The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM), 2025

Volume 36, Pages 21-27

ICBAST 2025: International Conference on Basic Sciences and Technology

Reinforcement Analysis of a Water Tank Wall by External Prestressing

Hocine Hammoum
Mouloud Mammeri University of Tizi-Ouzou

Karima Bouzelha
Mouloud Mammeri University of Tizi-Ouzou

Amar Aliche
Mouloud Mammeri University of Tizi-Ouzou

Abstract: Water storage structures age and deteriorate over time, which can make them vulnerable. There are many reinforcement methods available to rehabilitate them. Our research focuses on a system for reinforcing the wall of a concrete tank, subjected to hydrostatic pressure, by additional external prestressing. The role of the latter will be to relieve the wall of hydrostatic or even hydrodynamic tensile stresses, and allow it to return to an acceptable service state. This technique of adding external prestressing cables was initially introduced in the reinforcement and rehabilitation of civil engineering structures, mainly from the 1970s. In this study, a deterministic analysis is developed for the dimensioning of the external prestressing necessary to absorb part of the hydrostatic pressure exerted on the wall, taking into account the different instantaneous and deferred stress losses. Additionally, the hydrodynamic effect is evaluated by the Westergaard method, to analyze the stress state induced by the fluid-structure interaction with respect to the seismic action. In a second step, a reliability analysis is developed by considering three random variables, including the compressive strength of the concrete, the seismic intensity and the eccentricity of external prestressing cables. This reliability analysis is conducted using a computer code developed with Matlab© software based on the Monte Carlo simulations method to assess the probability of failure in tension of the circular wall for different seismic intensities. The developed approach was applied, for a practical example, whose dimensions are realistic. Fragility curves are developed representing the failure probability in the different levels of seismic acceleration.

Keywords: Tanks, External prestressing, Reliability, Seismic acceleration, Failure probability

Introduction

External prestressing is a construction technique that has been used for several years and is in fact a special case of post-tensioning. The use of external prestressing in bridge construction is experiencing spectacular growth after having been used to reinforce old structures. It consists of placing the prestressing cables in sheaths that are no longer embedded but external to the concrete in the running part. These sheaths are only placed in the concrete at the ends of the element and installed in "deflection bosses". This device is widespread in practice on civil engineering structures; this prestressing makes it possible to significantly increase the rigidity of a reinforced concrete structure. It is natural in arches, vaults, and circular structures as is the case for a circular water reservoir.

This study involves the rehabilitation of a drinking water reservoir in service, circular in shape and with a capacity of 5000 m^3. It has a serious defect, which makes this structure in its current state unacceptable from a health point of view; they do not offer sufficient health protection to the stored water. During a survey carried out on the tank to identify the origin of the leaks, it was found that the cylindrical tank had cracked, visible from

- Selection and peer-review under responsibility of the Organizing Committee of the Conference

the outside, at the tank-radiator interface, and more precisely above the gusset plate. The rehabilitation project will include additional prestressing.

The Tension at the Origin

This tension represents the actual stress transmitted to the prestressing steel by the jack, obtained by a combination of measuring the hydraulic pressure in the jack and measuring the elongation of the cable during tensioning. Most jacks are calibrated by manufacturers based on load cells and are generally accurate to within a few percent. The prestressed concrete regulation (BPEL) recommends, for the evaluation of the maximum tension at tensioning also called tension at origin, and noted σ_{p0} the following relationship:

$$\sigma_{p0} = \min(0.8f_{prg};0.9f_{peg})$$

Where, f_{prg} and f_{peg} are respectively the guaranteed breaking stress, and the conventional elastic limit.

Combinations of Actions

The combinations that define the actions to be taken into account for the justification of prestressed concrete structures intended to retain liquids are taken from Fascicule 74, as follows:
Ultimate Limit States (ULS), under fundamental combinations:

$$C1: P_t + 1.5Q$$
$$C2: P_t + 1.3Q$$

Ultimate limit states (ULS), under accidental combinations:

$$C3: P_t + Q + F_a$$

Serviceability Limit States (SLS), Rare to Frequent Combinations:

$$C4: P_t + Q$$

Where, P_t, Q and F_a designate respectively the prestressing force, the live load which is represented by the hydrostatic loads and the accidental action which is represented by the hydrodynamic loads.

Allowable Constraints

The allowable compressive stress of the concrete, calculated in homogeneous section with the prestressing force P_t, is given by:

$$\sigma_{bc} = 0.6f_{c28}$$

The allowable tensile stress of the concrete, calculated in homogeneous section is given by:
Under the effect of rare combinations, inside the embedding section: $\sigma_{bt} = f_{t28}$
Under the effect of rare combinations, outside the embedding section: $\sigma_{bt} = 1.1\theta f_{t28}$
Under the effect of frequent combinations, inside the embedding section: $\sigma_{bt} = 0$
Under the effect of frequent combinations, outside the embedding section: $\sigma_{bt} = 1.5f_{t28}$
Allowable tensile and compressive stresses for fc28=45 MPa are given in Table 4.5

Table 1. Allowable tensile and compressive stresses.

	Tensile stress [MPa]		Compressive stress [MPa]	
	Rare	Frequent	Rare	Frequent
outside the embedding section	-3.63	-4,95	27,00	
inside the embedding section	-3,30	0,00		

For external prestressing, the allowable stresses for outside the embedding section must be considered.

Deterministic Analysis

The structure that is the subject of this study is a circular reinforced concrete tank, with a capacity of 5000 m^3, placed on the ground, to which is applied external prestressing. The geometric characteristics of this structure are summarized in the table.

Table 2. Geometric characteristics of the tank.

Parameters	Values	Unit
Theoretical capacity of tank V	5000	m^3
Internal Diameter	24.00	m
Water height	11.00	m
Real volume Vr	4 976.28	m^3
Deflection f	2.50	m
Radius of curvature R	30.05	m

The hydrodynamic calculation of the tank is performed by the Westergaard method, considering the characteristic values of seismic acceleration and compressive strength of concrete. The tensile stresses at the level of the internal fibers (full reservoir) and the compressive stresses at the level of the external fibers (empty reservoir) are evaluated for different combinations of action. The calculation results showed that these stresses are lower than the allowable stresses, which allows us to conclude that the tank is not at risk of failure. The prestressing forces at different levels of the tank wall, and at different abscissas, along the cables, are considered after all prestress losses (instantaneous and delayed).

We note, however, that the significant values of the tensile constraints are obtained for the C3 combination, taking into account the seismic action and this at the level of the bottom sections of the wall. The latter are graphically presented under the C3 combination in the first two sections of the bottom of the wall, as a function of the cable length X.

The significant values of the compressive stresses are obtained for the C1, C2, C3 combinations, at the level of the external fibers when the tank is empty. The latter are graphically presented under the C1, C2, C3 combinations in the first two sections of the bottom of the wall, as a function of the cable length X. We find that the compressive and tensile stresses at different levels of the tank wall, and at different abscissas, along the cables, are lower than the allowable compressive and tensile stresses.

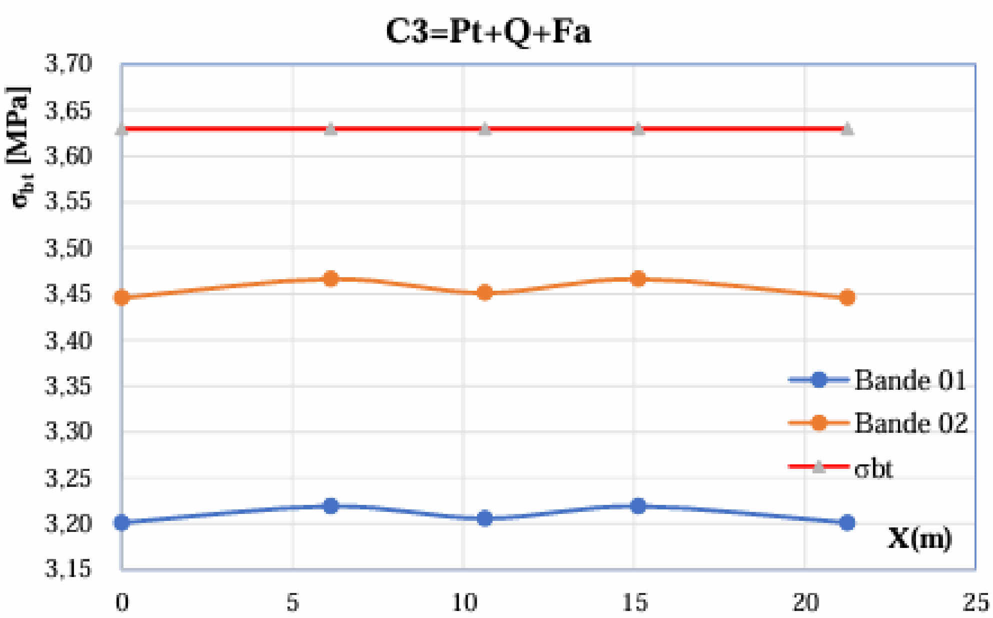

Figure 1. Tensile stresses in the internal fiber of the first two sections of the circular wall, under C3 combination (Tank full).

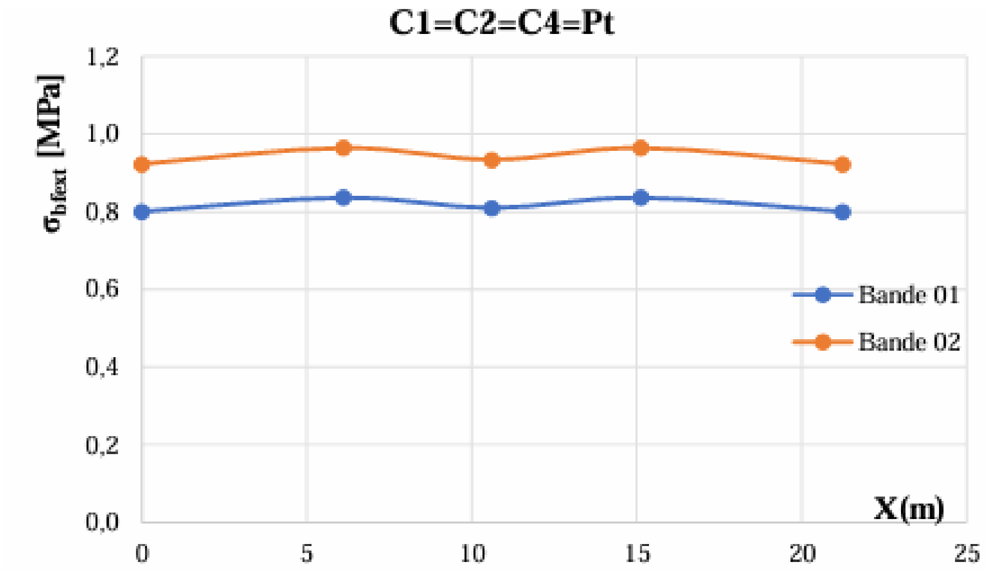

Figure 2. Compressive stresses in the external fiber of the first two sections of the circular wall, under C1, C2, C3 combinations (Tank empty).

Reliability Analysis

In the structural reliability approach, influencing parameters are considered as random variables. Reliability theory is based on a probabilistic approach to structural safety based on the Monte Carlo method, which recognizes a limit state criterion and the variability of the parameters involved in this criterion (Aoues, 2018). The structure is ultimately considered safe if the probability of failure is less than a reference value called the allowable failure probability. This study, which aims to conduct a reliability analysis of an externally prestressed concrete tank, is conducted in this context. The random variables considered are the seismic zone acceleration coefficient (A), the compressive strength of the concrete (fc), and the eccentricity (e) of the prestressing cables. The normal distribution is fitted for both parameters (A) and (fc), and the uniform distribution is fitted for the eccentricity (e). The limit state criterion used is tensile stress.

The Probabilistic Approach

The probabilistic approach is the method that relies on reliability theory to assess the probability of failure or the reliability index of the structure. The operating mode of the structure is, as with the semi-probabilistic approach, described by a limit state, but the uncertainties related to the input parameters are introduced in the form of a probability law assigned to each variable. These probability laws are established from statistical studies on the parameters concerned. The probabilistic approach consists of calculating the probability of exceeding the limit state criterion, called the probability of failure P_f, which is compared to an allowable probability of failure P_f^{adm} (Ballière et al, 2012).

$$P_f = P(G \leq 0) \leq P_f^{adm}$$

To quantify the risk of failure of a concrete tank due to loss of stability, it is necessary to define the different limit state functions G(X) which define its behavior. These functions delimit the domain of proper functioning as well as that of failure of the structure. A limit state function G(X) can be written in the following form depending of the structural resistance R(X) and the applied loading S(X) (Lemaire, 2005):

$$G(X) = R(X) - S(X)$$

The limit state function considered in this study corresponds to the failure mode of the tank due to loss of tensile strength of its wall at the serviceability limit state (SLS). It is given as follows:

$$G(X) = \sigma_{bt}^{adm} - \sigma_{max}$$

σ_{bt}^{adm} is the allowable tensile stress of the concrete given by Fascicle 74 (See Table 1).

σ_{max} being the maximum applying tensile stress.

The probability of failure is calculated by considering, in a first time, two random variables (A and f_c). The probability of failure at the tensile limit state as a function of the different seismic zones and coefficients of variation is illustrated Figure 3.

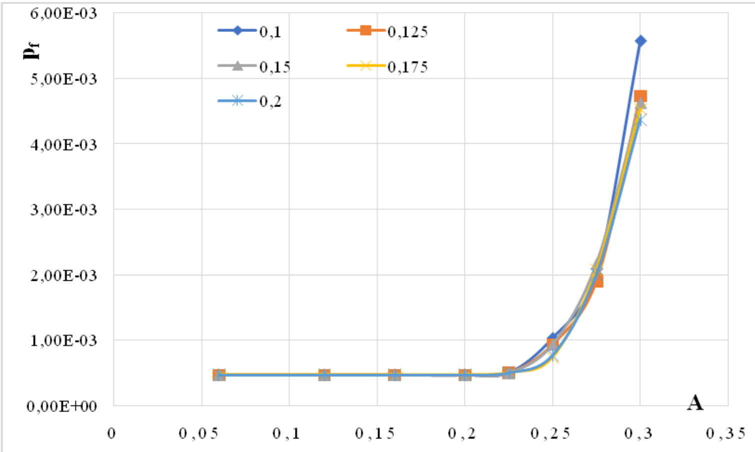

Figure 3. Probability of failure as a function of the different seismic zones and coefficients of variation

The prestressed concrete tank is of consequence class 2 (CC2), because the losses in terms of human life, economic, social and environmental will be considerable in the case of the structure failing. This leads us to take as admissible values of the reliability index β; 4.7 for an equal reference duration of one year and 3.8 for a reference duration of 50 years, which correspond to admissible failure probability values of 10^{-3} and 10^{-6} respectively, in accordance with Eurocode 2 (table 3).

Table 3. Relationship between β and P_f.

Category	Values						
β	1.28	2.33	3.09	3.72	4.26	4.75	5.20
P_f	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}

Table 4 illustrates the allowable values of β according to the consequence class.

Table 4. Minimum values of β according to the consequence class.

Reliability class	Reference period (1 year)	Reference period (50 years)
RC2	4.7	3.8

The analysis of the results shows that in the low and medium seismicity zone (IIa), the probability of failure is lower than the allowable probability ($P_f^{adm} = 10^{-3}$) regardless of the coefficient of variation; it is concluded that the tank is stable. On the other hand, the probability of failure P_f is higher than this allowable value in the high and the very high seismicity zone. The tank is therefore not suitable for these two zones.

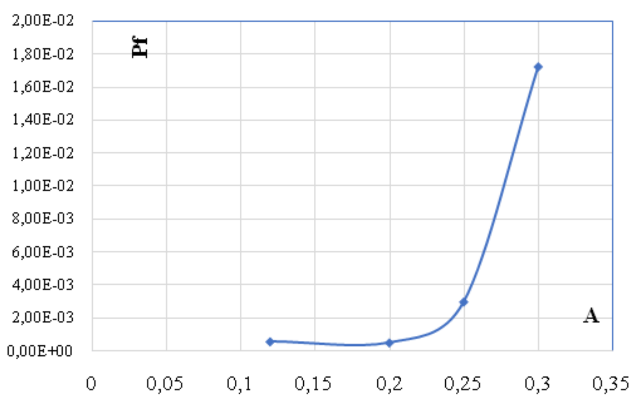

Figure 4. Probability of failure as a function of the different seismic zones and coefficients of variation

In a second step, the probability of failure is calculated by considering as random variable the eccentricity (e) and the compressive strength of the concrete (fc) for the different seismic zones. The results are illustrated in Figure 2.

Conclusion

This study focused on the deterministic analysis of the cylindrical wall of a tank placed on the ground in externally prestressed concrete, under hydrostatic and hydrodynamic stress. The Westergaard method was used to approach the hydrodynamic stress. It was possible to highlight that certain input parameters such as the eccentricity (e), the compressive strength (fc) and the zone acceleration coefficient (A) had a considerable influence on the variation of the tensile stresses, particularly in the internal fiber when the tank is full, as well as on the compression stresses in the external fiber when the tank is empty. The reliability approach based on the Monte Carlo method, which takes into account uncertainties, concludes that the analyzed structure is stable in low and medium seismicity zones (IIa). Conversely, in high seismicity zones (IIb) and in very high seismicity zones (III), the structure presents a probability of failure (Pf) beyond the admissible values recommended by Eurocode 2 which stipulates that $10^{-6} \leq P_f \leq 10^{-3}$, this demonstrates that this kind of rehabilitation is not suitable for these seismic zones. The uncertainty in eccentricity is by far the most influential and dominant in reliability calculation, which leads us to recommend careful implementation of external prestressing cable trays.

Scientific Ethics Declaration

*The authors declares that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

*The authors declare that they have no conflicts of interest

Funding

*The authors wish to thank the Algerian Ministry of higher education and scientific research for funding the University education research project (PRFU – N° A01L02UN150120220004).

Acknowledgements or Notes

*This article was presented as an oral presentation at the International Conference on Basic Sciences and Technology (www.icbast.net) held in Budapest/Hungary on August 28-31, 2025.

*The information on data of concrete compressive strength has been kindly provided by Eurl ECE of Tizi Ouzou (Algeria).

References

Aoues, Y. (2008). *Optimisation fiabiliste de la conception et de la maintenance des structures* (PhD thesis). Blaise Pascal University of Clermont, France.

Ballière A. et al., (2012). *Théorie de la fiabilité, application à l'évaluation structurale des ouvrages d'art*. Rapport d'étude.

Carlton M. A, & Devore J. L. (2014). *Probability with applications in engineering*. Springer edition.

Dehmous, H. (2007). *Fiabilité et micromécanique des matériaux composites Application à la passerelle de Laroin* (PhD thesis). Institut National Polytechnique de Toulouse.

DTR B.C.2.2, (1988). *Charges permanentes et charges d'exploitations.* CNERIB, Alger.

Eurocode 2 (2003). *Bases de calcul des structures, norme européenne.* Retrieved from https://www.febelcem.be /fileadmin/user_upload/autres-publications/fr/EC2Condense.pdf

Fascicule 74 (1998). *Construction des réservoirs et châteaux d'eau en béton armé, en béton précontraint ou en maçonnerie*. Retrieved from https://piles.cerema.fr/IMG/pdf/fascicule_74_cctg_1998_construction_reservoirs_beton_ cle795f61.pdf

Guerrin, A., & Lavaur, R. C. (1972). *Traité de béton armé tome 6, réservoirs, châteaux d'eau et piscines*. Eyrolles edition.

Haddad, L., & Sellam, Y. (2017). *Analyse mécano-fiabiliste d'un réservoir surélevé soumis à l'action du vent* (Master's thesis). Mouloud Mammeri University.

Rychilk, I., & Ryden, J. (2006). *Probability and risk analysis, an introduction for engineers*. Springer.

Author(s) Information

Hocine Hammoum
Mouloud Mammeri University of Tizi Ouzou, Department of civil engineering, 15000 Tizi Ouzou, Algeria.
Contact e-mail: *hocine.hammoum@ummto.dz*

Karima Bouzelha
Mouloud Mammeri University of Tizi Ouzou, Department of civil engineering, 15000 Tizi Ouzou, Algeria.

Amar Aliche
Mouloud Mammeri University of Tizi Ouzou, Department of civil engineering, 15000 Tizi Ouzou, Algeria.

To cite this article:

Hammoum, H., Bouzelha, K., & Aliche, A. (2025). Reinforcement analysis of a water tank wall by external prestressing. *The Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM), 36,* 21-27.