as an additional loading of the tank. The static model of the tank was created in the ANSYS program, which works on the basis of the finite element method (FEM).

1 Direct integration method

The theoretical solution of the method of direct integration in time (step-by-step method) has been dealt with in [1]. This method consists in a procedure, when the behaviour of the system at the end of the time step has been derived from the conditions at the beginning of the same step. As the solution proceeds gradually in time steps, it is possible to consider the non-linear response of the structure. The time step is very small (hundredths to thousandths of a second) at which we must define the acceleration change in that time step. Accelerograms that are used to simulate an earthquake can be natural - obtained from an earthquake, or synthetic - generated by programs to meet specified boundary conditions.

The dynamic analysis of tanks that are fixed or rested on an elastic subgrade has been mentioned e.g. in works [2-6], which inspired us in some details.

2 Model

The tank analyzed in this article is a rectangular, above-ground, reinforced concrete tank with a fixed bottom plate. The ground plan dimensions are 11.0 m x 7.5 m and its height is 4.5 m. The filling in the tank is water, its level reaches to a height of 4 m, which limits the possibility of splashing under dynamic load. The static model of the tank made using the finite elements is shown in Fig. 1.

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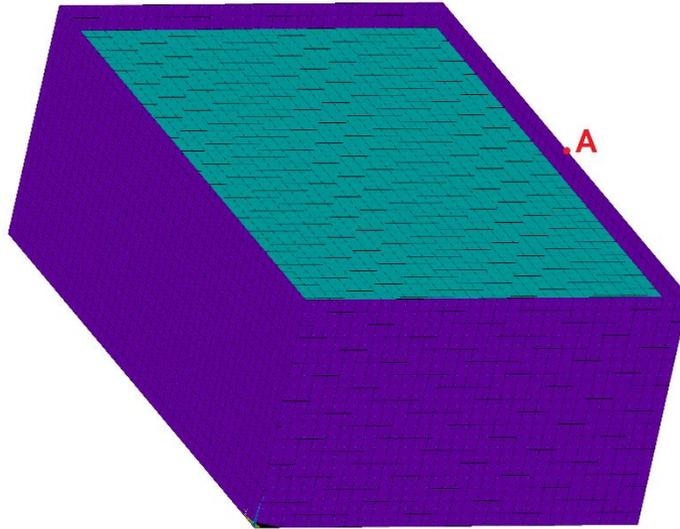


Fig. 1. FEM model of the tank.

The SHELL181 quadrilateral planar shell element was used in the ANSYS program for static modeling of tank walls with a thickness of 200 mm and tank bottom with a thickness of 500 mm. The liquid 3D element FLUID80 was used for modeling water as a tank filling.

3 The Accelerogram

The input value for a dynamic calculation was the earthquake accelerogram (Fig. 2). Its time step is 0.01 s.

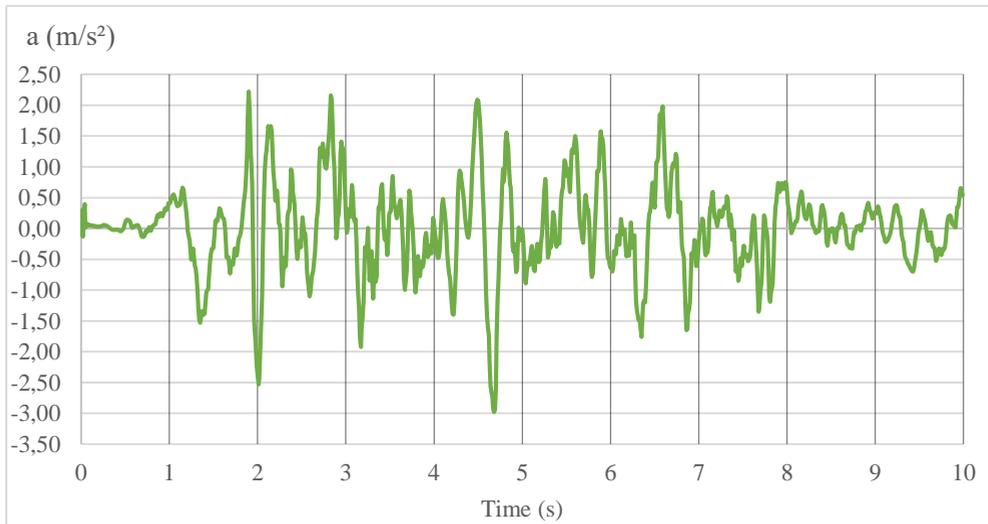


Fig. 2. Accelerogram of an applied earthquake (Varpalota, 1995, Hungary).

This accelerogram was imported into ANSYS software. We considered a 2% damping of the structure (recommended for reinforced concrete structures). The amount of damping was taken into account using Reyleigh damping (set values $\alpha = 0.741525$ and $\beta = 0.0005391$).

In Fig. 3 there is a graph showing the horizontal displacement of one point in time. This point is located on the upper edge in the middle of the longer wall (point A in Fig. 1). In this point, the maximum displacement values have been reached.

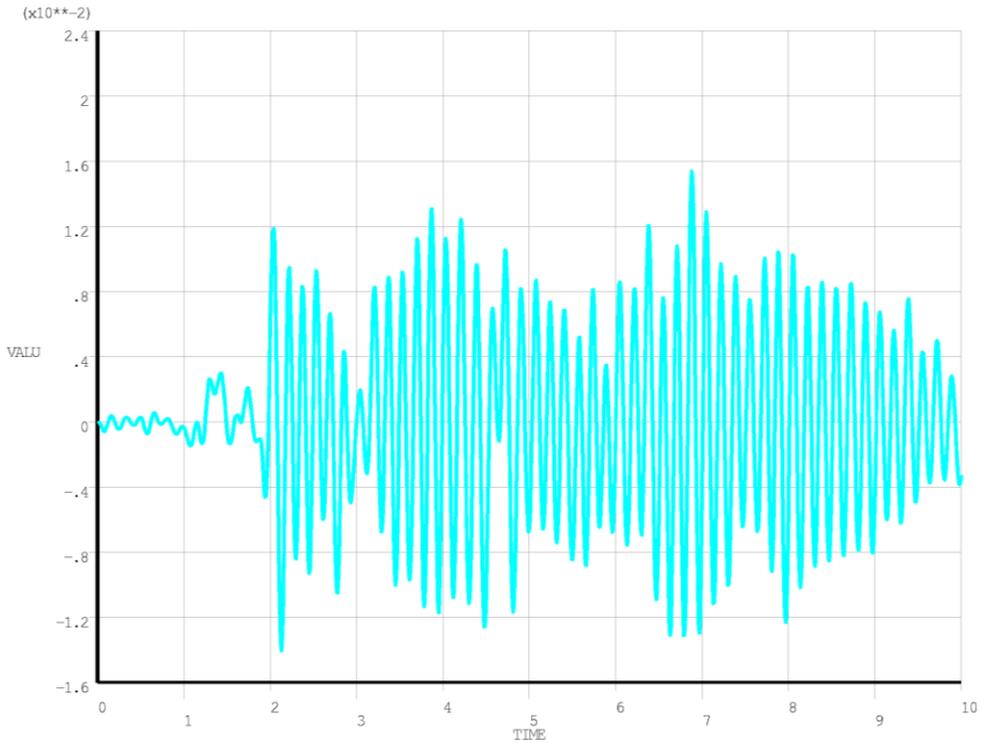


Fig. 3. Displacement of the point in the x-axis direction (m) in time (point A in Fig. 1).

The specific time t at which the displacement reached its highest value was $t = 6.88$ s. At this time, the deformations of the tank were plotted in the x-axis direction (Fig. 4) and in the y-axis direction (Fig. 5). The caption of the figure presents the maximum values of deformation of the tank walls.

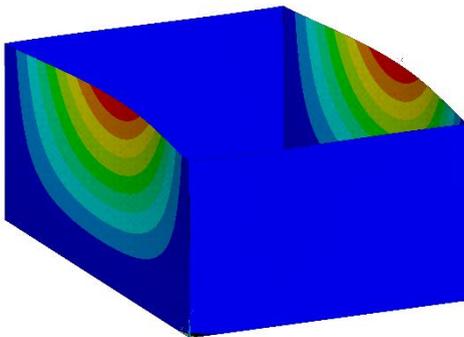


Fig. 4. Deformation in the x-axis direction at time 6.88 s ($u_x = 15.429$ mm).

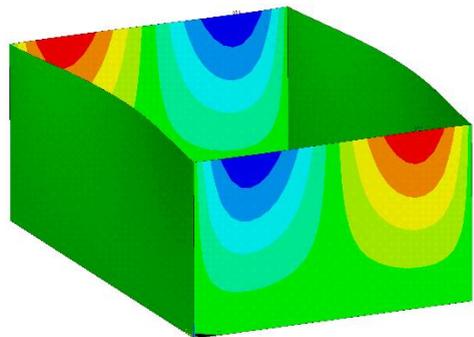


Fig. 5. Deformation in the y-axis direction at time 6.88 s ($u_y = 1.377$ mm).

The specific bending moments in the tank walls m_x (Fig. 6) and m_y (Fig. 7) at time $t = 6.88$ s were also plotted on the structure.

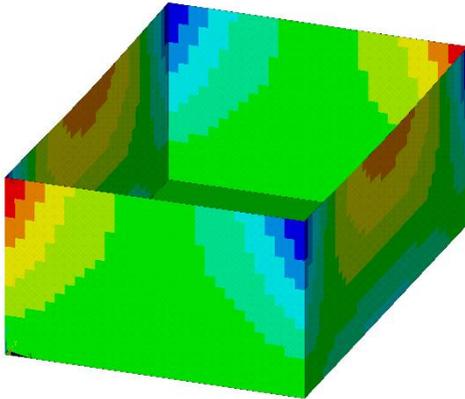


Fig. 6. Specific moment m_x in the tank walls at time 6.88 s (maximum $m_x = 46.004$ kNm/m).

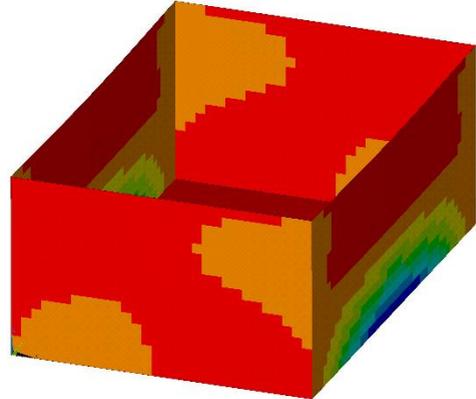


Fig. 7. Specific moment m_y in the tank walls at time 6.88 s (maximum $m_y = 46.004$ kNm/m).

Water at the investigated time ($t = 6.88$ s) reached the largest deformation in the z-axis direction, with the wave size of 118.85 mm (Fig. 8). The water level at rest is 500 mm lower than the walls, so there is no risk of splashing out of the tank.

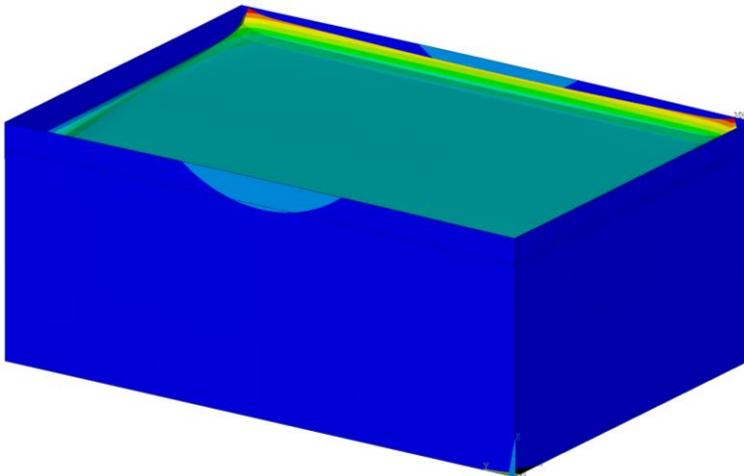


Fig. 8. Waving of the water surface in the tank at time $t = 6.88$ sec. due to earthquake effects ($u_z = 118.85$ mm).

4 The response spectrum

To compare the results from the step-by-step method with the results obtained using the simpler spectral method, the response spectrum from the used accelerogram was created. This spectrum was generated by means of a subroutine in the RFEM Dlubal calculation software and recalculated for different number of time steps. From these courses an envelope – response spectrum was created, by which the tank was loaded (Fig. 9).

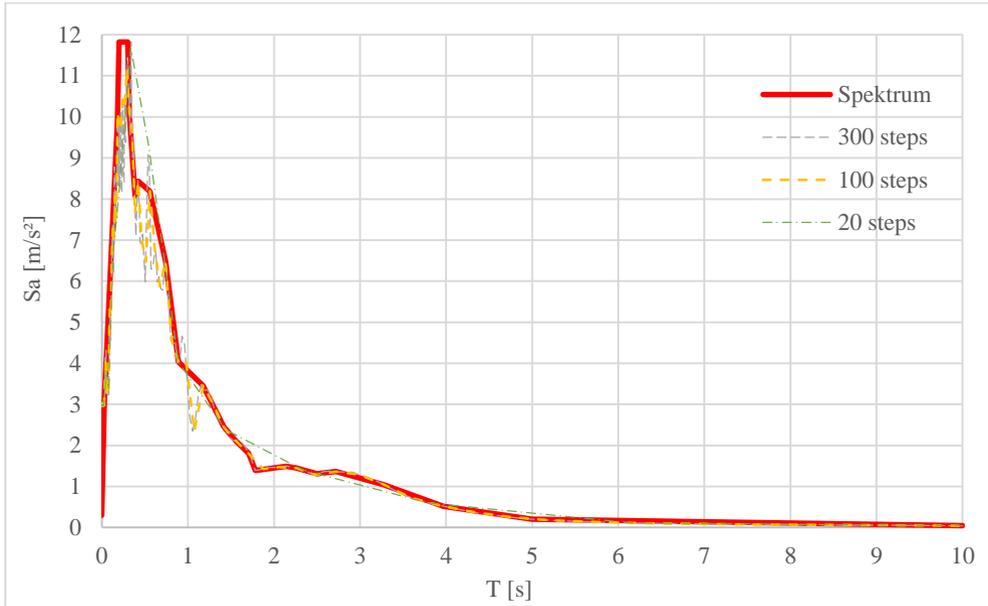


Fig. 9. Response spectrum obtained from accelerogram (Fig. 2) with 2% damping.

From the results obtained on the structure of the tank loaded by the response spectrum, see Fig. 9, we present the values of maximum tank wall deformations u_x (Fig. 10) and u_y (Fig. 11). The maximum reached values have been mentioned in captions of the figures.

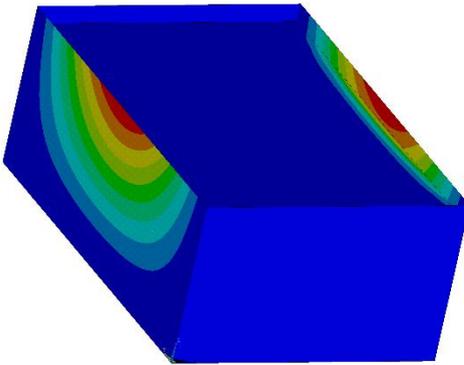


Fig. 10. Deformation in the x-axis direction ($u_x = 16.839$ mm).

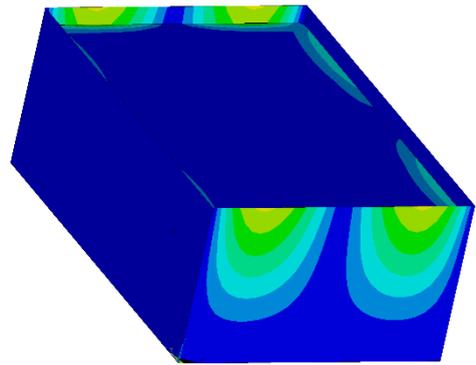


Fig. 11. Deformation in the y-axis direction ($u_y = 2.217$ mm).

The specific bending moments in the tank walls m_x (Fig. 12) and m_y (Fig. 13) were also plotted on the structure.

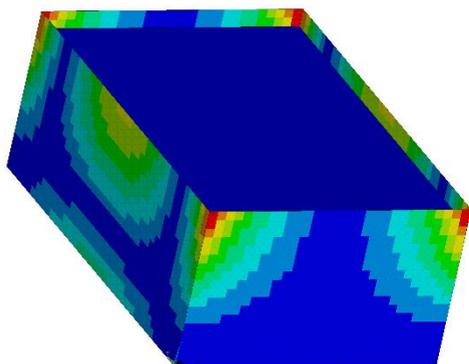


Fig. 12. Specific moment m_x in the tank walls (maximum $m_x = 51.054$ kNm/m).

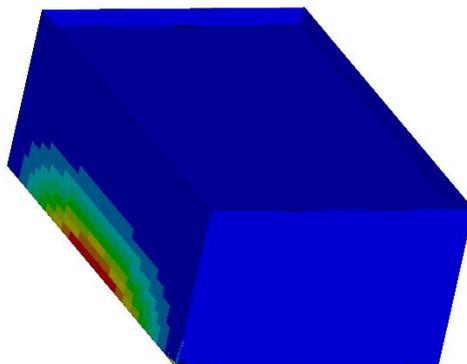


Fig. 13. Specific moment m_y in the tank walls (maximum $m_y = 90.651$ kNm/m).

5 Comparison of results

As it can be seen in Table 1, when applying the accelerogram loading and response spectrum loading (obtained from the given accelerogram), there is a difference in both the resulting deformations and the specific moments in the walls. The values obtained by spectral analysis are higher. This confirms the correctness of both calculations since the results obtained from the response spectrum should be higher than those obtained by direct integration over time.

Table 1. Comparison of deformations and specific moments during an earthquake with 2% damping.

	Accelerogram	Spectrum
u_x [mm]	15.429	16.839
u_y [mm]	1.377	2.217
m_x [kNm/m]	46.004	51.054
m_y [kNm/m]	87.527	90.651

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