Computational Assessment of a RC Water Tank
– A Comparative Static Analysis

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Abstract. Liquids storage tanks are special structures and strategically very important. Water tanks, in particular, are important to assure continued operation of water distribution system in the event of unpredicted events. The aim of this article is to investigate the structural behaviour of a buried reinforced concrete water tank in different exploitation stages. A comparative study based on a finite element method (FEM) was considered in order to identify the most subjected areas of the structural elements (stress distribution). Numeric analysis using two advanced structural analysis and design software programs (Axis VM and SCIA Engineer) have been used for more accurate results. It was taken into consideration the extreme possibilities: case when the water tank is empty and when the water tank is at full capacity. The numerical results obtained were compared and the obtained results of both approaches has revealed minimal values differences.

Keywords: static analysis, finite element method, buried water tank;

1. Introduction
A structure must meet the exploitation, strength and stability requirements throughout the project lifetime without any significant loss of functionality and unforeseeable maintenance work [2]. In the current context, the requirements of strength, stability and safety in use must be handled with particular attention to reinforced concrete construction due to particular operating conditions. The operating conditions of the tanks are assessed in accordance with the data collected in relation to the projected technological process taking place inside the basins, the operation of the technological equipment and associated facilities and the characteristics of the aggressive environment inside and outside the basins [1].

In general, the static actions applied to the water tanks during operation, the long-term influence of a series of climatic factors (variations in temperature, humidity) as well as the aggressive action of the corrosive agents contribute significantly to the reduction of the service life of these types of structures. In the case of buried reinforced concrete tanks, the calculation of static actions is performed considering the liquid - structure interaction using approximate or exact calculation methods.

2. Particularities regarding the static behaviour of water tanks
In order to ensure the optimal exploitation, from a structural point of view, circular water tanks are preferred instead of rectangular ones. The radial pressure given by the stored liquid (water) is evenly distributed in the circular sections producing axial forces.

Another factor to be considered for operational safety is represented by the structural dimensions of the structure, which are limited by deformation and cracking conditions. The specific (radial or annular) deformation is independent of the tank diameter, the risk of cracking being directly proportional to the diameter of the tank [6].

The site of the structure is also a very important factor in the exploitation of the structure. It will follow
the fitting of the reservoir in the water supply scheme and the ground foundation characteristics. If the water tank is built in areas with steep slopes, unstable terrains with high compressibility or moisture sensitivity, additional measures need to be taken [8].

The site is regularly checked with regard to stability (levelling measurements on the tank and the emplacement). In case of buried water tanks, the protection against infiltrations will be represented by an effective waterproofing.

Other aspects of current operating conditions that must be considered in the structural design stage are: the use of appropriate materials for maintaining the water quality in the required quality parameters, cleaning the tank by providing a slope suitable for the foundation, ventilation, loading and unloading of the tank, protecting the pipes against corrosion [3].

3. Case study

3.1. Description of the structural system

The construction is a buried cylindrical reinforced concrete tank situated in Vișan village, Iași county, built during the 1980s, with the structural system presented in Figure 1.

The water tank has a circular shape, in horizontal plane, having an inner diameter of 13.40 m and a useful height of 3.80 m which is covered with earth. Within the objective under consideration, there is a pump room and a room for access to the tank

![Figure 1. Buried RC water tank – Vișan village](image)

a). Longitudinal section; b). Transversal section;

Structurally, the water tank consists of a reinforced concrete perimeter wall (20 cm thick) supported on a continuous foundation and internal reinforced concrete columns with caps at the extremities. The slab of the water tank is made of reinforced concrete and has a thickness of 20 cm, supported by the perimeter circular wall and nine interior 30 × 30 cm concrete columns.

The tank has a reinforced concrete wall inside, placed between the central columns, which partially divides the tank into two volumes and a bay next to the pump chamber.

The reinforcement of the concrete elements consists of PC52 and OB37. In order to ensure a proper rigidity and to avoid infiltrations, the water tank has been cast monolithically on site.

3.2. Comparative analysis by FEM

The analysis of constructions (static, dynamic) in general, and of water tanks in particular, has been carried out using the Finite Element Method (F.E.M.). The use of F.E.M. allows the determination of stress and displacement fields for all load categories, considering special structural shapes [4,5].

In the domain of static analysis, for water tanks, the following calculation categories are based on the finite element method:

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- static linear analysis;
- static nonlinear analysis;
- identification of the failure mechanism and safety factor assessment;
- optimization of automated design.

The studied structure was modelled, discretized and analysed by using Axis VM and SCIA Engineer software programs. The linear analysis computed in two software offer accurate results and can be efficiently and successfully used to simulate and predict the structural behaviour in different exploitation stages, in order to emphasize the stress distribution within the structural elements. The linear static analysis was performed according to the following structural models (Figures 2, 3, 4).

The main objective of this analysis is to the assessment of structural behaviour (stress distribution) in different exploitation stages (full water tank and empty water tank).
3.3. Loading hypotheses

The accuracy of the considered analysis depends on the model’s static scheme, which must be in line with the structural model (the nature of the links between the component elements, the abutments, etc.). The loads considered (Table 1) in the calculation of the water tank are of different nature:

**Table 1. Loads acting on the water tank**

| Load                                                      | AxisVM software | SCIA Engineer software |
|-----------------------------------------------------------|-----------------|------------------------|
| The self-weight of the tank and its attachments           |                 |                        |
| (pump and tank access rooms);                             |                 |                        |
| The pressure of the liquid stored in the tank (water);    |                 |                        |
| The pressure of the earth                                 |                 |                        |
| Variable actions (snow)                                   |                 |                        |

Partial safety coefficients for the combinations of actions in Service Limit State (SLS) checkings are:
- 1.00 for permanent actions;
- 0.40 for variable actions.

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

\[
\sum_{k=1}^{n} G_{k,j} + \sum_{j=1}^{m} \psi_{2,i} Q_{k,i}
\]

(1);

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.

Taking into account that the structure is considered in different exploitation stages, the static calculations are performed for the assumptions presented in Table 2.

### Table 2. Loading hypothesis

| Type of combination | Service Limit State (SLS) | Service Limit State (SLS) |
|---------------------|---------------------------|---------------------------|
| Full water tank     | 1.00·SW+1.00·EP+0.40·S    | 1.00·SW+1.00·EP+0.40·S+0.40·W |
| Empty water tank    |                           |                           |

where:  
- SW = the self-weight of the structure;  
- EP = the earth pressure;  
- S = snow;  
- W = the pressure of the stored liquid (water).

For this particular case study (buried water tank), the most important loads taken into consideration are the pressure of the stored liquid and the earth pressure.

The two loading hypotheses may be independent of one another, resulting in the need for additional iterations of the results.

### 3.4. Comparative analysis of the results

Meshing of a structure is a complex process of elaborating a discrete model that approximates the actual continuous structure from various points of view, such as geometric shape, load application, etc [5].

In the Axis VM program, the mesh network (Figure 5.a.), was automatically generated for the entire domain of analysis, the elements being triangularly divided, while in SCIA Engineer program (Figure 5.b.), the elements are rectangular.

Both programs automatically meshed the linear supports attached to the linear elements and the edges of the domains are considered as support elements automatically being divided into meshing.
The obtained results from the linear static analysis in the software programs considering the two hypotheses (full water tank and empty water tank) are very similar, differences less than 5% for the stress distribution within the analysed structure being recorded.

3.4.1. Full water tank. In this situation, it is considering that the buried RC water tank is at its full capacity, the stress distribution being illustrated in the Figures 6, 7, 8.

![Figure 5. Meshing network](image)

a). Axis VM software  
b). SCIA Engineer software

![Figure 6. Stress distribution – top view of the RC buried water tank](image)

a). Axis VM software  
b). SCIA Engineer software

![Figure 7. Stress distribution - bottom view of the RC buried water tank](image)

a). Axis VM software  
b). SCIA Engineer software
In terms of stress distribution, the maximum normal stress, $\sigma_X$, computed by both programs is:
- at the top of the columns (Figure 6) - 3195.4 KN/m$^2$ in Axis VM and 3134.0 KN/m$^2$ in SCIA;
- at the base of the circular wall (Figure 8) - 1083.9 KN/m$^2$ in Axis VM and 1040.4 KN/m$^2$ in SCIA;
- at the continuous foundation level (Figure 7) - 3195.4 KN/m$^2$ in Axis VM and 3134.0 KN/m$^2$ in SCIA.
In the case of the interior wall (Figure 9), the self-weight of the element and the pressure of the water exerted on both sides, lead to mutual suppression of the effects of this action. In this situation the normal stress distribution ($\sigma_X = 32.0$ KN/m$^2$ in Axis VM, $\sigma_X = 30.6$ KN/m$^2$ in SCIA), remain constant along the whole structural element.

3.4.2. Empty water tank. The loading hypothesis considering that the water tank is empty, therefore not acted by the pressure of the liquid, the stress distribution is shown in Figures 11, 12, 13.
In terms of stress distribution, the maximum normal stress computed by both programs are:
- at the top of the columns (Figure 10) - 3183.1 KN/m$^2$ in Axis VM and 3134.0 KN/m$^2$ in SCIA;
- at the base of the circular wall (Figure 12) - 1081.7 KN/m$^2$ in Axis VM and 1040.4 KN/m$^2$ in SCIA;
- at the continuous foundation level (Figure 11) - 3183.1 KN/m$^2$ in Axis VM and 3134.0 KN/m$^2$ in SCIA.
In terms of stress distribution, the maximum normal stress computed by both programs are distributed symmetrically at the top of the columns (Figure 10) and in some parts of the continuous foundation (Figure 12).
Figure 10. Stress distribution - top view of the RC buried water tank
a). Axis VM software  
b). SCIA Engineer software

Figure 11. Stress distribution - bottom view of the RC buried water tank
a). Axis VM software  
b). SCIA Engineer software

Figure 12. Stress distribution - lateral view of the RC buried water tank
a). Axis VM software  
b). SCIA Engineer software

In the case of the inner wall, the self-weight of the element does not influence the values of the normal stress distribution ($\sigma_X = -6.9$ KN/m$^2$ in Axis VM, $\sigma_X = -6.4$ KN/m$^2$ in SCIA), this being constant along the whole structural element (Figure 13).
4. Final remarks

In the case of the full water tank the most stressed areas have been identified as follows:
- at the top of the columns ($\sigma_X = 3195.4$ KN/m$^2$ in Axis VM, $\sigma_X = 3134.0$ KN/m$^2$ in SCIA);
- at the base of the circular wall ($\sigma_X = 1083.9$ KN/m$^2$ in Axis VM, $\sigma_X = 1040.4$ KN/m$^2$ in SCIA);
- at the continuous foundation level ($\sigma_X = 3195.4$ KN/m$^2$ in Axis VM, $\sigma_X = 3134.0$ KN/m$^2$ in SCIA).

At the inner wall level, due to the liquid pressure exerted on both sides, the stress distribution has smaller values ($\sigma_X = 32.0$ KN/m$^2$ in Axis VM, $\sigma_X = 30.6$ KN/m$^2$ in SCIA).

In the situation when the water tank is empty, values of the estimated stresses are:
- at the top of the columns ($\sigma_X = 3183.1$ KN/m$^2$ in Axis VM, $\sigma_X = 3134.0$ KN/m$^2$ in SCIA);
- at the base of the circular wall ($\sigma_X = 1081.7$ KN/m$^2$ in Axis VM, $\sigma_X = 1040.4$ KN/m$^2$ in SCIA);
- at the continuous foundation level ($\sigma_X = 3183.1$ KN/m$^2$ in Axis VM, $\sigma_X = 3134.0$ KN/m$^2$ in SCIA).

At the inner wall level, the stress distribution has values ($\sigma_X = -6.9$ KN/m$^2$ in Axis VM, $\sigma_X = -6.4$ KN/m$^2$ in SCIA).

In both loading hypotheses (full water tank and empty water tank) the results obtained from the two software programs shows that the most stressed areas (red colour) are at the top of the internal columns and at the foundation level. In the same time, obtained results shows that both computer programs are compatible in order to be used for the analysis of those types of reinforced concrete structures, being considered that are realised from homogeneous material.

Taking in consideration that each FEM software program have its proper manner of introducing the structural model corroborated with the fact there are very small differences in the resulting values (less than 5%), this research can be suitable for the other types of water tanks (semi-buried, over ground).

In order to be generalised to the entire lot of the water tanks existing in Moldova county (which were realised in the same period, same conditions, same materials and same workmanships and exploited in the same conditions), it can be considered that the general structures “health” stage does not affect the proper functionality state.

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