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CASE STUDY OF A WATER TANK BEHAVIOUR ON AN IMPROVED COLLAPSIBLE SOIL

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ABSTRACT

The geotechnical report performed for the design stage of a water tank revealed a soil profile consisting in a thick layer of collapsible/loessial soil. The paper firstly presents the complex characterization of the natural ground conditions before and after the soil cushion performance, during the water filling tests of the tank. Specific charts are presented to emphasize the physical and mechanical parameter differences of the natural and improved ground by the soil cushion. The prediction of the supplementary settlement profile on the construction site of the water tank has been performed due to a significant water leakage from the tank during the filling tests, and thus endangering the tank stability and serviceability. Charts presenting the soil-tank interaction during service are included together with settlement diagrams related to potential water leakage from the tank. The paper presents in the second part the stress and strain states that have been comparatively analyzed for various moistening hypotheses with different risk level, according to the settlement increase based on the up going of the moistening front.

INTRODUCTION

The most important protection measure of a construction on loess and loessy soils, disregrading its group and the adopted foundation solutions is the infiltration avoidance of the running waters both during construction performance and service and also of the accidental water loss from the water supply and sewage systems.

Loess and loessial soils (collapsible soils) are spread over 40,000km^2 representing 17% of the Romanian surface. The thickness of such deposits varies within the same region, having the limit interval established by site investigations as 6m the minimum up to 40m.

The construction built on a similar soil profile is a water tank (Fig.1) with a storage capacity of 5,000m3, located in the city of Roman, and it is made of prestressed reinforced concrete, with an annular cross-section. The tank height is 8.60m, the outer diameter 29.40 m and inner diameter 28.76m. The maximum water level within the tank is at +7.73m from the ground development.

The precast roof elements are radially displayed towards a central column with square cross-section 50 × 50cm, that continues with a flexible spread footing of 4.00 × 4.00m. The tank walls are provided with annular flexible footing of 1.60m width at -1.20m depth. The annular footing is firmly connected with the tank's raft and this one with the spread footing of the column. The joining sections are subjected to differential settlements during service due to the stiffness and load variation of the foundation system.

There are four contraction joints radially displayed within the raft that begin from the corners of the column's footing and end up at the annular footing of the wall with a 90^o orientation towards each other.

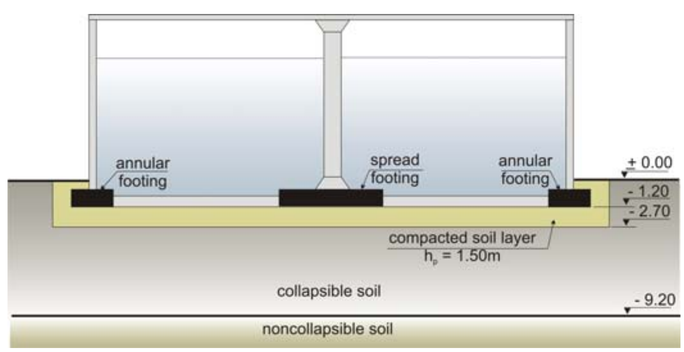

Fig.1. Current vertical section of the water tank

The city of Roman, is framed according to the Romanian Standard [STAS 6054-77] to the zone with a frost depth of 90cm and related to this value the design code [NP 112-2004], supplements it with another 10cm to reach the minimum foundation depth.

All these restrictions considered, the annular footing of the tank is located at –1.20m (Fig. 1), the column's footing at –0.95m and the raft at –0.85m. The foundation system is performed on a compacted soil cushion of 1.50m thickness with sideways of 2.00m with from the outer diameter of the annular footing and the base level at –2.70m.

INVESTIGATION WORKS ON THE COMPACTED SOIL AND NATURAL GROUND

A technical assessment has been performed regarding the performance quality of the compacted soil cushion and the foundation ground behaviour during a flooding situation as a consequence of water loss from the tank. This assessment was demanded due to important water leakage from the tank during the filling tests, endangering the tank's stability and influencing its safe service. The more justified is the need to analyze the soil behaviour once the soil involved is a collapsible one.

Flooding conditions are created when there is water loss from the tank that exceeds the thickness of the compacted soil cushion and may enter within the natural soil underneath. Supplementary settlements are thus developed as a consequence of the accidental water loss and their differential values can be the cause of endangering tank's stability.

The physical and mechanical properties revealed by the laboratory tests performed on soil samples are presented for the cushion zone beneath the foundation system [Stanciu et al. 2004a].

As a result from the granulometric analysis and identification based on the ternary diagram [STAS 1243-88] the soil is silty clay and according to the Norm [P7-2000], Appendix 1, the soil is designated as clayey loess.

The supplementary strain in flooding conditions i_{mp} indicates values less than 2cm/m for pressures $p_i \leq 3$ daN/cm^2.

The natural moisture content (w) from undisturbed soil samples is higher at the top level 20.45% and base level of the cushion 20.27%, whereas in the middle part is only 17.46%.

The consistency index (I_c) has values more than 1.0 both on disturbed and undisturbed soil samples.

The plasticity limits are approximately constant across the cushion thickness: w_p – 16.23%…18.31%, w_L – 32.3%…34.76%. Plasticity index (I_p) varies between 14.35%…16.55% for all soil samples.

The soil unit weight (γ), increases from 18.64kN/m^3 at the top and base level of the compacted stratum up to 20.0 kN/m^3 in the middle part.

The dry unit weight (γ_d), is confined between 14.74 kN/m^3 and 17.11 kN/m^3 in the middle zone of the cushion.

Porosity (n) is 36.2% in the middle part and increases up to 40-44% on the top and base level while void ratio (e) varies in between 0.567 to 0.81.

The saturation degree (S_r) increases as well from la 0.7 at the top level to 0.825 in the middle zone to decrease again to 0.77 at the base level of the cushion.

The oedometer modulus M_{2-3} from the stress-strain curve performed on soil samples in their natural state vary from 6060 to 13333 kPa and when flooding the samples, the variation of the modulus is between 4444 kPa to 7407 kPa; the supplementary strain due to moistening at 3daN/cm^2 (i_{m3}) increases from 1.6% at the top level to 2.2% at the base level of the cushion.

The maximum dry unit weight (γ_{dmax}), based on the Proctor test performed on several soil samples from the cushion is approximately constant 17.2-17.25 kN/m^3 for optimum moisture content (w_{opt}) of 16.8-17.3%.

The shear strength parameters (Φ' and c') resulted in drained conditions varies between 18-25^o for the internal friction angle and 20-55 kPa, the cohesion.

For the soil samples taken from the natural ground underneath the soil cushion, the test results are presented by the following description.

The granulometric analysis resulted in clayey silt and according to the norm [P7-2000], Appendix 1, the soil is identified as clayey loess with medium to high sensitivity to moistening, based on the K_0 criterion (Fig.2), with i_{m3} > 2cm/m. The bonding coefficient K_0 is given by the relationship:

$$K_0 = \frac{mass\%\ of\ \ clay}{mass\%\ of\ \ silt + mass\%\ of\ \ sand} \tag{1}$$

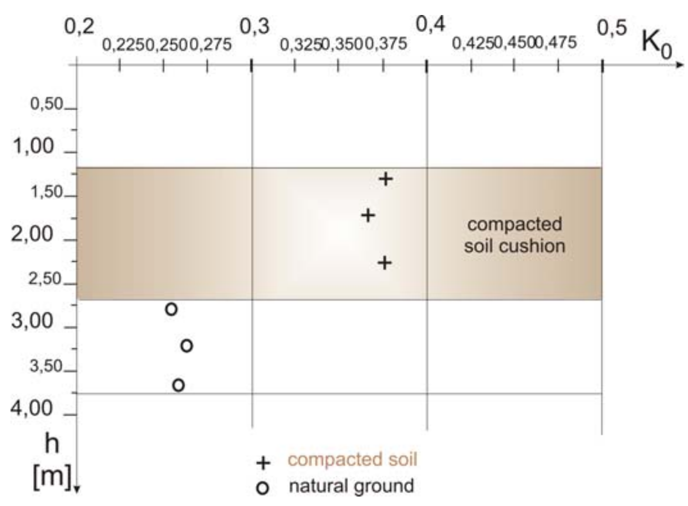

Fig.2. The bonding coefficient K_0 variation over depth

The moisture content (w) is variable in the range of 16.84%…21.16%, the consistency index I_c = 0.83…1.19, and the plasticity limits w_p = 18.51%…2 0.56%, w_L = 31.3% … 36.15%.

The natural unit weight (γ) and dry unit weight (γ_d) varies between 14.27…15.26kN/m^3 and 12.34…13kN/m^3 respectively; porosity (n) is of 51 to 55%, and void ratio (e) 1.053…1.244; the saturation degree (S_r) ranges between 0.38…0.6.

The oedometer modulus (M_{2-3}) based on the stress-strain curve in soil natural state varies between 2222…3175 kPa and in case of flooding conditions 2424…3226 kPa with a supplementary strain due to moistening at 3daN/cm^2 (i_{m3}) of 4.8…5.5cm/m.

The maximum dry unit weight γ_{dmax}, based on the Proctor test ranges between 16.82…17.2 kN/m^3 for an optimum moisture content w_{opt} of 14.7…17.8%.

The shear strength parameters in drained conditions are ranging Φ' = 28…33^o, and approximately 10 kPa, cohesion c'.

The porosity variation (Fig.3) as well as the phases diagrams (Fig.4) and the supplementary strains due to moistening indicate a significant difference between the natural and compacted soil, most relevant for the middle part of the cushion where the compaction degree reaches a value of 99.4%.

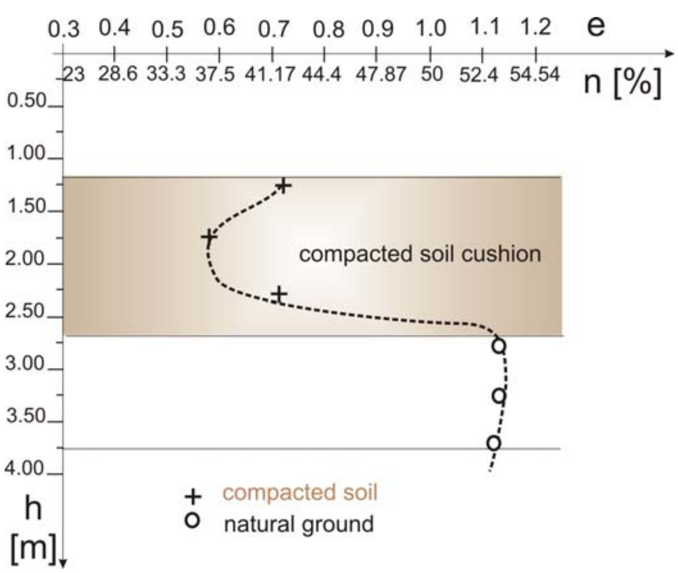

Fig 3. Void ratio – e and porosity – n variation over depth

The compaction performed on the soil revealed by porosity with a mean value of 42,95% indicates that for the soil within the cushion the sensitivity to moistening was eliminated i_{mp} < 2cm/m, for pressures $p_i \leq 3$ daN/cm^2. This conclusion is consistent with a computed supplementary settlement due moistening and only to the soil self weight of 0.5cm, the entire cushion behaving as a regular one, but with a high to medium compressibility (M_{2-3} = 5000…10000 kPa).

A soil characterization may conclude that the cushion consists of a clayey soil, yellow-brownish, with medium plasticity, stiff, wet, with medium cu high compressibility.

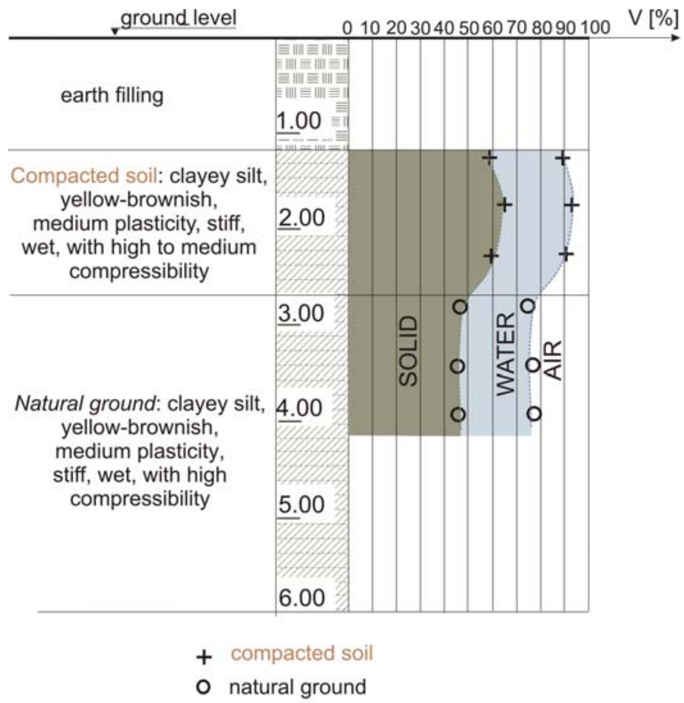

Fig.4. The variation of phases within the compacted soil and the natural ground

The collapsible soils can be classified in two groups/categories, depending on the development of the supplementary settlement due to moistening under the load generated by the geological pressure [STAS 1243-88].

Group A includes soils for which the supplementary settlements due to moistening are developed only within the limits of the active zone of foundations, as the consequence of the net pressures delivered by the footings or other external loads; there are no settlements developed by the geological pressure (I_{mg}) or the one created are less than 5 cm.

Group B includes soils for which supplementary settlements due to the geological pressures are significant (I_{mg} > 5 cm) in case of complete flooding of the soil layer that are increased by those developed by the net pressures delivered by the footings, within the active zone.

The soil separation in a group category can be performed [STAS 1243-88], [Dianu, Istrate, 1982], [Dron, 1976], [Silion, Raileanu, 1978] also based on the stratum thickness of collapsible soil.

In case of stratum thickness (h) less than 5 m, the soil category is granted to be the A group. For a thickness included in 5≤ h ≤ 10m, the soils are granted the category of:

group A, if I_{mg}^{c} < 20cm, [Dron, 1976], [Raileanu et al., 1984] and 10cm [Dianu, Istrate, 1982], or group B, if I_{mg}^{c} > 20cm; where: I_{mg}^{c}, represents the computed supplementary settlement due to moistening under the effect of the geological pressure.

In case that the stratum thickness of the collapsible soil h > 10m, the soil is included to group B.

The stress-strain curves and the consequent supplementary settlements due to moistening i_{m3} > 2cm/m indicates a clayey loess, very sensitive to moistening, with a supplementary settlement due to moistening under the effect of the geological pressure of I_{mg}^{c} = 15.57 cm < 20 cm, for a stratum thickness h in between 5 – 10m. The soil belongs to group A – significant settlement will developed only under the net pressures delivered by the footings along the active zone.

The cushion dimensions are checked and accepted as final values based on the restrictions relevant for the deformation limit state:

$$\Delta_s = \overline{\Delta_s} \tag{2}$$

Potential displacements or deformations (Δ_s) of the construction, due to the settlements of the foundation ground (Δ_s) will include, together with the total settlements in natural state the ones developed due to the collapse of the soil structure due to excessive moistening [Stanciu, Lungu, 2006].

The deformations of the collapsible soils [P7-2000], depending on their group and the relationship between the stratum thickness and the extent of the moistening source consist of the followings [Bally, Antonescu, 1971], [Dianu, Istrate, 1982], [Kezdi, 1974]: settlements; horizontal deformations; tiltings.

The values are expressed based on the computed supplementary settlement I_{mg}, developed by the geological pressure or / and supplementary settlement I_{mp}, induced by the net pressures delivered by the footings.

The evaluation of the supplementary settlements should be consistent with the real potential of excess moistening of those soils together with reaching a certain saturation degree when considering the following influences:

the progressive wetting of the collapsible soil by flooding at the top level due to precipitations or other external sources (water supply or sewage pipes) and / or beginning with the base level of the layer by rising of the ground water table;

the gradual increase of the soil moisture until reaching moisture at equilibrium, due to the screening or sealing of the ground surface simultaneously considered or not with a misleading evacuation of the running waters.

The following calculation hypotheses are considered:
the complete saturation assumed for $S_r \geq 0.8$ or considering a final moisture content w_f as the moisture content at equilibrium in case of a partial wetting, that can be granted the value of the natural moisture content if $w \geq w_p$ and the plastic limit itself if $w < w_p$.

The pressures delivered by the footings have to be less than the bearing capacity of the cushion soil:

$$p_{\max} \leq m \cdot p_{pl} \tag{3}$$

where m is set 1,0; 1,2; 1,4 – depending on the load: centric, eccentric along one direction, or both; p_{pl} is the plastic pressure of the soil within the cushion for footing dimensions b - width, D_f - foundation depth, and $p_{\max}$ is evaluated for the loads during service.

In case of the bearing capacity limit state, the pressure restriction is the following:

$$p_{ef}' \leq m_c \, p_{cr} \tag{4}$$

m_c - the working condition coefficient, p_{cr} the critical pressure of the soil within the cushion, for reduced footing dimensions (b'; l') and the foundation depth D_f; p_{ef}' is the effective pressure evaluated under the special grouping of loads (including earthquakes or other exceptional loads).

The pressures within the soil at the cushion base under both, the geological pressure and the ones delivered by the footing should remain less than the bearing capacity of the natural ground under the soil cushion. When the soil underneath is other than a collapsible soil the bearing capacity is relevant as the plastic pressure whereas when being a collapsible soil the bearing capacity is restricted to the structural pressure of that soil p_0:

$$p_p \leq p_{pl} \text{ (soil, other than loess)} \tag{5}$$

$$p_p \leq p_0 \text{ (in case of loess)} \tag{6}$$

where:

$$p_p = \underbrace{\gamma \cdot D_f + \gamma_p \cdot h_p}_{\text{geological pressure}} + \underbrace{\alpha \cdot \left(p_{\max} - \gamma \cdot D_f\right)}_{\text{load delivered by the footing}} \tag{7}$$

When evaluating the soil pressure at the cushion base the following diagram is considered relevant - Fig.5.

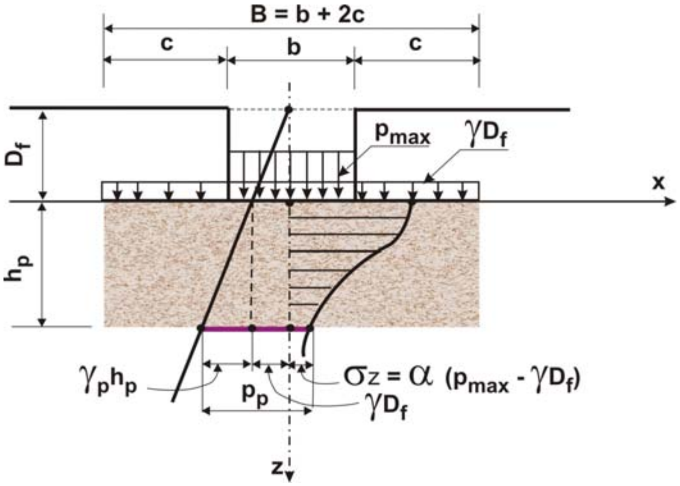

Fig.5. Typical calculation of the pressure at the base of the compacted soil layer

The term $(p_{\max} - \gamma \cdot D_f)$ represents the net pressure delivered by the footing; this pressure is distributed within the cushion based on the equivalent stratum model using the distribution coefficient of the vertical stress, α, according to STAS 3300/1-85, depending on the ratios $\alpha = f\left(\frac{L}{B}, \frac{D_f + h_p}{B}\right)$, where $B = b + 2c; \quad L = l + 2c$, with c as the sideway width of the cushion around the foundation system perimeter.

The plastic pressure of the natural soil p_{pl} (other than a collapsible soil) under the cushion level is assessed with the geotechnical characteristics of that specific layer for a width of the loading area $B = b + 2c$, at the depth of $\left(D_f + h_p\right)$. In this respect, the cushion layer is transformed into a similar foundation with the real one that extents and modifies the dimensions of the "new footing" to those presented above.

Finally, the bearing capacity restriction for the natural soil, considering the two variants described previously can be written such as:

$$\gamma \cdot D_f + \gamma_p \cdot h_p + \alpha \cdot \left(p_{\max} - \gamma \cdot D_f\right) \leq p_{pl} \qquad (8)$$

or

$$\gamma \cdot D_f + \gamma_p \cdot h_p + \alpha \cdot \left(p_{\max} - \gamma \cdot D_f\right) \leq p_0 \qquad (9)$$

If compacted soil layers acting as soil cushion on a ground profile consisting of a collapsible soil belonging to group A of sensitivity to moistening including the entire active zone under the footing, the supplementary settlement due to moistening is completely eliminated and that construction can be designed as being supported by a regular foundation soil.

No specific measures are required to protect that site against water infiltrations.

When soil cushions are performed on a ground profile consistent of a collapsible soil included in the B group, the soil sensitivity to moistening is only partially or totally eliminated within the active zone of the footing but supplementary settlements can develop under the effect of the geological pressure along the entire layer thickness.

THE LONG TERM EFFECTS OF THE ACCIDENTAL WATER LOSS ON THE COMPACTED SOIL LAYER AND NATURAL GROUND

The supplementary settlement prediction on the ground profile of the water tank site was important to reveal due to the significant water loss from that tank, thus endangering the construction stability and influencing the safe service.

When significant amounts of water leak from the tank, flooding conditions are created that exceeding the thickness of the compacted soil cushion reach the natural soil underneath. Thus, supplementary settlements are developed differentially across the tank footing as a consequence of accidental water loss that will reflect on the tank stability.

The local increase of the moisture content on a certain construction site can develop due to the surface water infiltrations within uneven ground surface profile, water loss from both internal or external water supply and sewage pipes (pipes damaged that have not been acknowledged and repaired in due time

The moistening advance both laterally and along depth within a ground profile consisting of collapsible soils is influenced by the following factors:

the permeability of the collapsible soil deposit and especially its variation along depth;

the amount of the water infiltrated, the rate of infiltration and the dimension of the wetting source.

In order to assess the compacted soil behavior together with the natural soil underneath, the following loading diagram is considered to act at the footing level - Fig.6.

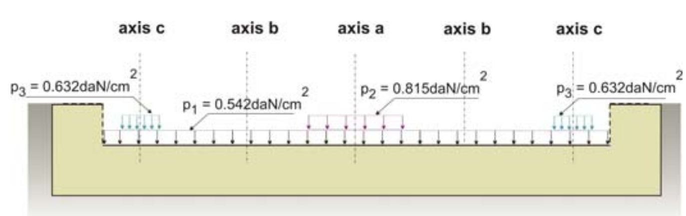

Fig.6. Diagram of loads acting on the foundation ground

The model considers that the footing – cushion contact is acting at -1.20m and the compacted soil layer is under the loads delivered separately by the column, the walls and the raft [Stanciu et al., 2004b]:

p_1 = 0.542daN/cm^2 acting uniformly distributed on the raft as the net pressure that is the effect of the water storage at the maximum capacity during service;

p_2 = 0.815daN/cm^2 acting uniformly distributed as a supplementary pressure on the column footing as the result from the column's dead load and the half load from the roof elements and snow load;

p_3 = 0.632daN/cm^2 acting uniformly distributed as a supplementary pressure on the annular footing as the result of the dead load from the wall and the other half of the roof elements and snow load.

Three significant vertical axes have been considered relevant related to the pressure diagram presented previously and the stress and settlement analysis followed based on the principles of settlement prediction for collapsible soils.

Axis a as the vertical that defines the centroid of the footing of the central column and that coincides with the axis of symmetry of the entire structure.

Figure 7 presents the pressures induced by footings in the calculation model that generated total settlements of 9.8cm immediately after the tank has been erected and 12.5cm during service, without any water leakage from the tank.

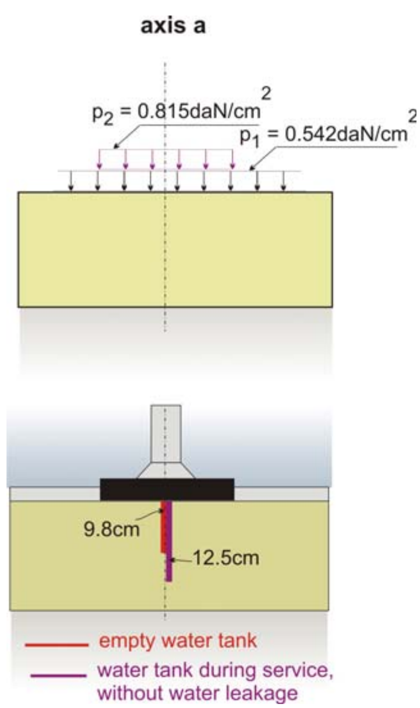

Fig.7. Settlements under the column when there is no water leakage from the tank

Axis b represents the vertical that crosses the midpoint of the radial joint at a mean radius R/2 from the raft central point.

During service of the water tank, the raft induces a maximum settlement estimated as 9.8cm, when there is no water leakage – Fig.8.

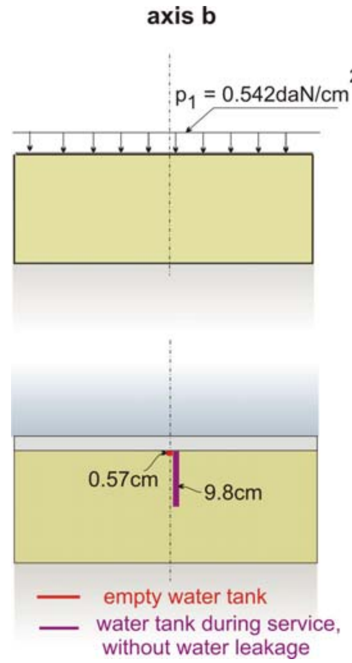

Fig.8. Settlements of the raft during service without water leakage from the tank

Axis c is the vertical that is the related to the centroid of the annular footing corresponding to the tank wall. The settlement prediction came out with the lowest value 7.11cm of the total settlement during service, when there is no water leakage from the tank – Fig.9.

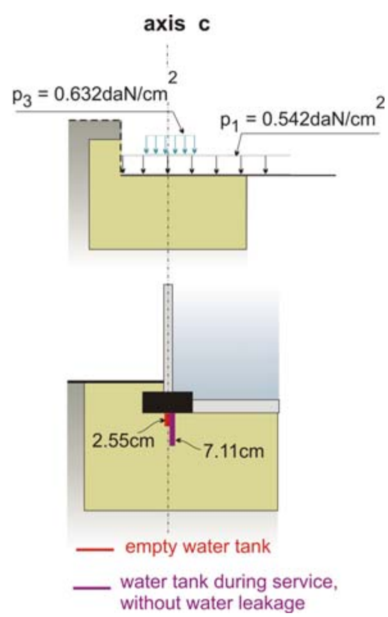

Fig.9. Settlements under the annular footing when there is no water leakage

The vertical stress distribution within foundation soil was assessed in each relevant axis of the structure and based on this stress state a settlement distribution was predicted immediately after the erection of the tank, when the tank was still empty, using the values of the p_2 and p_3 pressures and the stress-strain curves at the soil in-situ moisture content (Fig.10).

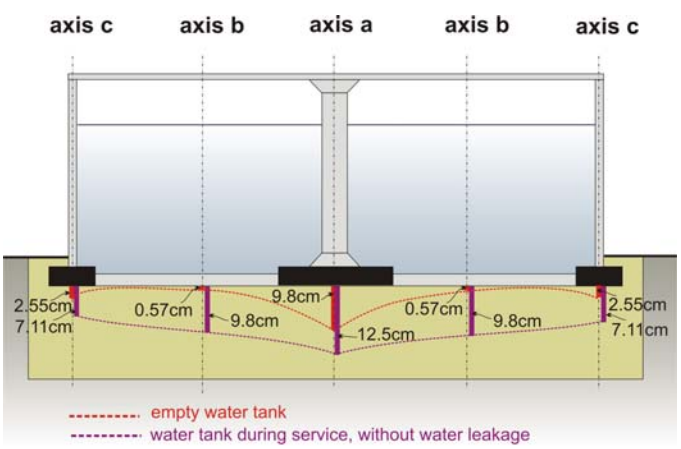

Fig.10. The settlement diagram during service, without any water leakage

The simple support of the roof elements as the working structural hypothesis (even when the fissures have been developed at the connection joints) the settlement of the central column is not going to induce excessive stresses due to the differential settlements developed between the column and wall footing. The potential settlements are below the values of the allowable ones presented in the Appendix C, STAS 3300/1-85. The maximum total settlement is s_{max} = 12.5cm < 15cm, while the relative settlement between column-wall footing is restricted to 0.0036 < 0.006.

Three wetting hypotheses were considered in order to assess the effects of accidental water leakage from the tank. They consider the complete saturation is developed within the collapsible soil due to water leakage at the dedicated joints between various footings of the structural members.

The 1st hypothesis regards water leakage developed only through the joints between the column and the adjacent raft.

Figure 11 presents by comparison with the settlement during service without any water leakage, the situation created by complete saturation of the foundation ground related to the active zone under the column's footing.

The complete saturation of the soil within the active zone of the column's footing is not significantly influencing the settlements developed under the annular footing. The soil underneath the raft is also not increasing the settlement profile. thus, the settlement diagram is altered only underneath the column's footing by comparison to the one developed during service without any water leakage.

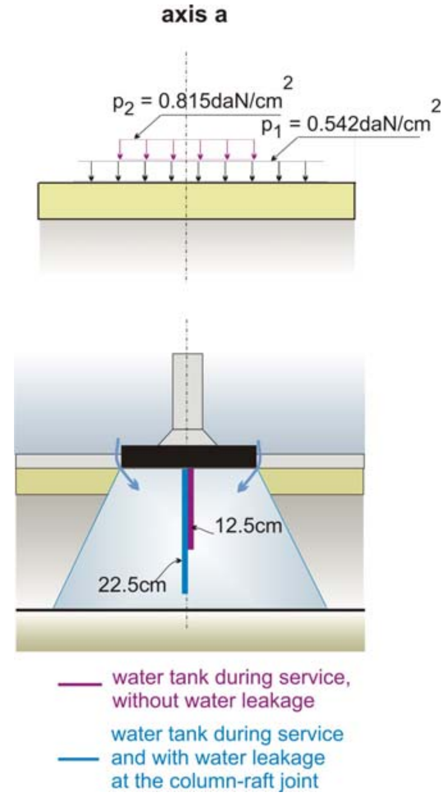

Fig.11. Settlements under the column in case of complete saturation of the corresponding active zone

The 2nd hypothesis considers water leakage developed along the entire annular footing perimeter.

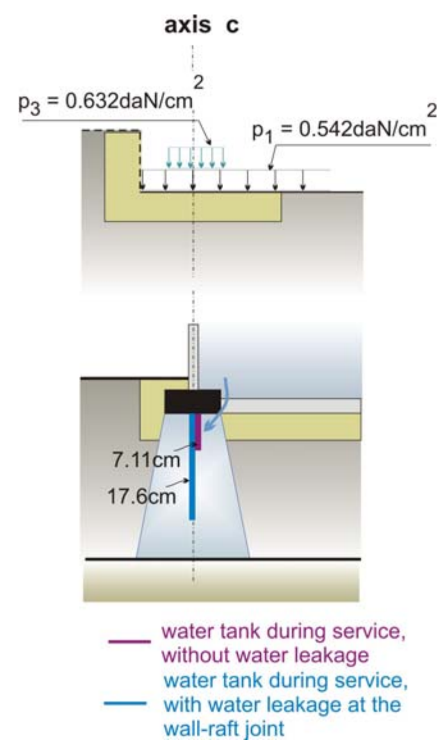

Fig.12. Settlements under the annular footing in case of complete saturation of the corresponding active zone

Figure 12 presents potential settlements of 17.6cm as a consequence of complete saturation of the soil under the annular footing, the advance of the water front being spread over the entire active zone, by comparison to 7.11cm settlement in case there is no water leakage during service.

The 3rd hypothesis considers that water leakage occurs at the joints between the foundations members, the radial joints in the raft included.

Figure 13 presents an increase of the potential settlement in the middle zone of the raft, from 9.8cm during service without any water leakage, up to 19.2cm when water leakage occurs along the radial joints in the raft.

This potential situation is superposed to the increase in total settlements underneath the other footing members during water leakage from the tank and complete saturation of their corresponding active zones.

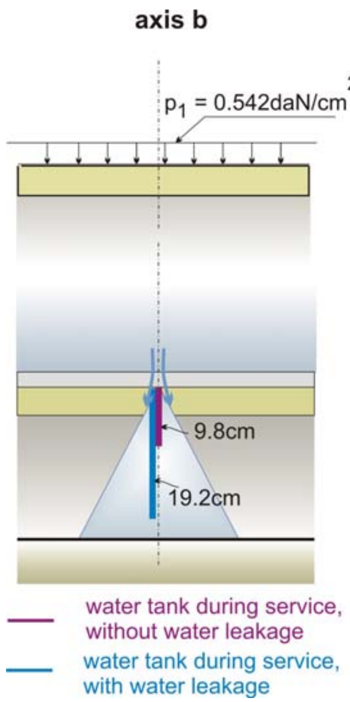

Fig.13. Settlements under the raft in case of complete saturation underneath the radial joints

For all the above presented hypotheses, the water tank was considered filled to the maximum storage capacity, the active zone within the collapsible soil in a complete saturation state till the maximum depth of –9.20m, and the advance of the water front with an angle of 50^o towards the relevant vertical axes.

The calculation of the supplementary settlements due to soil wetting performed in each hypothesis indicates the following developed situations.

For the case of 1st hypothesis – Fig.14 presents a settlement profile comparative to the one developed in the absence of any water leakage from the tank, the settlement increase being relevant only for the column's footing up 22.5cm, without influencing the settlement of the annular footing.

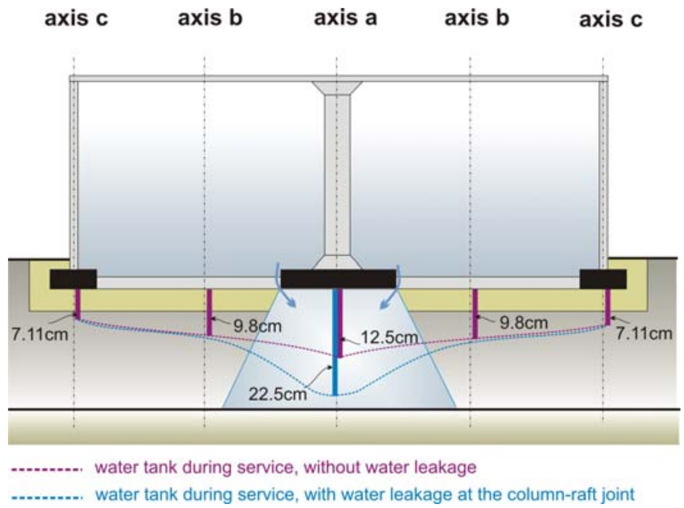

Fig.14. The advance of the water front and the corresponding settlement diagram according to the 1st hypothesis

For the case of the 2nd hypothesis – Fig.15 indicates the development of a supplementary settlement due to wetting up to 17.6cm along the vertical axis of the annular footing, without influencing the other soil zones within the outer tank perimeter.

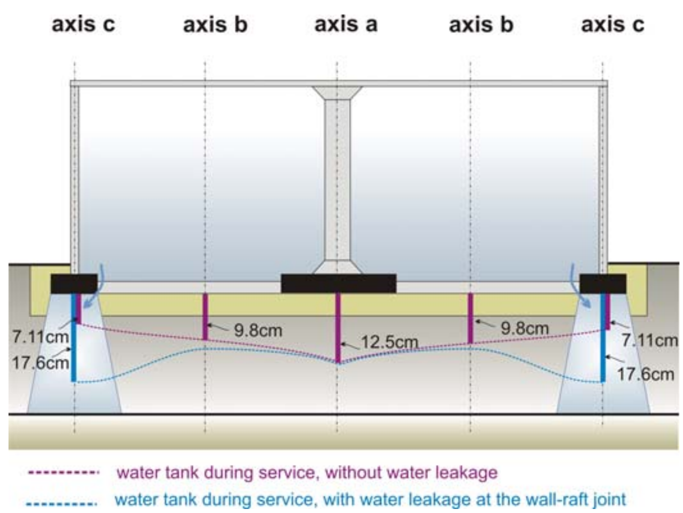

Fig.15. The advance of the water front and the settlement diagram according to the 2nd hypothesis

For the case of the 3rd hypothesis – Fig.16, the complete saturation of the soil in the active zones of all the tanks footings would develop and an increase of 22.5cm (axis a), 19.8cm (axis be) and 17.6cm (axis c).

All these potential supplementary settlements due to wetting according to the 3 working hypotheses are exceeding significantly the allowable settlement for the water tank. The probability of their development is related to the potential complete saturation of all active zones within the foundation ground.

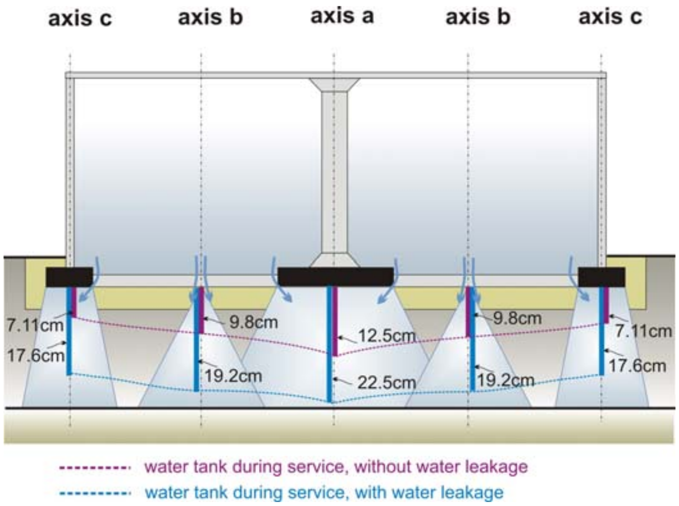

Fig.16. The advance of the water front and the settlement diagram according to the 3rd hypothesis

The advance of the water front continuously developed over the entire joints at the tank footings together with the low permeability coefficient of the compacted soil layer in comparison to the one for the natural ground underneath is creating a slow settlement rate without a collapsible effect within the soil.

The water volume required as necessary to induce complete saturation of the collapsible soil and generates the supplementary settlements (for a saturation degree $S_r = 0.85$) is assessed with the values presented in Table 1.

Table 1. Water volumes from leakage

Hypothesis	Soil volume flooded within (compacted layer + natural ground) [m3]	Water volume to reach saturation in (compacted layer + natural ground) [m3]	Time to reach saturation at a water loss of 2cm/24h [days]
1	1703	518	37,6
2	8725	2597	183
3	10598	3003	212

According to the registration files during the filling tests, for a rate of the water leakage of approximately 2cm/24h, the duration of the water accumulation within the foundation soil to create complete saturation for all the 3 hypotheses ranges between 37 days up to 212 days.

CONCLUSIONS

The settlement predictions based on the soil investigation program and technical assessment of the performance quality of the compacted soil cushion develops the following issues regarding the tank's behaviour during service.

The resulted data from the technical assessment compared with the date presented by the contractor's registration quality control files conclude that the moisture within the compacted soil is less than the optimum moisture content during compaction ranging between a minimum of 2.61% and a maximum of 11.59%, and by this, a unit weight of 18kN/m^{3}as the one presented in the files is impossible to reach.

The laboratory tests indicated a differential compaction degree along the cushion stratum, 99.4% in the middle part and approximately 85% on the sideways, though the soil within the cushion was completely converted into a soil insensitive to wetting, without a collapsible potential settlement.

The natural soil underneath the compacted layer, due to the supplementary strains due to wetting such as i_{m3} ranging between 4.8 – 5.5 cm/m, high porosities of more than 50%, dry unit weight γ_d of 12.5kN/m^3 is a clayey loess, with medium to high sensitivity to wetting, classified within group A, that can generate a maximum supplementary settlement I_{mp} (for complete saturation) of approximately 22cm.

The hypotheses for the advance of the water front indicates the higher risk induced by the potential supplementary settlement under the central column when water leakage occurs only at the column-raft joint (22cm in maximum 37 days for a water infiltration rate of 14.14m^3/24h). The perimeter water infiltrations would require a higher water volume and a longer duration to reach saturation, approx. 183 days and thus a lower risk, considering that previous situations reported collapse of the soil on 1/3 of the perimeter without structural collapse. These potential situations required immediate remedy works at the water proofing system to lower the risks, especially at the joining zone between column footing with the raft.

The settlement prediction performed over the foundations soil was considered during a structural assessment of the tank itself, and thus altering the stress and strain state within the tank structural members for each of the wetting hypothesis considered for the foundation ground. As a result, consolidation works have been performed consisting mostly in jacketing the walls and the raft, together with remedy works for the water proof system.

A monitoring program was established during the service of the water tank, to record the evolution of the deformations at the roofing supports on both the column and wall in accordance with the recorded water leakage from the tank, if any.

Water meter devices were installed to measure the water flow within the tank and record the potential water leakage after the consolidation and remedy works have been performed.

Avoidance and minimizing of wetting is the purpose of extra measures to avoid water infiltration in the ground. This included maintaining excellent surface drainage and water tightness of underground pipelines. The slope of the developed ground surface surrounding the tank is minimum 2% and a corresponding vertical arrangement of the soil profile was performed to induce immediate water evacuation from the site to the nearest outlet.

Pavements on the construction site have been reassessed with culvert on the sideways and remedy works performed to provide surface maintenance as stated previously and clay layers have been spread on the surface to avoid water infiltration.

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