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THE EVALUATION OF THE FUNCTIONAL CAPACITY OF THE CYLINDRIC PRE-STRESSED TANKS

BY

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Abstract. This paper approaches the problem of diagnosing the degradation and the safety estate in exploatation of the cylindrical tanks made out of pre-prestressed concrete, affected by execution errors, especially generated by the design non-observance stipulations, being suggested by a situation which hasn't been signalized into the specialty literature from our country. The effectuated study aimed to evaluate the functional capacity of cylindrical tanks, being proposed an original way (methodology) of identifying the real loading level of the horizontal sections from the walls of the pre-prestressed cylindrical tanks with cables and which relies on an original grapho-analytical procedure. This way there were realized etalon-graphics for different types of tanks and their geometrical and technical characteristics which allow a soft evaluation of the nominal functioning capacity of the analysed objectives, by comparing the quantity of existing reinforcement with the need quantity.

Key words: pre-stressing; etalon-graphic; concrete; errors; logical sketch.

1. General Conditions

There was built a lot in our country, during the last decades, but not always according to the technical requests. There is a rather high possibility that during different modernizing applications to certain similar constructions this kind of situations to have been observed but kept unpublic by the specialists.

The functional and structural particularities of the endorsed objectives (cylindric pre-stressed tanks with fascicles integrated into the walls), allow, according to the present normative, the evaluation of the real level of safety in exploitation, identifying the requested level of concrete and reinforcement, operation which lays on the numeric simulation of the requesting conditions [1].

In order to calculate the effort into the walls, the following mixtures of loadings were taken into consideration:

1° For the sunken tanks

a) the first mixture: water + pre-stressing + pushing the soil;

b) the second mixture: pre-stressing + pushing the soil;

c) the third mixture: water + pre-stressing.

2° For the surface tanks

a) mixture 1: water + pre-stressing.

The effort diagrams realized by analytical procedure represent the support for the generation of the etalon-graphics, necessary for estimating the tank's functional capacity.

The necessary reinforcement for each tank type and for each hypothesis has been determined according to the present Romanian Standards (STAS 10107/0-1990), the losses of tension being determined in advance.

In order to use the etalon-graphics it is necessary to know only the quantity of reinforcement existing into the analysed objective and, by comparing it with the etalon-graphic, it can be easily seen until what loading percent the tank may be used, without affecting the safety in exploitation and the tightness state.

It may be concluded that the scientific objective of the research has been realized, by implementing a solution with a recency character and which consists in the correct and quick defining of the safety level which it presents in the exploitation of the existent pre-stressed tanks, under the aspect of avoiding the state of cracking [2], [3].

For the softening of the deficiencies which the experimental studies imply, the establishing of the intensity estates which develop under the loadings and which are emphasized by the execution errors, was made with the numeric calculations' help.

The advantages of the proposed manner of approach, under the conceptual aspect of costs and of the study period, are obvious, if it is made a comparison with the classic procedures of solving some aspects of this type and which lays on laboratory or on the field testing [4].

2. Determining the Requests and Evaluating the Sunken Circular Tanks

Because the axial efforts develop themselves in a horizontal plan, in order to take them over it is necessary to foresee circular reinforcement on the cylinder's outline, while the bending moments develop themselves in a vertical plan, and in order to take them over there it must be foreseen vertical reinforcements.

The evaluation of the axial efforts from the membrane phase water's action, for a given section, is realized with the relation

(1) $$n_{\varphi 0} = \gamma b R\left(\frac{h_u}{b} - \xi\right),$$

where: $n_{\varphi 0}$ is the axial effort from the water's action into the membrane phase into a certain section, x; γ_a – the water's specific weight, having the value of 10 kN/m^3; R – the radius of the tank's cylinder; b – the coefficient given by the relation

(2) $$b = \sqrt{\frac{R\delta^2}{\sqrt{3}}};$$

δ – the thickness of the tank's wall; h_u – the tank's available height, defined by the water's level; ξ – the coefficient given by the relation

(3) $$\xi = \frac{x}{b};$$

x – the height at which the section where the effort's evaluation is done; $x \in [0, h_u]$.

The size of the axial efforts from the water's action into the bending phase, into a x section, is given by the relation

(4) $$n_{\varphi R_a} = bR_a \frac{k_1}{\delta},$$

where: $n_{\varphi R_a}$ is the axial effort from the water's action, into the bending phase, into a certain section; R_a – a coefficient having the value

(5) $$R_a = \frac{1}{2}\gamma b h_u;$$

k_1 – a coefficient which may be extracted from labels or which may be calculated with relation

(6) $$k_1 = -2\sqrt{3}\cos\xi \; \mathrm{e}^{-\xi}.$$

The final value of the axial efforts from the water's action in section x is obtained with relation

(7) $$n_{\varphi a} = n_{\varphi 0} + n_{\varphi R_a},$$

where: $n_{\varphi a}$ is the total axial effort from the water's action in section x; $n_{\varphi 0}$ – the axial effort from the membrane phase water's action into a certain x section, according to the eq. (1); $n_{\varphi R_a}$ – the axial effort from the bending phase water's action into a certain x section, according to the eq. (4).

The evaluation of the axial efforts from pre-stressing to the membrane phase is realized on the ground of the requirements given by the water's action. Practically, the pre-stressing effort must balance the water's action namely

$$n_{\varphi 0p} = -n_{\varphi 0}, \tag{8}$$

where: $n_{\varphi 0p}$ is the axial effort from the pre-stressing action into the membrane phase, in section x; $n_{\varphi 0}$ – the axial effort from water's action into the membrane phase in section x, according to eq. (1).

The axial effort of the pre-stressing from the bending phase is calculated with the relation

$$n_{\varphi R_p} = bR_p \frac{(-k_1)}{\delta}, \tag{9}$$

where: $n_{\varphi R_p}$ is the axial effort from the pre-stressing's action into the bending phase into section x; R_p – a coefficient given by

$$R_p = \frac{1}{2}\left(\delta H \gamma_b + \frac{D h_p \gamma_b}{4}\right); \tag{10}$$

H – the tank's height; D – the tank's diameter; γ_b – the specific weight of the pre-prestressed concrete (25 kN/m^3); k_1 – the determinant coefficient according to eq. (6).

The final value of the axial efforts from the pre-stressing's action into section x, is obtained with the relation

$$n_{\varphi p} = n_{\varphi 0p} + n_{\varphi R_p}, \tag{11}$$

where: $n_{\varphi p}$ is the total axial effort from the pre-stressing's action in section x; $n_{\varphi 0p}$ – the axial effort from the pre-stressing's action into the membrane phase, in section x, according to eq. (8); $n_{\varphi R_p}$ – the axial effort from the pre-stressing's action into the bending phase in section x, according to eq. (9).

The evaluation of the axial efforts produced by pushing the soil is realized with the relation

$$n_{\varphi \text{soil}} = -0.6 n_{\varphi a}, \tag{12}$$

where: $n_{\varphi\text{soil}}$ is the total axial effort from the soil's action in section x; $n_{\varphi a}$ – the total axial effort from the water's action in section x, according to (7).

The calculus of the bending moments produced by the water's action is performed with the relation

$$m_{xa} = bR_a k_2 , \tag{13}$$

where: m_{xa} is the bending moment from the water's action into a certain section x; R_a – the calculated coefficient according to eq. (5); k_2 – a coefficient which may be extracted from the labels or which may be calculated with the relation

$$k_2 = -\mathrm{e}^{-\xi} \sin\xi . \tag{14}$$

The calculus of the bending moments produced by the pre-stressing's action may be performed with the relation

$$m_{xp} = bR_p k_2 , \tag{15}$$

where: m_{xp} is the bending moment from the pre-stressing's action in section x; R_p – a coefficient calculated according to eq. (10); k_2 – a coefficient calculated according to eq. (14).

The evaluation of the bending moments produced by pushing the soil is realized with the relation

$$m_{x\text{soil}} = bR_{\text{soil}} k_2 , \tag{16}$$

where: $m_{x\text{soil}}$ is the bending moment from the soil's pushing in section x; R_{soil} – the coefficient of pushing the soil in Rankine's theory, calculated with the relation

$$R_{\text{soil}} = \gamma_{\text{soil}} x \ \mathrm{tg}^2\left(45^o - \frac{\phi}{2}\right); \tag{17}$$

γ_{soil} is the soil's specific weight (18 kN/m^3); x – the height of the section where the effort's evaluation is made; $x \in [0, h_u]$; ϕ – the angle of the interior friction, according to the soil's stratification (its value being usually found into the geotechnical study); k_2 – a coefficient calculated according to eq. (14).

The efforts are calculated on the entire height of the tanks, the results' precision being directly proportional to the number of the chosen sections. For a good accuracy of the results a number of 20 height sections have been established, for each of them, the efforts being calculated according to eqs. (1),…,(17).

The real requirement situations are taken into consideration with the help of some mixtures of loadings, these being: the first mixture, composed of the water's pushing effect, of pre-stressing and of soil's pushing

$$n_\varphi^1 = n_{\varphi a} + n_{\varphi p} + n_{\varphi \mathrm{soil}}, \qquad m_x^1 = m_{xa} + m_{xp} + m_{x\mathrm{soil}}; \tag{18}$$

the second mixture is composed of the pre-stressing's effect and of the soil's pushing

$$n_\varphi^2 = n_{\varphi p} + n_{\varphi \mathrm{soil}}, \qquad m_x^2 = m_{xp} + m_{x\mathrm{soil}}; \tag{19}$$

and the third mixture consists in the water's pushing and in the pre-stressing effect

$$n_\varphi^3 = n_{\varphi a} + n_{\varphi p}, \qquad m_x^3 = m_{xa} + m_{xp}. \tag{20}$$

For the ten types of analysed sunken tanks which have diameters of 15, 20, 25, 30, 35, 40, 45, 50, 55 and 60 m, there are reproduced in a graphical form the efforts resulted from the action of the water, of the soil and of the pre-stressing, as well as mixtures of these. For further examinations there will be used the efforts obtained under the most unfavourable mixture of requirement (Figs. 1,…,4).

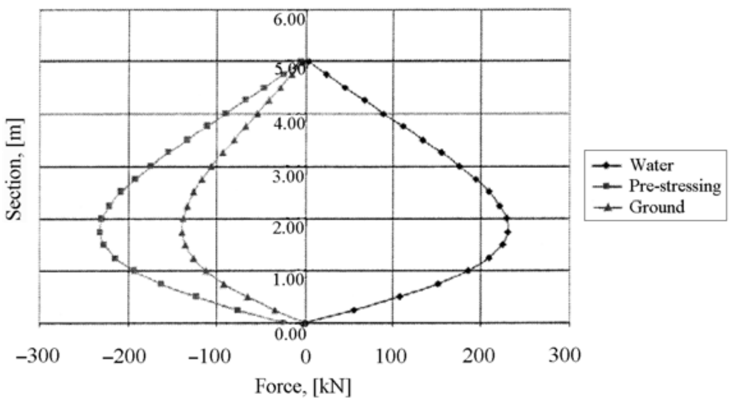

Fig. 1 – Axial efforts into a tank with the diameter of 15.0 m.

The efforts diagrams established by analytical procedures lay at the base of the determination of the reinforcement quantities necessary for the tanks to function at nominal capacity and, through comparisons, with the existent reinforcement, will form the departure base for the possible estimations regarding the reduction of the bearing capacity [5], according to the existent situation on the field.

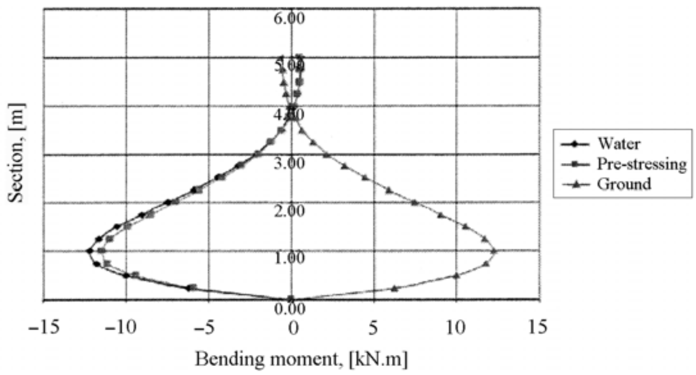

Fig. 2 – Bending moments into a tank with the diameter of 15.0 m.

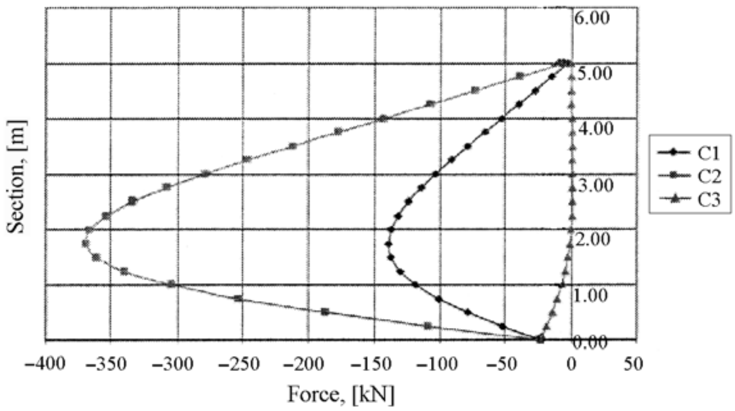

Fig. 3 – Mixtures of forces from a tank with the diameter of 15.0 m.

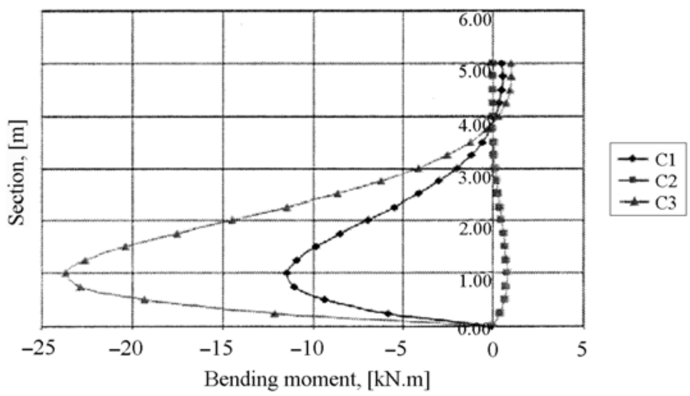

Fig. 4 – Mixtures of moments from a tank with the diameter of 15.0 m.

3. Determining the Requests and Evaluating the Circular Surface Tanks

Similar to the sunken tanks, for the surface tanks has also been realized an analytical study on a number of 10 such sunken objectives, having their diameters between 15.0 m and 60.0 m, the variation step being of 5.0 m.

The efforts' calculus is realized similarly to the one in the case of the sunken tanks, with the specification that, in the surface tanks' case, the soil's pushing is not present anymore. So it may be written

(21) $$n_{\varphi\text{soil}} = 0,$$ (22) $$m_{x\text{soil}} = 0.$$

So, for the surface tanks the axial efforts and the bending moments have been determined only for the water's and pre-compression's actions. Under the conditions in which the number of hypothesis has been reduced to two (water and pre-compression) only one single combination may be realized, namely

(23) $$n_{\varphi}^{1} = n_{\varphi a} + n_{\varphi p}, \qquad m_{x}^{1} = m_{xa} + m_{xp}.$$

Although the calculus volume necessary to be performed in the case of the surface tanks is smaller than the one corresponding to the sunken tanks, the efforts' disappearance from the soil's pushing constitutes an exploitation disadvantage, because this action compensated a part of the pre-compression' effect, leading to a smaller circular reinforcement use.

The lack of the soil's pushing effect leads to the existence of a bigger pre-compression effort, therefore to a rise of the radial reinforcement quantity.

For the ten types of analysed surface tanks (with the diameter of 15, 20, 25, 30, 35, 40, 45, 50, 55 and 60 m) have been realized graphics which reproduce the efforts' distribution from the water's and pre-compression's action, as well as the mixture of the two hypothesis (Figs. 5,…,8).

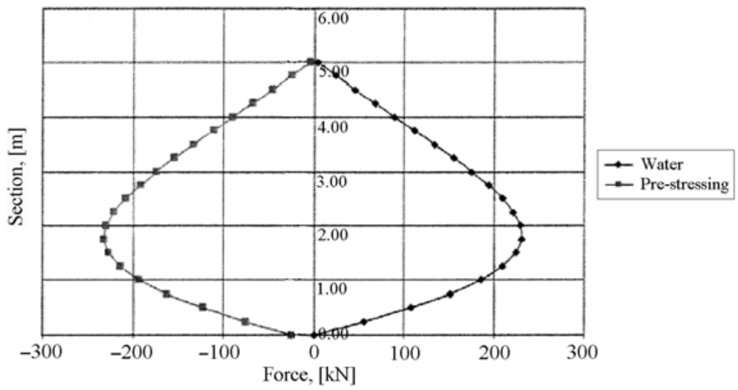

Fig. 5 – Axial efforts into a tank with diameter 15.0 m.

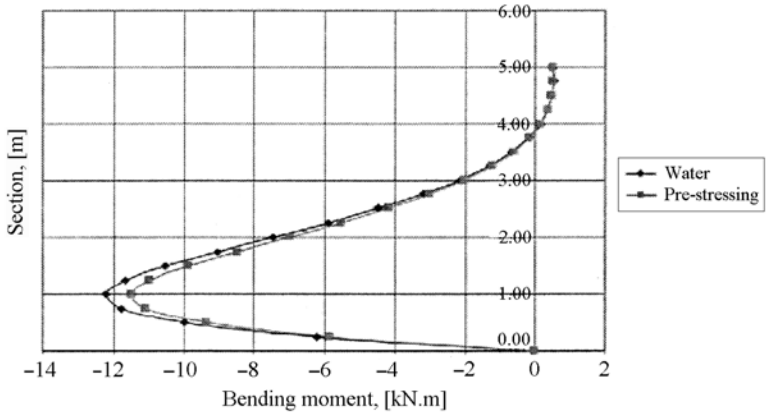

Fig. 6 – Bending moments into a tank with diameter 15.0 m.

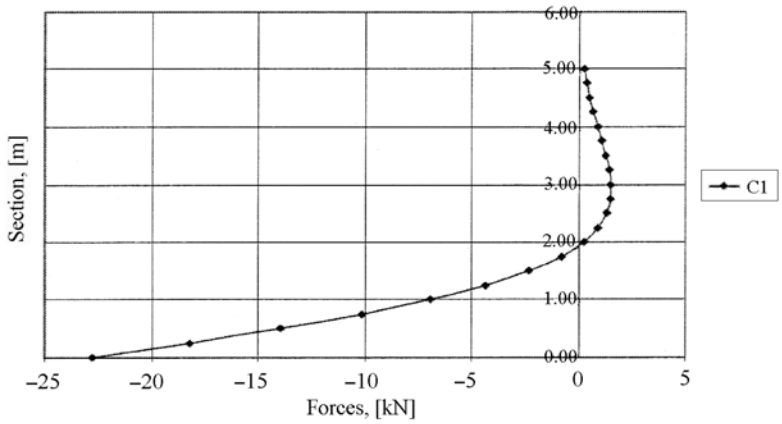

Fig. 7 – Mixtures of forces from a tank with the diameter of 15.0 m.

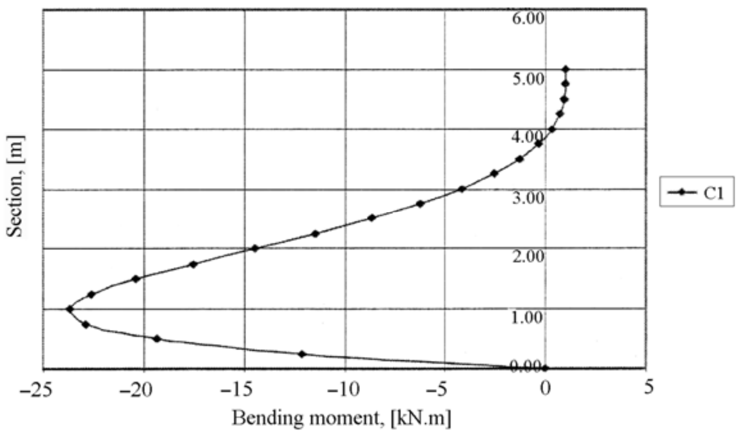

Fig. 8 – Mixtures of moments from a tank with the diameter of 15.0 m.

There are reproduced only the final graphics which were obtained for the tank with the diameter of 1.50 m.

4. Establishing the Etalon-Graphics for the Sunken Tanks

In order to evaluate the exploitation capacity of the sunken tanks made out of pre-compressed concrete some etalon-graphics have been elaborated for the five exploitation situations (use level at 20%, 40%, 60%, 80% and at 100% of its nominal capacity), which allow a quick and efficient evaluation (Fig. 9). The necessary reinforcement for each tank type and for each hypothesis has been determined according to the present Romanian standards, only after before that the lost of specific intensities have been evaluated [6], [7], [8], [13].

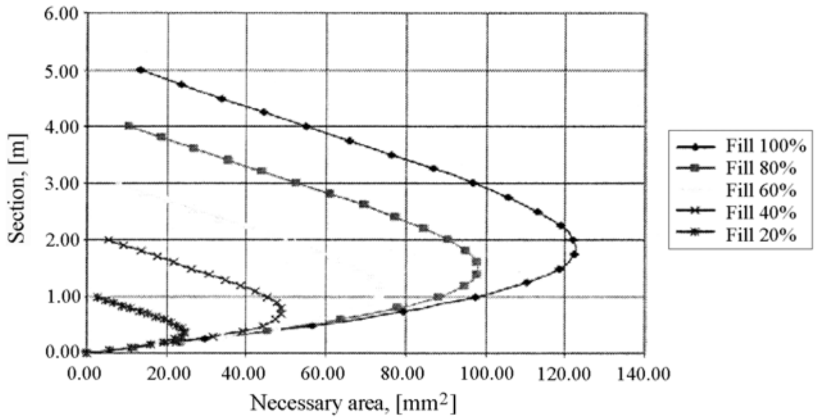

Fig. 9 – The etalon-graphic for a sunken tank with the diameter D = 15.0 m.

In order to use the etalon-graphics characteristic for the sunken tanks it is only necessary to know the quantity of the reinforcement existent into the analysed objective and, through comparing it with the etalon-graphic it may be immediately evaluated till the loading percent at which the tank may be used without affecting the safety in exploitation and the tightness estate.

5. Establishing the Etalon-Graphics for the Surface Tanks

As in the sunken tanks case, in this case have also been taken into consideration five situations of exploiting the tank: the tank used at 20%, 40%, 60%, 80% and at 100% from its nominal capacity, the five situations being enough into the most practical situations met so far. If the analysis of some intermediary situations is wanted, these may be obtained by linear interpolation of the above results.

In order to generate the etalon-graphics it was necessary to evaluate the requirements, the necessary reinforcement for each type of tank; each hypothesis being determined according to the present Romanian standards, before that the intensity lost have been evaluated for each particular case (Fig.10).

Knowing the quantity of the existent reinforcement into the analysed objective and, by comparing it with the etalon-graphic, it may be established till what loading percent may the tank be used, without affecting its exploitation safety [9],…,[12].

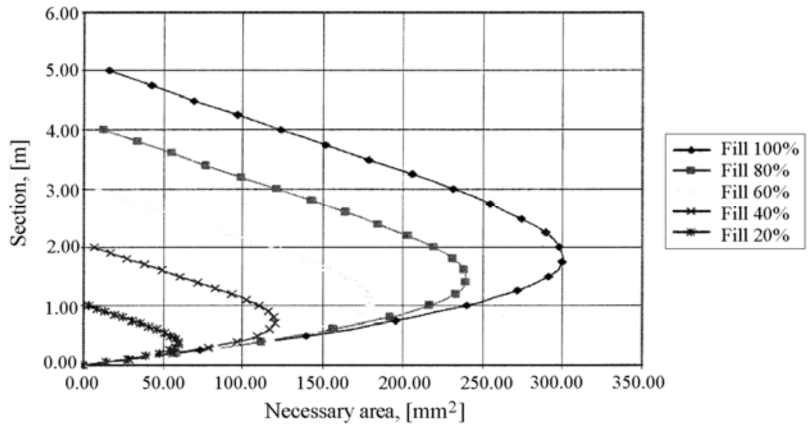

Fig. 10 – The etalon-graphic for a surface tank with the diameter D = 15.0 m.

Through the proposed research theme it was chosen the way of drawing up some etalon-graphics which cover the majority of the situations met in practice and which allow the quick evaluation of the working capacity of the tanks made out of pre-compressed concrete to which, from different reasons [14], the elaborated execution project was not respected (Fig. 11).

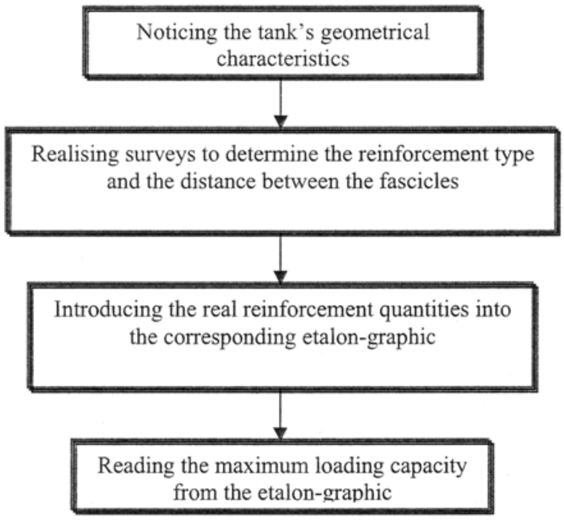

Fig. 11 – The quick evaluation of the tanks' loading capacity.

6. Conclusions

The final aim of the research made by the authors, was that of establishing the conditions of intensity which develops into the constituent elements, mainly in concrete, as means of distribution and intensity, under different types, groups and sizes of specific loads, identifying the estate of request which satisfies or not the exigencies of the technical regulations.

The resulted conclusions permit to define the safety level in exploitation, under the aspect of the size of the resistance reserve available until the appearance of cracks into the concrete.

The necessary reinforcement for each tank type and for each hypothesis has been determined according to the present Romanian standards (STAS 10107/0-1990), the losses of tension being determined in advance. In order to use the etalon-graphics it is necessary only to know the quantity of reinforcement existing into the analysed objective and, by comparing it with the etalon-graphic it can be easily seen until what loading percent the tank may be used without affecting the safety in exploitation and the tightness state.

The *originality* of the manner the problem was approached consists in the fact that it wasn't intended to elaborate some procedures of remediating the signalised deficiencies, but the *fast diagnosing* of the insecurity level for some constructions of a great value. It may be concluded that the aim of the research was accomplished, and that the proposed solution into this work can be successfully used for the evaluation process's efficiency of the sunken and surface tanks made out of precompressed concrete, when there are identified deficiencies into the reinforcement manner.

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INFLUENȚA UNOR GREŞELI DE EXECUȚIE ASUPRA SIGURANȚEI ÎN EXPLOATARE A REZERVOARELOR CILINDRICE DIN BETON PRECOMPRIMAT

(Rezumat)

Studiul efectuat oferă o sinteză completă a informațiilor de ordin general din domeniul abordat şi prezintă detaliat aspecte de o importanță deosebită în teoria şi practica betonului armat şi a celui precomprimat, contribuind la îmbunătățirea conținutului ştiințific al procedeelor de calcul şi alcătuire, precum şi a activităților de cercetare, proiectare sau expertizare.

Elementul esențial îl constituie un studiu teoretico-aplicativ bazat pe simulare numerică, efectuat pentru rezervorul de formă circulară, precomprimat cu cabluri postîntinse, construcție utilizată pe scară largă în diverse tipuri de lucrări hidrotehnice, iar originalitatea modului de abordare a cercetării derulate constă în faptul că nu s-a urmărit elaborarea unor procedee de remediere a deficiențelor semnalate, ci diagnosticarea rapidă a gradului de insecuritate.

Astfel, este fundamentată o metodă eficientă de stabilire a nivelului real de siguranță a rezervoarelor de formă circulară, precomprimate prin cabluri postîntinse, supuse unor grupări uzuale de încărcări, în situația în care, datorită unor greşeli grave de execuție, armarea pereților diferă de schema prevăzută în proiect. În acest sens, prin simulare numerică, s-au întocmit în total un număr de 120 grafice–etalon pentru o serie largă de tipuri de rezervoare ce au caracteristici geometrice şi tehnice întâlnite curent în

practică şi care permit compararea cu uşurinţă a ariilor de armătură existentă cu cele necesare, operaţie ce permite formularea unor concluzii rapide şi obiective privind condiţiile în care este sau nu este garantată siguranţa obiectivului.