Assessment of the Time-dependent Behaviour of a Reinforced Concrete Water Tank by using the Finite Elements Method

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Abstract. Determinants factors (design and execution errors, site location, environmental & exploitation conditions) could generate the over-time degradation of the buildings. In order to assure the safety during the service period (imposed by the norms) the time-dependent monitoring of the structure’s behaviour is required. As a case study a reinforced concrete water tank was analysed. The structural analysis in two different stages was considered: initial stage (as in design project) and current stage (after approximately 35 years of exploitation). A parametric study based on a computational model (by using Finite Element Method - FEM) was carried out using SCIA Engineer software program. The computational model was designed (for both stages) by using mechanical characteristics of the material (collected from initial project) and data resulted from destructive and non-destructive tests in current stage. The objective was to estimate the level of degradations which could occur in structural elements during the exploitation period by comparing the evolution of stress distribution in the two stages. The durability factors were analysed in order to the studied structure's life-cycle assessment.

Keywords: structural behaviour, FEM method, water tank;

1. Introduction

1.1. General considerations on the durability of concrete structural elements

Buildings are usually subjected to actions from their normal exploitation, but also to exceptional actions (heavy snow, floods, fires, earthquakes).

Under these circumstances, depending on the quality of the materials used, the way in which the design assumptions made are approaching the reality, as well as the possible mistakes in execution, various degradations can occur [3].

The importance of studying the durability of concrete in water tanks is essential because the presence of water corroborated with the destructive action of the external environment and with various physico-chemical reactions favours the occurrence of degradations in the structural elements. Due to the differences between the properties and the structure of a concrete made under laboratory conditions (according to the data included in the project) and those of a concrete put into operation (after approximately 35 years of exploitation), the appreciation of the durability of the concrete represent a complex problem.

The tracking of factors that influence the durability of a building is made throughout its existence and includes all activities of direct examination or investigation with specific observation and measurement means to maintain the quality requirements imposed by law. In addition to meeting the quality and technical standards, this cumulative action and factors (mechanical, physical, chemical) is based on the notion of durability [1,4,5].
1.2. Particularities regarding water tank’s time-dependent behaviour

Site monitoring of buildings represent a systematic process of observing, examining and investigating how buildings react when they are exploited [9]. This process can be applied in the following situations:
- inadequate operation of the construction due to accidental overloads;
- producing chemical reactions between constituents of structural elements and various aggressive agents;
- corrosion of the fittings;
- the amplification of some destructive physical processes;

The main objective of tracking the behaviour of water tanks over time is to evaluate and identify changes in the current state of construction (by destructive and non-destructive methods) compared to the original one (according to the technical project data).

In this case, the operating conditions are assessed according to the nature of the technological process, the functioning of the related installations and the characteristics of the aggressive environment (the nature of the fluvial stored, the concentration of the fluid, the water solubility of the corrosive products) [8].

1.3. Time-dependent assessments

Time-depending behaviour of the water tank could be conducted considering the factors which affect the durability of concrete structures and also by knowing the mechanical characteristics of the materials taking into consideration the evolution in time [7].

In the considered case study were considered two stages:
- Initial stage;
- Current stage;

In the initial stage (design and execution process), the structure has been modelled knowing all the mechanical characteristics of the materials being collected from the technical project.

In the current stage (after approximately 35 years of exploitation) the structural system hasn’t changed.

By using destructive and non-destructive testing methods in order to determine the characteristic value of materials, samples of concrete have been collected.

The aim of these numerical analysis is to assess the level of degradations in the structural elements by comparing the stress distribution in the two stages and to propose different technical interventions.

2. Case study

2.1. Structural system

The analysed construction is a ground water tank made of reinforced concrete having a capacity of 5000 cubic meters. It was built in the 1980’s and it is still in exploitation, providing the necessary water for the Miroslava village and the Nicolina neighbourhood in Iasi, Iasi county.

The water tank has a circular shape in the horizontal plane (Figure 1.a.) with an inner radius of 13.85 m and a useful height of the tank of 8.05 m supported by a continuous foundation (C18/22.5). Inside, there is a central reinforced concrete column with the dimensions of 70 x 70 cm sustained by an isolated footing (C18/22.5) provided at the top with a circular cap.

The wall of the tank is made of precast elements (C25/30) of 17 cm thick. At the top of the wall was made a reinforced concrete belt with the dimensions of 70 x 70 cm sustained by an isolated footing (C18/22.5) provided at the top with a circular cap.

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At the top, the tank was closed with precast T-shaped roof elements (C25/30), radially disposed, supporting one end on the top of the wall and the other on the central pillar cap.
Figure 1. Water tank, Miroslava village, Iași county
a). Longitudinal section; b). Transversal section c). Detail A

The circular wall section was built by on three different stages (Figure 1.c.)
- in-site monolithization of precast reinforced concrete elements (1);
- post-tensioning of the circular wall with wires packed in strands SBPI Ø5 (2);
- protection at the exterior surface by applying consecutive layers of shotcrete M400 of 3 cm thick and finished with a special layer of waterproofing mortar of 1 cm thick (3).

The most common form of attack on the intimate structure of concrete is represented by the action of chloride in the chlorinated water [2].

2.2. Numerical analysis by Finite Element Method – initial stage

The analysis of constructions (static, dynamic) in general, and of water tanks in particular, has carried out by the finite element method (FEM).

In the case of water tanks, the use of the Finite Element Method (FEM) allows the determination of stress and displacement fields for all load categories, considering complicated structural shapes.

In the domain of static analysis for water tanks, the following calculation categories are based on the finite element method:
- static linear analysis;
- static nonlinear analysis;
- identification of the failure mechanism and safety factor assessment;
- optimization of automated design.

In the initial stage of the analysis, the mechanical characteristics of the materials has been collected from the technical project (Table 1).

The original values (from the project) of the control force in the strand is 2110 daN and the shotcrete layer has M400 class.
Table 1. Input data

| Structural element                  | Concrete class  |
|-------------------------------------|-----------------|
| Roof element                        | B400 (C25/30)   |
| Circular wall                       | B400 (C25/30)   |
| Wall continuous foundation          | B300 (C18/22.5) |
| Central column foundation           | B300 (C18/22.5) |

The studied structure was modelled, discretized and analysed by using SCIA Engineer software program and the linear static analysis was performed to compute the maximum efforts according to the following structural model (Figure 2).

![Figure 2. 2D perspective of the structure](image)

a). Longitudinal section b). Transversal section

The accuracy of the calculation depends on the considered static scheme introduced in the software program, which must be in line with the structural model is made (the nature of the links between the component elements, the abutments, etc.). The loads involved (Table 2) in the calculation of the water tank are:

Table 2. Acting actions on the water tank

| Loads                        |
|------------------------------|
| The own weight of the tank   |
| Variable actions (snow)      |
The pressure of the water stored in the tank

Post-tension force

In this case it was also taken in consideration the seismic load and the wind load, corresponding to the norms for the Iași county conditions at the moment when the structure was designed and executed. Partial safety coefficients for the combinations of actions in service limit state (SLS) checks are:
- 1.10 for permanent and accidental actions;
- 0.50 for variable actions.

The load combination (quasi-permanent) for the service check can be calculated as in equation (1) [10]:

$$\sum_{i=1}^{n} P_i + \sum_{i=1}^{m} V_i$$

where:
- $P_i$ – the characteristic value of the permanent action;
- $V_i$ – the characteristic value of the associated variable action;

Considering that the structure is analysed in different stages (execution stage and current stage), the static calculation is performed for the following assumption (Table 3):

**Table 3. Loading hypothesis**

| Type of combination | - service limit state (SLS) |
|---------------------|-----------------------------|
| Load combination depending on loading hypothesis [10] | $1.10 \cdot SW + 0.50 \cdot S + 0.50 \cdot W + 1.00 \cdot SL$ |

where:
- $SW =$ the self-weight of the structure;
- $S =$ snow;
- $W =$ the pressure of the stored liquid (water);
- $SL =$ the seismic load.
Meshing of a structure is a complex process to create a discrete model that best approximates the actual continuous structure from various points of view, such as geometric form, load application, etc.

In the SCIA Engineer program, the mesh network was generated for the entire domain of analysis, the elements being rectangular divided.

2.3. Numerical analysis by FEM – current stage

In the current stage, the mechanical characteristics of the materials has been determined by using destructive and non-destructive methods. The specimen used due to laboratory tests on concrete – from roof’s elements (figure 3.a.) and shotcrete specimens – from wall’s elements (figure 3.b.).

![Test specimens](image)

**Figure 3.** Test specimens  
(a). concrete  
(b). shotcrete

From physical and mechanical determination, the numerical values obtained were:
- for the concrete specimens tested in the laboratory, by using destructive methods, the characteristic in-situ compressive strength is $f_{ck,\text{cube}}=24$ MPa, corresponding to the concrete class C20/25.
- for the shotcrete specimens, it has been used the hydraulic press (tension and compression strength determination) and physical degradation method (carbonated zones, determination of water absorption) to determine the mechanical characteristics in order to estimate the level of degradations which have occurred in the structural elements.

After the tests, the same structural model has been used in the software program by using numerical values obtained from the determinations.

In this case it was also taken into consideration the seismic load and the wind load, corresponding to norms for nowadays Iași county conditions.

Partial safety coefficients for the combinations of actions in service limit state (SLS) checks are:
- 1.00 for permanent and accidental actions;
- 0.40 for variable actions.

The load combination (quasi-permanent) for the service check can be calculated as in equation (2) [6]:

$$
\sum_{j=1}^{n} G_{k,j} + \psi_{2,i} \cdot Q_{k,i} (2);
$$

where:

$G_{k,j}$ – the characteristic value of the permanent action;

$Q_{k,i}$ – the characteristic value of the associated variable action;

$\psi_{2,i}$ – factor for the quasi-permanent value of the variable action.

Regarding that the structure is considered in different stages (project stage and current stage), for the second case, the static calculation is carried out according to the current norms, considering the following assumption:

$$
1.00 \cdot SW + 0.40 \cdot S + 0.40 \cdot W + 1.00 \cdot SL
$$

The loading hypothesis considering that the water is at its full capacity will display the maximum stress distribution (Figure 4).
3. Final remarks

After the analysis (based on the numerical modelling) was performed, no significant discrepancies were found: the exception being the decreasing of the concrete class (from C25/30 to C20/25). Also, due to chlorinated water actions from the interior surface of the tank’s walls, the concrete was degraded by carbonated occurring zones.

Internal factors (chlorinated water) has deteriorate the intimate structure of the concrete wall from the inside as well, since the structure is not waterproof (micro-cracks occurrence) and external factor (aggressive environmental agents, rainwater, snow, freeze-thaw cycles) amplifies the degradation state of the structure (due to lack of thermo-insulation).

A proper numerical analysis based on conclusive data correlated with the detailed investigation of durability factors (destructive and non-destructive test, in-situ and in specialised laboratories) represents an effective way to predict the level of degradation and to ensure a safe continuous exploitation of the structure.

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