BULETINUL INSTITUTULUI POLITEHNIC DIN IAȘI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iași
Volumul 64 (68), Numărul 4, 2018
Secția
CONSTRUCȚII. ARHITECTURĂ

# A COMPREHENSIVE APPROACHING OF THE WATER TANKS DURABILITY'S AFFECTING FACTORS IN DIFFERENT STAGES

BY

**DANIEL COVATARIU[1,*] and ALEXANDRU FILIP[2]**

[1]”Gheorghe Asachi” Technical University of Iaşi,
Faculty of Civil Engineering and Building Services,
[2]Doctoral School of the ”Gheorghe Asachi” Technical University of Iași

Received: November 10, 2018
Accepted for publication: December 17, 2018

**Abstract.** Any construction represents a complex system in a continuous interaction with both, the natural and anthropic environment, permanently accumulating the consequences of all the categories of actions that require it (including those specific to operating mode). It is therefore possible to admit that in their structure, various degradations and failures occur with the passage of time. For a good analysis and interpretation of the effects generated by factors affecting the sustainability of the reinforced concrete structures could be identified (multicriterial) causes. In the paper was discussed, in chronological order, the main factors which may determine its durability, *i.e.* on stages of evolution of the structure: at the design stage, execution, exploitation and finally at the stage of repair/rehabilitation work.

**Keywords:** water tank; durability; exposure class; risk of degradation.

## 1. Introduction

Durability represents the capability of a structure to last a long time without significant deteriorations/damages, having a reduced environment impact.

---

[*]Corresponding author: *e-mail:* daniel.covatariu@tuiasi.ro

Regardless of how it is accomplished, any construction it represent a complex system in a continuous interaction with both, the natural and anthropic environment, permanently accumulating the consequences of all the categories of actions that require it (including those specific to operating mode). It is therefore possible to admit that in their structure, various degradations and failures occur with the passage of time.

For a good analysis and interpretation of the effects generated by factors affecting the sustainability of the reinforced concrete structures could be identified (multicriterial) their causes:

**Natural causes** (due to exposure to environmental conditions):

- of physical nature;
- of chemical nature;
- of biological nature;
- occurring after normal wear of properly designed, executed and exploited structures;
- due to exceptional actions (earthquake, accident, landslides, subsidence, floods, fires, explosions).

**Anthropogenic causes**:

- due to design;
- due to execution;
- due to exploitation;

These cases together with risk factors have led to the classification of environmental conditions in *exposure classes*, depending on the environmental actions and the concrete degradation mechanisms (detailed in Table 1 of NE 012 – 1 – 2007). These are classified in relation to the risks of degradation (major factors that may affect the quality of the concrete).

Depending on the classification in a given class of exposure (or a certain grouping of these classes – Table 1a from NE 012 – 1 – 2007), in the same normative, the limit values for the requirements for ensuring the sustainability of concrete structures shall be required.

Taking into account these and the degree of damage of the structure can be evaluated the sustainability characteristics of the structure in analysis.

The degree of affection of the constituent elements of the reinforced concrete structures depends directly on three aspects:

- The intensity of the action of aggressive agents (of the anthropic natural environment);
- The degree of exposure of construction elements to the action of such agents;
- Duration of exposure.

**Table 1**
*Exposure Classes (conf. Table 1 from NE 012 – 1 – 2007)*

| Exposure class | Risk of degradation | Environmental conditions |
|---|---|---|
| X0 | No risk of corrosion or attack | |
| XC | Corrosion due to carbonate | XC1– Dry or permanently damp<br>XC2 – Wet, rarely dry<br>XC3 – Moderate Humidity<br>XC4 – Alternation Moisture-drying |
| XD | Corrosion due to chlorine (having origin other than marine) | XD1 – Moderate humidity<br>XD2 – Wet, rarely dry<br>XD3 – Alternation Moisture-drying |
| XS | Corrosion due to chlorine in seawater | XS1 – Exposure to air that circulates marine salts, but is not in direct contact with sea water<br>XS2 – Permanently immersed<br>XS3 – Areas of docking bay, areas subject to splashing or fog |
| XF | Attack from frost-thaw with or without defrosting agents | XF1 – Moderate saturation with water without defrosting agents<br>XF2 – Moderate water saturation with defrosting agents<br>XF3 – Strong saturation with water, without defrosting agents<br>XF4 – Strong water saturation with defrosting agents or sea water |
| XA | Chemical Attack | XA1 – Environment with poor chemical aggression<br>XA2 – Environment with moderate chemical aggression<br>XA3 – Environment with intense chemical aggression |
| XM | Mechanical application of concrete through wear | XM1– Moderate wear request<br>XM2 – Intense Wear request<br>XM3 – Very intense wear request |

For a better understanding of how the sustainability of a reinforced concrete tank is affected, we preferred to present in chronological order the factors that determine sustainability, *i.e.* on stages of evolution of the structure: at the design stage, execution, exploitation and finally at the stage of repair/rehabilitation work. It has chosen this presentation manner because the identification of any errors is easier chronologically and, obviously, measures to remove/mitigate these causes and effects should be applied at the specific stage where it appears.

## I. DESIGN STAGE

### 1. Zone placement

The choice of location of a reservoir is certainly dictated by the urbanism regulations (imposed by the local authority), close to the sources/networks of refill and water treatment, the proximity of inhabited areas. It can be a factor of influence of sustainability and the risk of earthquake; If the location area is active seismically, additional measures will be provided in the project (damping system/seismic isolators).

### 2. Materials

The materials used in the construction of the water tank are imposed on the project, taking into account the environmental location and conditions (concrete vs. steel). The choice will influence the life of the structure and depending on the exposure classes, the construction price, the price and the current repair period.

### 3. Quality of the subsoil

The forms of relief will also require the choice of the shape of the tank, the type of foundations used (depending on the quality of the soil), the constructive type (over ground & underground). Tests for determining the soil's characteristics shall require the type and material used for the construction of the water tank's foundation and for hydro-thermoinsulation used for them.

### 4. Type

The constructive type (buried, semi-buried, over ground, suspended) influences sustainability due to the smaller or larger areas exposed to the risk of aggressive environmental agent's attacks, the protection being much increased in the case of underground structures. In addition, for the over-ground water tanks, the pressure of the stored water on the walls of the tank has a much amplified effect than in the case of those buried (which may result in an accelerated degradation in the case of a non-compliant design).

### 5. Shape

It is obvious the difficulty of choosing the shape - circular vs. parallelepiped shape - due to the complexity of the different technologies of execution. For the cylindrical shape it is necessary to apply a pre-tensioned of the thin curved plates (the walls of the tank), and the place where the ends of the strands will be connected, shall be treated with special care because it can be the most sensitive area where different types of degradations could occurs. Also, the coating layer with mortar of the pre-tensioned reinforcements could be damaged (adherence to the support layer).

Similarly for rectangular water tanks, the location of the wall joints (edges) will be energy concentrators and may be susceptible to earthquakes or to ground's settlements.

**6. Joints**

Although it is clearly stated in the normative, for special constructions (and the case of the water tanks) the position of the work joints must be indicated in the project and also the treatment procedure - sealing tapes, processing, etc (NE 012-2-2010). In fact, the presence of work joints can be a sensitive problem and a risk factor present at all stages of a reservoir: from design (special conditions) to the phase of execution (special sealing technology), as well as in the phase of exploitation, but certainly at the repair/rehabilitation stage (appropriate materials and technologies for each individual case depending on the type of damage specific to the degradation observed).

**II. ERECTING STAGE (EXECUTION)**

**1. Cement Content & Quality**

When cement content used is lower than is required in the mix, then water-cement ratio becomes reduced and workability also reduced. If is necessary to increase the workability (by adding more water to the mix) it results the capillary voids which will make concrete as permeable material. This is not allowable for an water tank, especially.

It is important to enhance that the quality of the cement used in concrete mixes is important, especially for the water tank construction. Maybe would be necessary to use hydraulic cement to increase the capability of the tank to work in the presence of the water. If cement content is used in excess drying shrinkage or alkali-silica reaction may occur which will affect the durability of concrete.

Fig. 1 – Cement content.

## 2. Aggregate Quality

The durability of hardened concrete is given also by the quality and shape of the aggregates. The shape of aggregate particles should be smooth and round. Flaky and elongated aggregates effects the workability of fresh concrete (could occur voids in concrete's structure). Aggregate should be well graded to achieve dense concrete mix.

For better bond development between ingredients rough textured angular aggregates are recommended some admixtures used in concrete's mix (but not exchanging the others concrete's characteristics).

Aggregates should be tested for its moisture content before using. Excess moisture in aggregate may lead to highly workable mix.

Fig. 2 – Aggregates.

## 3. Water Quality (used in concrete's mixes)

Quality of water used in concrete mixing also effects the durability of concrete. Potable water is recommended for making concrete. Water should be clean and free from oils, acids, alkalies, salts, sugar, organic materials etc. Presence of these impurities will lead to corrosion of steel or deterioration of concrete by different chemical reactions.

Water's ph shall be in the range of 6 to 8.

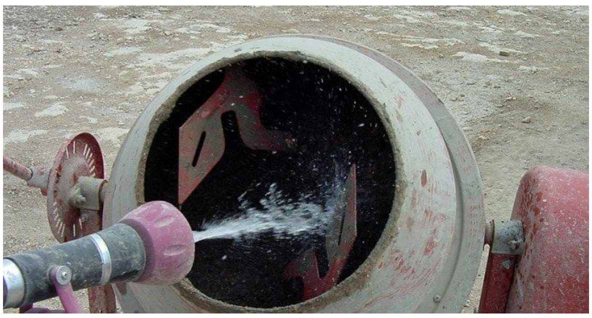

Fig. 3 – Adding water to concrete mix.

**4. Concrete Compaction**

Improperly compacted concrete contains number of air voids, which reduces the concrete strength and durability. While placing concrete, it is important to compact the placed concrete without segregation.

Fig. 4 – Compacting fresh concrete.

**5. Curing Period**

Proper curing in initial stages of concrete hardening result in good durability of concrete.

Improper curing leads to formation of cracks due to plastic shrinkage, drying shrinkage, thermal effects etc. thereby durability decreases.

Fig. 5 – Drying shrinkage due to poor curing.

**6. Temperature effects (during curing)**

Concrete ingredients have different thermal coefficients, so at higher temperatures, spalling and deterioration of concrete happens.

Concrete is heterogeneous material, when fresh concrete is subjected to high temperature rate of hydration gets affected and strength and durability becomes reduced.

Fig. 6 – Thermal cracks in concrete.

## III. EXPLOITATION STAGE

### 1. Permeability

Concrete durability gets affected when there is a chance of penetrability of water into it. Permeability of water into concrete expand its volume and lead to formation of cracks and finally disintegration of concrete occurs.

Generally concrete contains small gel pores and capillary cavities. However, gel pores do not allow penetration of water through them since they are of very small size. But, capillary cavities in concrete are responsible for permeability, which are formed due to high water cement ratio.

To prevent permeability, lowest possible water cement ratio must be recommended and also the use of pozzolanic materials also helps to reduce permeability by filling capillary cavities.

Fig. 7 – Capillary absorption in concrete block.

**2. Moisture**

Moisture present in the atmosphere will also affects durability of concrete structures.

Due to moisture, efflorescence in concrete may occurs, which will convert salts into soluble solutions and when it evaporates salts become crystallized on the concrete surface. This will definitely damage the concrete structure and durability will be reduced.

Fig. 8 – Efflorescence in concrete.

**3. Carbonation**

Corrosion of reinforcement causes cracks in concrete and deterioration will be present.

When moist concrete is exposed to atmosphere, $CO_2$ present in atmosphere reacts with concrete and reduces pH of concrete. If pH of concrete reaches below 10, reinforcement present in the concrete starts corroding.

Fig. 9 – Carbonated concrete.

**4. Wetting and Drying Cycles**

When concrete is exposed to alternate wetting and drying conditions (such as long-time rains, acid rains, floods etc.) secondary stresses are developed in concrete. Due to these stresses cracks will form and reinforcements are exposed to the atmosphere. When chlorides or sulphates (from aggressive environmental agents) contact reinforcements, corrosion occurs and durability of concrete is reduced. In order to avoid these, is necessary to use low-permeable concrete and an adequate cover of the reinforcement.

Fig. 10 – Concrete affected by alternate wetting and drying.

**5. Freeze-Thaw Cycles (with/without thermos-insulation)**

Depending on the season, concrete (fully saturated) is exposed to repeat cycles of freezing of thawing. This situation creates degradation of the concrete elements and decreasing of the mechanical characteristics. It causes cracking on concrete surface in a shape called “map cracking” and affects durability of concrete.

The coarse aggregate embedded in the concrete’s structure also affected by freeze-thaw cycles, leads to spalling of concrete.Durability of concrete can be achieved by adding air-entraining admixtures to the mix and also reduce the maximum size of coarse aggregate.

Fig. 11 – Concrete affected by freeze-thaw cycles.

### 6. Alkali-Aggregate Reaction

Another major factor effecting durability of concrete is *alkali-aggregate reaction* or *alkali-silica reaction*, which occur between alkali content of cement and silica content of aggregates.

Due to this reaction, concrete expansion occurs which finally lead to severe cracking and concrete gets deteriorated.

To overcome this risk is recommended the use of the cement with less alkali content, non-reactive aggregates, pozzolanic materials (fly ash or slag cement), and lithium-based admixture in concrete.

Fig. 12 – Alkali-aggregate reaction.

### 7. Water Quality (chlorine attack from water's reserve from tank)

If the water does not qualitatively match it, it should be treated, keeping certain concentration limits and thus enrolling in the drinking standards. This also avoids destructive action on tanks and pipelines.

The water treatment process is carried out with a complex set of constructions and installations designed to improve the qualitative parameters. In Romania, the most used method of water treatment is achieved by chlorination, due to technical and economic considerations.

The chlorination of water is carried out by various processes (chlorination with normal chlorine doses and super-chlorination with increased chlorine doses increase), and this method applies both in water-centralized supply systems and at local level.

The most common form of attack on the intimate structure of concrete is represented by the action of chlorine in the treated water, the speed of the corrosion process being influenced by the operating conditions, temperature, humidity, etc.

During the corrosion process produced by chlorine ions (Fig. 13), the passive layer at the surface of the reinforcement is destroyed. Since the anode area is reduced and the cathode area is extended over the entire surface of the reinforcement, there is a substantial reduction in the section of the reinforcement.

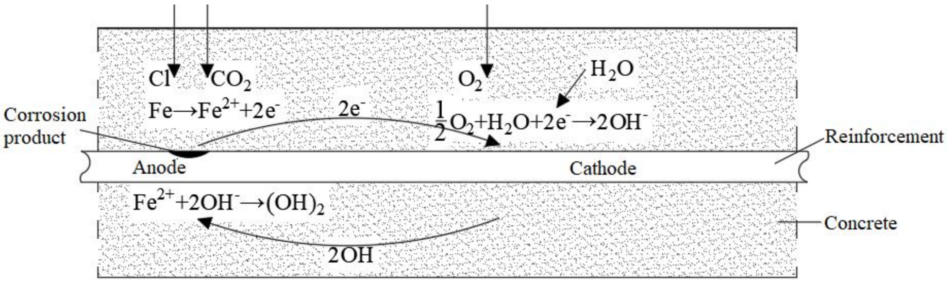


Fig. 13 – Simplified model for corrosion reinforcement in concrete.

Due to the constant exploitation of the water tank and possible execution errors, the exploitation environment favoured the triggering and evolution in various forms of the corrosion of the reinforcements in the structural elements (Fig. 14), thus diminishing the durability of the construction.

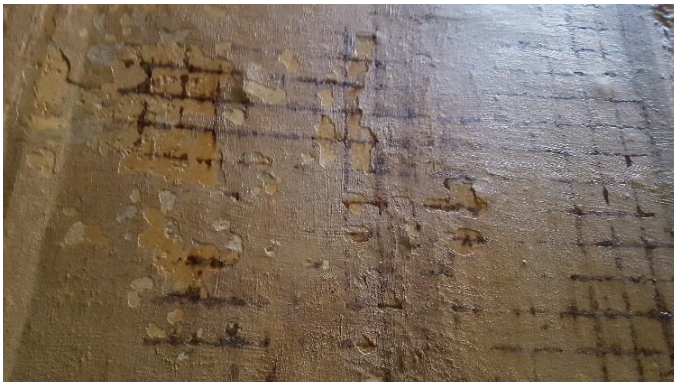

Fig. 14 – Corroded reinforcements at the level of the water tank wall – Miroslava commune, Iaşi County.

The prevention of severe degradation in concrete elements under high aggressive environmental conditions, as in the illustrated example, can be achieved by adopting protective measures such as: increasing the concrete cover layer, using special mortars (fiber reinforced mortars, mortars containing corrosion inhibitors), etc. These interventions aim to bring in service the analysed objective and increase the nominal values of the durability characteristics to ensure a regular service period.

### 8. Sulphate Attack

Sulphate attack generally happens when water used for concrete mix contains high sulphate content (due to unwashed aggregates, when soil around the concrete structure contains sulphates in it etc.).

When concrete structures are attacked by sulphates (sodium sulphate, magnesium sulphate etc.) concrete disintegration happens. This reaction is due to the chemical reaction between hydrated cement products and sulphate solutions.

This situation can be prevented by using sulphate resisting cement, by adding slag cement, by decreasing permeability, by adding special admixtures in concrete mix a.s.o.

Fig. 15 – Spalling of concrete due to sulphate attack.

### 9. Abrasion

When concrete is subjected to abrasion, continuously wearing of surface occurs and durability gets affected.

Severe abrasion could create severe deterioration of the concrete structure if it is placed in a zone with high velocity winds. Different particles from the soil (sand or small particles) could be entrained by the wind and hit the external surface of the structure, causing cracks (reinforcements could be exposed).

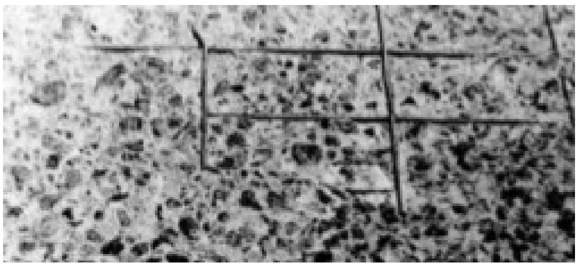

Fig. 16 – Abrasion of concrete surface could expose the reinforcements.

## IV. REHABILITATION/REPAIRING STAGE

### 1. The adherence between old and new materials

Perhaps the most important step in applying the rehabilitation procedure is to ensure the adhesion of the new material applied to the existing support layer. This is done by carefully preparing the support layer (cleaning, pickling and roughening). Negligence in the application of such preparations and the non-compliant application of the "new" material will not create a homogeneous rehabilitated system, the existence of which (hence durability) will be much limited in time.

### 2. Rehabilitation Materials Characteristics Compatibility

One of the principles of structural rehabilitation implies that the choice of materials should be taken into account, firstly, of the compatibility of the characteristics of new materials (used in the rehabilitation process) with existing ones (degraded), so that, after completing the rehabilitation process they work together in the newly created ensemble. Failure to assume this requirement leads to a failing of the rehabilitation process, which does not, in any case, create a sustainable structure.

### 3. Time-period when are required reparation/rehabilitation procedures

The postponement of current repair/maintenance work for indeterminate periods (often justified by lack of funds) can] lead to an acceleration of the processes of degradation/deterioration of the water tank structure, which may cause non-compliance in operation and possibly increased costs for a structural rehabilitation work. Obviously a choice that severely influences the durability of the tank assembly.

### 4. The influence of the working capacity of the machinery from water tanks equipment

Another aspect that is often not taken into account is represented by the noise and vibrations induced by the equipment attached to the water tank (pumping systems, valves, etc.). The process of water pumping in conjunction with operating conditions (temperature differences, humidity) is a cause that can lead to progressive degradation of concrete elements by the appearance of microcracks. During the exploitation of the objective, these microcracks amplify the degradation processes in the concrete structure.

In this case, different vibration dissipation procedures such as reinforced cork insulation (Fig. 15 *a*) and rubber band (Fig. 15 *b*) will be used for proper damping.

*a* *b*

Fig. 15 – Materials used for vibration dissipation:
*a* – cork insulation; *b* – rubber band .

**5. Choice of proposed rehabilitation method: classic vs. modern techniques**

Is always difficult to choose which is the most efficient method used in order to rehabilitate a damaged/degraded concrete structure.

Depending on the choice made – modern methods vs. classical methods – an analysis of the effectiveness of the application of these methods and the compatibility of the degraded structural system (requiring rehabilitation) and applied method, by default of all, is required. The advantages/disadvantages involved in applying a method compared to another.

There is a trend (probably a misunderstood engineering routine) to design and perform rehabilitation works by classical methods, the most common for Romania (and especially the region of Moldova) jacketing with special mortars (to ensure protection of pre/post tensioned reinforcements and a new layer of protection for the existing structural concrete). This method can be successfully applied due to the manufacturer's routine. It is also a method that involves wet processes and long-running period (shotcrete's hardening time). On the other hand, a newer method may be preferred, which involves the FRPC (Fibre Reinforced Polymeric Composite) of the water tank walls (post-tensioned) resulting in faster results, an unaffected structure of corrosion, sometimes even a lower price, without impact on the environment, in short periods of execution, a.s.o. Shortly, a rehabilitated structure much more DURABLE than that obtained by a classical method.

## 6. Conclusions

In the paper was discussed the main factors which could affect the water tank's durability (chronologically order) in different stages: at the design stage, execution, exploitation and finally at the stage of repair/rehabilitation work.

It was chosen this presentation manner because the identification of any errors is easier chronologically and, obviously, measures to remove/mitigate these causes and effects should be applied at the specific stage where it appears.

## REFERENCES


Biczok I., *Coroziunea şi protecţia betonului*, Editura Tehnică, Bucureşti, 1965.

Farrar C.R., Worden K., *An Introduction to Structural Health Monitoring*, Philosophical Transactions of The Royal Society, A, 365, 303-315 (2007).

Gosav I., *Durabilitatea elementelor şi structurilor din beton – Note de curs*

Ilinoiu G., *Controlul calităţii betoanelor*, Bucureşti, 2004.

Hobjilă, V., Luca, M., *Complemente privind proiectarea şi expertizarea unor tipuri de construcţii hidrotehnice*, Editura Cermi, Iaşi, 2000.

Oneț T., Kiss Z., Becski A., *Efectul fisurării asupra durabilităţii betonului*, 2000.

Teoreanu I., Moldovan V., Nicolescu L., *Durabilitatea betonului*, Editura Tehnică, 1982.

Traian O., Zoltan K., Almos B., *Efectul fisurării asupra durabilităţii betonului*, Ovidius University Annals of Construction, vol. **1**, nr. *2*, Constanța, May 2000.

Zamfirescu D., Postelnicu T., *Durabilitatea betonului armat*, Editura Matrix Rom, Bucureşti, 2003.

* * * http://www.revistaconstructiilor.eu/index.php/2008/02/28/coroziunea-betonului-i-cauze-si-fenomene.

* * * http://civildigital.com/freeze-thaw-damage-concrete-effects-preventive-measures/.

* * * https://www.slideshare.net/gauravhtandon1/durability-and-permeability-of-concrete-43200739.

* * * https://theconstructor.org/concrete/factors-affecting-durability-concrete/1115/.


## O ABORDARE CUPRINZĂTOARE A FACTORILOR CE AFECTEAZĂ DURABILITATEA REZERVOARELOR DE APĂ ÎN DIFERITE ETAPE DE LUCRU


(Rezumat)

Orice construcţie reprezintă un sistem complex aflat într-o continuă interacţiune atât cu mediul natural cât şi cu cel antropic, acumulând permanent consecinţele tuturor categoriilor de acţiuni ce o solicită (inclusiv cele specifice modului de exploatare). Se poate admite astfel, faptul că în structura acestora, odată cu trecerea timpului apar diverse degradări şi avarii.

Pentru o corectă analiză şi interpretare a efectelor generate de factorii care afectează durabilitatea rezervoarelor de apă din beton armat se pot identifica (multicriterial) cauze. În prezentul articol au fost discutaţi (în odine cronologică), factorii care pot afecta durabilitatea, în diferite etape de lucru: în stadiul de proiectare, de execuţie, de exploatare şi, în final, în etapa lucrărilor de reparaţii/reabilitare.