

REINFORCED CONCRETE WATER TANK RESPONSE UNDER A SEISMIC LOAD

Jozef SUMEC, Norbert JENDŽELOVSKÝ
Slovak University of Technology in Bratislava

1. Introduction

Analysis of the seismic response of water towers in interaction with the fluid media still belongs to the topical problems of continuum mechanics. From the physical point of view it is an interaction between different mechanical behaviour of two materials. Water tower structure is located near Žilina, where seismic parameters were taken into account. The value of ground acceleration is $a_g = 1,25 \text{ m.s}^{-2}$ according to [2]. The deterministic model for the problem solution was used. The displacements and stressed levels are used for the check of the structure response with respect to the ultimate strength state and reliability. The solutions of similar problems were given e.g. in [3, 4, 5, 7, 8].

2. Structural model description and seismic characteristics

Reinforced concrete tank tower is supported by annular monolithic reinforced concrete column with the outside diameter 2600 mm and the thickness of wall 300 mm. The cone tank is made from of the same material as the column. The total volume of the tank is more than 630 m^3 . The foundation of the reservoir is a one-stage reinforced concrete circular plate with diameter 5000 mm and the thickness 1500 mm. The type of the concrete is B 20. The scheme of the cross-section of the tank tower is given in Fig. 1. The further technical details are obvious from [3]. In Fig. 2 it is showed the geometrical scheme of the whole water tower.

The seismic loading is considered according to standard (EC8) [6].

3. Loading and boundary conditions

The static load of the water tank is considered as a roof loading according to the standard EC1 [2] (dead load of the whole structure, snow, etc.). Two types of states of loading are taken into account:

- a) empty water tank,
- b) full water tank (during the working mode).

Similarly, two “limited” types of boundary conditions are assumed:

- c) rigid fixing of foundation plate into the subsoil,
- d) elastic bearing capacity of foundation plate on Winkler subsoil with bed coefficient $C = 35 \text{ MN/m}^3$.

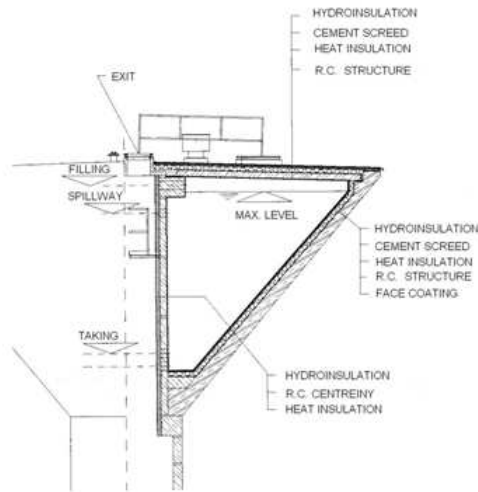


Fig. 1 Cross-section of the reinforced concrete water reservoir

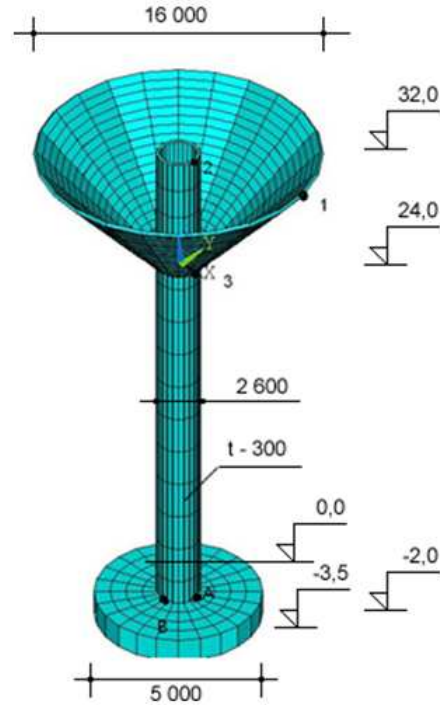


Fig. 2 Geometrical scheme of the structure

4. Analyses of results

Structural model of the tank including the fluid media was calculated using the FEM. 3D calculation models of the tank were created mostly by shell elements SHELL 43. The fluid media was modelled by elements MASS 21. Concentrated mass properties were taken into account for variable load and distributed masses are used for lateral area of the cone. In order to get the overall view of the dynamic response, the initial eigen frequencies were calculated. With regard to the rotational symmetry of the structure, the obtained values of eigen frequencies in directions of x-axis and y-axis were equal. Due to this fact the values of rotation around z-axis are important. In Fig. 3 and Fig. 4 the natural mode frequencies in directions of x- and y-axes as well as the rotation around the z-axis, which are dependent on the boundary condition of type "d", are showed.

In the first step of the solution the eigen-frequency analysis under the dynamic load by the iterative Lanczos method was realized. All eigen-frequencies of the structure up to the 50th mode and/or up to frequencies 40 Hz were calculated. Obtained results are summarized in Tab. 1.

Tab. 1 First three eigen-frequencies of the calculation model

Type of the model	x-, y- direction	rotation around z-axis
Full water tank + boundary cond. „c“	0,377 Hz	1,4098 Hz
Full water tank + boundary cond. „d“	0,338 Hz	2,475 Hz
Empty water tank + boundary cond. „c“	0,533 Hz	1,674 Hz
Empty water tank + boundary cond. „d“	0,479 Hz	2,6345 Hz

FREQ=,377216
USUM (AVG)
RSYS=0
DMX =,044533
SMX =,044533

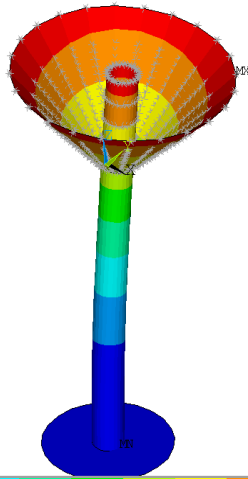


Fig. 3. Structural natural-mode frequencies of displacements in directions of x- and y-axes. Boundary condition type “d”.

FREQ=1,41
USUM (AVG)
RSYS=0
DMX =,068126
SMX =,068126

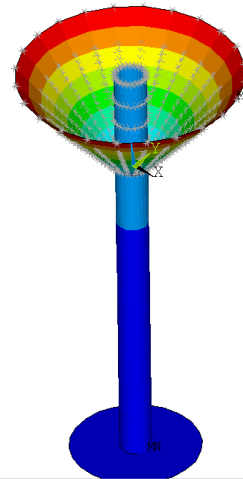


Fig. 4. Structural natural-mode frequencies in rotation around z-axis. Boundary condition type “d”.

For the solution of the problem, the method of seismic spectrum response was used. The seismic excitation was applied according to the seismic response spectra (EC8) for three orthogonal directions. Two different spectra for horizontal and vertical directions were used. Five percent of damping effect in the spectrum were taken into account.

The spectrum curve of the elastic horizontal response S_e is assembled by individual functions in these following intervals:

$$\begin{aligned}
 0 \leq T \leq T_B : S_e(T) &= a_g S \left[1 + \frac{T}{T_B} (\eta \cdot 2,5 - 1) \right], \\
 T_B \leq T \leq T_C : S_e(T) &= a_g \cdot S \cdot \eta \cdot 2,5, \\
 T_C \leq T \leq T_D : S_e(T) &= a_g \cdot S \cdot \eta \cdot 2,5 \left[\frac{T_C}{T} \right], \\
 T_D \leq T \leq 4s : S_e(T) &= a_g \cdot S \cdot \eta \cdot 2,5 \left[\frac{T_C \cdot T_D}{T^2} \right].
 \end{aligned} \tag{1}$$

The spectrum curve of elastic vertical response S_{ve} is assembled by individual functions in these following intervals:

$$0 \leq T \leq T_B : S_{ve}(T) = a_{vg} \left[1 + \frac{T}{T_B} (\eta \cdot 3,0 - 1) \right],$$

$$T_B \leq T \leq T_C : S_{ve}(T) = a_{vg} \cdot \eta \cdot 3,0,$$

$$T_C \leq T \leq T_D : S_{ve}(T) = a_{vg} \cdot \eta \cdot 3,0 \left[\frac{T_C}{T} \right],$$

$$T_D \leq T \leq 4s : S_{ve}(T) = a_{vg} \cdot \eta \cdot 3,0 \left[\frac{T_C \cdot T_D}{T^2} \right].$$

(2)

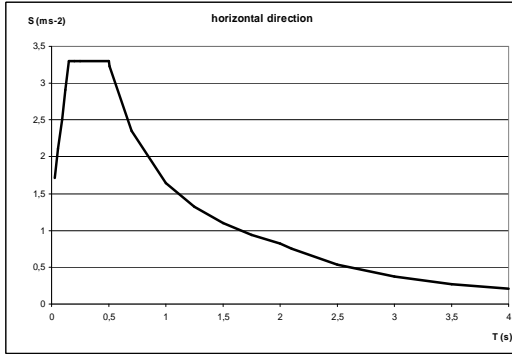


Fig. 5. Horizontal elastic response spectrum S_e

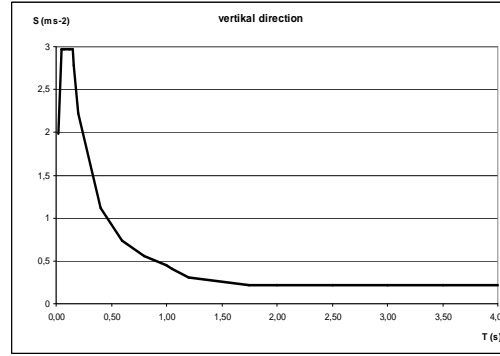


Fig. 6. Vertical elastic response spectrum S_{ve}

In evaluation of resultant response in individual directions i ($i = x, y, z$) the well-known SRSS rule was used,

$$R_i = \sqrt{\sum_j R_{j,i}^2}, \quad (3)$$

where symbol R represents the examined variable (displacement, stress, internal force).

Combination (K1, K2, K3) of responses from the three basic directions (X, Y, Z) were calculated as followed:

$$\begin{aligned} K1 & 1,0X + 0,3Y + 0,3Z \\ K2 & 0,3X + 1,0Y + 0,3Z \\ K3 & 0,3X + 0,3Y + 1,0Z \end{aligned} \quad (4)$$

The resultant response is defined as an envelope of maximum values of K_i .

$$R = \max(K_i) \quad i = 1, 2, 3 \quad (5)$$

In the tables 2 and 3 the maximum values of stresses, forces and displacements are showed.

Tab.2 Displacements U, V, W of points 1, 2, 3 (see Fig. 2)

loading+ boun.cond.	U1 [mm]	V1 [mm]	W1 [mm]	U2 [mm]	V2 [mm]	W2 [mm]	U3 [mm]	V3 [mm]	W3 [mm]
b)+c)	58,70	58,65	4,79	90,64	90,38	34,12	90,06	89,97	4,69
b)+d)	65,84	65,93	5,33	98,58	99,49	35,41	98,12	98,16	5,39
a)+c)	59,23	59,24	4,99	90,86	90,82	34,12	90,55	90,55	5,08
a)+d)	60,8	60,8	5,10	90,62	90,61	32,51	90,4	90,4	5,22

Tab. 3 Stresses in points A and B (crossing points of column with foundation circular plate).

loading+ boun.cond.	A σ_x [MPa]	A σ_y [MPa]	A σ_z [MPa]	B σ_x [MPa]	B σ_y [MPa]	B σ_z [MPa]	τ_{xy} [MPa]
b)+c)	0,029	2,239	11,512	2,238	0,038	11,510	1,063
b)+d)	2,248	1,982	10,524	1,982	2,248	10,520	0,942
a)+c)	0,041	2,351	12,052	2,351	0,041	12,052	1,197
a)+d)	2,175	1,898	10,023	1,898	2,176	10,023	0,966

5. Conclusions

The numerical analysis of the reinforced concrete water tank allowed us to identify that the zone of possible maximum deflections is in the upper part of the tower. It was confirmed that concentrations of the stresses (normal and shear) occurs in zones of connections between the foundation plate and the column as well as between the column and the conical shell. Due this fact it is important to supplement the additional vertical reinforcement into these zones from the point of view of structural reliability. These stresses have a local character.

Denotations of symbols

- T – is the eigen-period of vibration of linear system with 1DOF
- a_g – the design of seismic acceleration on the subsoil (1,1) [m.s⁻²]
- a_{vg} – the design of vertical seismic acceleration ($a_{vg} = 0,9 a_g$)
- T_B – the lower bound of part of spectra with constant acceleration (0,15 ; 0,05) [m.s⁻²]
- T_C – the upper bound of part of spectra with constant acceleration (0,5 ; 0,15) [m.s⁻²]
- T_D – the value determining the initial part of spectrum with constant deviation (2,0; 1,0) [m.s⁻²]
- S – the subsoil parameter (1, 2)
- η – the correction parameter of damping; $\eta = 1$ for 5% viscous damping

Remark: The values given in brackets were used in numerical calculations in our solved problem. The first number given in the brackets represents the values used for construction

of spectrum curve of elastic horizontal response S_e (see Fig. 5) and second one for spectrum curve of elastic vertical response S_{ve} (see Fig. 6), respectively.

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ODOZVA ŽELEZOBETÓNOVÉHO VODOJEMU NA ÚČINKY SEIZMICKÉHO ZAŤAŽENIA

Anotácia

Predkladaný príspevok sa zaoberá štúdiou seizmickej odozvy železobetónového vežového vodojemu. Model vodojemu je štandardný, vyrábaný firmou Teplotechna Ostrava [1] o objeme 630 m^3 s výškou 37m. Vodojem je situovaný v okolí Žiliny, z čoho vyplýva aj seizmické zrýchlenie $a_g = 1 \text{ m.s}^{-2}$. Nádrž je škrupina kónického tvaru nesená železobetónovým dutým stĺpom kruhového priemeru. Základ vodojemu tvorí kruhová železobetónová doska o priemere 5m. Uvažované sú dva prípady okrajových podmienok. Pevné podoprenie a zemina s koeficientom ložnosti $c = 35 \text{ MN.m}^{-3}$. Pre výpočet seizmickej odozvy konštrukcie bola použitá metóda spektrálnej odozvy podľa EC 8. Analyzované sú detailne napätovo – deformačné charakteristiky vo vybraných bodoch konštrukcie.