Study of the Buffer Tank for the Industrial Waste Water Treatment Plant

Malek Jedidi1,2,* and Salem Mabrouki1

1Department of Civil Engineering, Higher Institute of Technological Studies of Sfax, Sfax, Tunisia
2Civil Engineering Laboratory, National Engineering School of Tunis, University of Tunis El Manar, Tunis, Tunisia

Abstract: This paper presents a study on a buffer tank for the waste water treatment plant at the level of “Oued Noumer”. A geotechnical study was carried out to predict the profile of the site and the mechanical characteristics of the soil by the pressuremeter test (PMT) and two pressiometric soundings. A convergence study was developed to choose the appropriate mesh for the buffer tank in order to model the structure by the ROBOT software. The permanent and variable loads were calculated from the different equations and the combinations of actions to be taken into account in the different construction phases with the appropriate weighting coefficients were carried out according to the rules of BAEL91-revised 99. Test results have shown that the soil exhibits a good permissible soil stress equal to 2.00 bar. The value of the reaction modulus $K$ calculated from the results of PMT and introduced into the ROBOT software is chosen equal to 2000 t/m$^3$. The reinforcement of the different elements of the buffer tank was determined in the form of steel sections in cm$^2$/m using the ROBOT software.

Keywords: Buffer tank, waste water treatment, pressuremeter test, mesh, modeling, ROBOT software, reinforcement

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1 INTRODUCTION

In the face of scientific and technological advances, new technologies are continuing to recur with a significant increase while invading all fields and sectors of industry. Admittedly, these new techniques bring added value with incredible advantages over productivity, performance or other industrial criteria. Environmental pollution is the most atrocious ecological crisis that man is facing today. Of the total 220 million deaths per year it was estimated that the causes of death in 12–20 million are due to water and nonfatal infections which is very high (Alam et al. 2009).

Water is an important production factor. In industry water is required that corresponds with the differing needs of respective processes. The spectrum of industrial water ranges from cooling and boiler feed water in power stations and process water for a wide range of industrial uses to ultra pure water for the electronics and pharmaceutical industries.

Industrial wastewater contains a diversity of impurities and therefore for this reason alone, its treatment constitutes a special task. Furthermore, the emission limits for industrial effluent are constantly being tightened up. Closed circuits and product recovery in various production processes are becoming an increasing priority among manufacturing companies. These measures represent an additional contribution to the protection of aquatic eco-systems and possess great cost-cutting potential. The best strategy to clean highly contaminated and toxic industrial wastewater is in general to treat them at the source (Peringer 1997) and sometimes by applying onsite treatment within the production lines with recycling of treated effluent (Hu et al. 1999).

A variety of strategies are necessary to remove the different types of contamination of wastewater. Treatment levels of wastewater are often identified as primary, secondary and tertiary:

1. Primary treatment involves separating a portion of the suspended solids from the wastewater. Screening and sedimentation usually accomplish this separation process. The effluent from primary treatment will ordinarily contain considerable organic material and will have a relatively high BOD.
2. Secondary treatment involves further treatment of the effluent. Biological processes generally accomplish the removal of the organic matter and the residual suspended solids. The effluent from secondary treatment usually has little BOD5 (30 mg/l as average) and a low suspended solids value (30 mg/l as average).
3. Tertiary treatment requires several operations and processes such as coagulation, filtration, activated carbon adsorption, electrodialysis, reverse osmosis, ozonation, advanced oxidation processes etc.

*Corresponding author. Email: malekjedidi@yahoo.fr
Wastewater treatment has therefore been necessary to preserve the quality of natural environments, especially surface and groundwater. The purified water is currently mainly rejected. The generalization of the reuse of these waters can thus contribute to partially fill the water deficit first hand. Recycling water in industries and using water for watering recreational areas can therefore help to reduce the pressure on good quality natural resources. The use of unconventional water in agriculture can contribute to the creation of new irrigated perimeters or to provide a source of support for existing perimeters. It is practiced both in developed and developing countries.

Advanced Oxidation Processes (AOP) are efficient methods that remove the non degradable organic pollutants by means of biological processes (Asgher et al. 2009; Ayed et al. 2011). the AOP can be applied for the disinfection of water, air and for remediation of contaminated soils (Babel and Kurniawan 2003; Babu et al. 2007). In general AOP are economical to set up but comprise high operating fixed cost due to the input of chemicals and requirement of the power required (Das et al. 2010; Dawlar et al. 2009; Dos Santos 2005; Dos Santos et al. 2004; Dua et al. 2002).

Chemical industrial wastes usually contain organic and inorganic matter in varying degrees of concentration. They can be treated by some biological oxidation methods such as trickling filters, lagoons (Nemerow and Dasgupta 1991; Jobbagy et al. 2000). Waste minimization in the production process in chemical industry is the first and most important step to avoid waste formation during the production (Carini 1999; Alvarez et al. 2004).

In this context, the Regional Directorate of Hassi R’mel is committed very early to the implementation of an ambitious program. It aims at the elimination, if not the reduction to the maximum, of the significant environmental impacts related to its activities and services by realizing the industrial wastewater treatment plant at the “Oued Noumer” level. Indeed, this study was carried out on a buffer tank for the waste water treatment plant. The ROBOT software was used to model the structure and determine the reinforcement of each finite element subjected to stress.

2 PRESENTATION OF THE PROJECT

The buffer tank (Figure 1) with a volume of 500 m$^3$ receives the oily waters from the purges of different units. The pH of the treated water at the station exit is acid. The aim of the project is to recover all oily waters of industrial waste from the “Oued Noumer” field and to treat them in such a way as to reduce the level of hydrocarbons to a level lower than 5 mg/l and suspended solids less than 30 mg/l.

The design of the buffer tank is based on the difference in density between oil, water and solids. The buffer tank allows the flow rate to be regulated, to produce a homogenization of the various effluents upstream of the de-oiling station and to carry out a preliminary separation in order to reduce the oil content and to favor the precipitation of the suspended materials. Generally, the water produced with the crude, as well as the wastewater from treatment units and storage tanks, contain hydrocarbons, solid particles and suspended solids (Renault et al. 2009b). The removal of hydrocarbons and suspended solids is carried out by purely physical methods such as:

1. The separation CPI (Corrugated Plate Interceptor): It is a gravity separation device. The design of the separator is based on the difference in density between the oil and the water based on the design criterion. Most suspended solids will be collected at the bottom of the separator as a layer of sediment, the oil will float in the upper part of the separator, and the water will be at the middle layer between oil and solids.

2. Decantation: It is based on the density difference between the oil, water and suspended solids. This separation is carried out by HDPE plates. The supernatant oil will be recovered by an oil separator rotating disc and sent to the oil recovery vessel. The sludge will be collected at the bottom of the separator as a layer of sediment, the oil will float in the upper part of the separator, and the water will be at the middle layer between oil and solids.

3. Filtration: The treated water from the pumps enters through the top of the filter. The water percolates from top to bottom on the ceramic bed by fixing the spherules

![Figure 1. General view of the buffer tank](image)
of oil and the fine particles of suspended matter which magnify and fill the gaps, thus creating a progressive increase in the pressure drop.

4. Flotation: This operation consists in further reducing the free oils content of the decanted waters. This tank is equipped with a submerged racket on which are attached air diffuser discs. This racket of diffusers is equipped upstream with a manometer for the control of air flow and an isolation valve for the regulation of this air flow. The fine air bubbles are introduced into the liquid to be treated via air suppressor

3 GEOTECHNICAL STUDY

As part of the preparatory work for the construction of the buffer tank for the industrial wastewater treatment plant at Oued Noumer, a two pressiometric soundings SP1 and SP2 depths of 20 m were carried out as well as two drill holes SC1 and SC2 at depths of 20 m. From the results of the geotechnical study, the profile of the site and the mechanical characteristics of the soil can be predicted.

3.1 Pressuremeter Test PMT

3.1.1 Description and Procedure

The PMT is an in-situ testing method used to achieve a quick measure of the in-situ stress-strain relationship of the soil. In principle, the pressuremeter test is performed by applying pressure to the sidewalls of a borehole and observing the corresponding deformation. The PMT is typically performed by inserting a cylindrical probe into an open borehole, supporting it at the test depth, and then inflating a flexible membrane in the lateral direction to a radial strain of as much as 40% depending on the probe design (Figure 2). The PMT operator may expand the pressuremeter probe in equal pressure increments (stress controlled test) or in equal volume increments (strain controlled test), typically stopping the test when initial volume of the probe has doubled or when reaching the maximum allowable pressure. PMT was performed in accordance with the requirements of ASTM D 4719 (ASTM D4719-07 2007).

According to the PMT, the following parameters have been determined:

1. \( E_m \): The modulus used for the calculation of the settlement of foundations
2. \( P_l^* \): The limit pressure used for the calculation of the bearing capacity of the soil with regards to a specified foundation
3. \( P_f \): The creep pressure which is the boundary between the pseudo-elastic type of reaction of the soil and the large displacements type of reaction, for the pressuremeter stress path.

3.1.2 Calculation of \( P_{le}^* \) and \( E_m \) According to PMT Results

The calculations were carried out according to standards of fascicle 62 (Fascicle No. 62 1993). The determination of the equivalent limit pressure \( P_{le}^* \) is given by Equation (1):

\[
P_{le}^* = \sqrt[n]{P_{l1}^* \times P_{l2}^* \ldots P_{ln}^*}
\]  

(1)

For the calculation of \( P_{le}^* \), a geometric mean is applied to the ground soil \([D; D + 1.5B]\). The determination of the equivalent limit pressure \( P_{le}^* \) is given by Equation (2):

\[
\log(P_{le}^*) = \frac{1}{1.5B} \int_D^{D+1.5B} \log \left[P_l^*(z)\right] dz
\]  

(2)

Where, \( B \) is the width of foundation element, \( D \) is the depth of foundation and \( P_l^*(z) \) is obtained by joining by line segments on a logarithmic scale the different measured values of \( P_l^* \).

The determination of the equivalent modules \( E_{C} \) and \( E_{d} \) is given by Equations (3) and (4):

\[
\frac{4.0}{E_d} = \frac{1}{E_1} + \frac{1}{0.85E_{1,5}} + \frac{1}{E_{1,5} \times 2.5E_{0,8}} + \frac{1}{2.5E_{0,16}}
\]  

(3)

\[
E_C = E_1
\]  

Where, \( E_1 \) is the value of the modulus measured in the B/2 thickness soil located immediately below the foundation and \( E_{ij} \) is the harmonic mean of the modules measured in the ground soil \( i \) to \( j \).

3.1.3 Permissible Soil Stress According to the Bearing Capacity of the Soil

The permissible soil stress was calculated from the results of PMT using the Equation (5):

\[
q_{soil} = q_u - \gamma \times D \quad \text{or} \quad q_u = q_{soil} + \gamma \times D
\]  

(5)

where \( D \) is the founding depth, \( \gamma \) is the unit weight of the soil removed and \( F_s \) is the factor of safety.

The rupture stress \( q_u \) is given by Equation (6):

\[
q_u = K_p \times P_l^* + \gamma \times D
\]  

(6)

where, \( K_p \): the soil pressure factor, \( P_l^* \): the equivalent net pressure calculated as the mean value of the net limit pressures at a depth of 1.5B.

3.1.4 Permissible Soil Stress According to the Soil Settlement

In the case of a homogeneous soil, a reliable estimate of settlement could be obtained from the PMT and would be composed
of two components, one arising from the deviatoric strain tensor and one from the spherical strain tensor (Meigh 1963; Menard 1965). The final settlement is given by Equations (7), (8) and (9):

\[
S_f = S_c + S_d
\]

\[
S_c = \frac{\alpha}{9E_c} (q' - \sigma'_{e0}) \times \lambda_c \times B
\]

\[
S_d = \frac{2}{9E_d} (q' - \sigma'_{e0}) \times B_0 \times \left( \frac{\lambda_d \times B}{B_0} \right) ^\alpha
\]

where, \( S_f \): the final settlement, \( S_c \): the settlement due to the volume change, \( S_d \): the settlement due to shear distortion, \( B \): the foundation width, \( B_0 \): the reference width usually equal to 0.6m, \( \lambda_c \) and \( \lambda_d \): the shape factors, \( \alpha \): the reological factor depending on soil type, \( E_c \) and \( E_d \): the equivalent modules, \( q' \): Average effective stress applied to the soil by the foundation, \( \sigma'_{e0} \): the initial effective stress applied to the soil by the foundation, \( \lambda \): the initial effective stress at the level of the foundation base.

### 3.2 Reaction Modulus \( K \)

The reaction modulus \( K \) was introduced by WINKLER (Daloglu and Girija Vallabhan 2000) assuming a proportionality of the stresses \( P \) and the corresponding settlements \( S \), in contact with a foundation and an elastic soil. The reaction modulus is given by Equation (10):

\[
P = K \times S
\]

In this case, the settlement of any element of the charged surface is absolutely independent of the charge on the neighboring elements, which is arbitrary and inaccurate.

The reaction modulus can be determined using many expressions from theory of elasticity solution for a rigid plate on a semi-infinite elastic soil medium subjected to a concentrated load (Timoshenko and Goodier 1951; Harr 1966; Kameswara Rao 2000). As settlement depends on the size and shape of the foundations and the mechanical complexity of the soil, we are therefore limited to semi-empirical correlations formulated by MENARD. The reaction modulus is given by Equation (11):

\[
\frac{1}{K} = \frac{2B_0}{9E_d} \left( \frac{\lambda_d \times B}{B_0} \right) ^\alpha + \frac{\alpha}{9} \frac{B}{E_c} \times \lambda_c
\]

### 4 MODELING OF THE BUFFER TANK WITH ROBOT SOFTWARE

#### 4.1 The Meshing Methods

A mesh is the discretization of a plane or three-dimensional panel into a finite number of elements (called finite elements), of triangular or quadrangular forms (Figure 3), on which the nodes of the computation model will be generated. It is preferable not to use triangular elements at 6 nodes or quadrangular elements at 8 nodes.

There are several mesh generation methods:

1. Coon’s Method: Coons’ surfaces are 3D surfaces spread over quadrilateral or triangular contours whose opposite sides are divided into the same number of segments. The shapes of the created elements correspond to the region on which the mesh is created. Using this method, all points created on the selected contour edge are connected with the points on the opposite edge of the contour.
2. Delaunay’s Method: You can use Delaunay’s triangulation method to create an FE mesh for any 2D surface. Any openings that are inside the domain should be defined as contour edges. They will not be taken into consideration during creation of the finite element (FE) mesh. After you select Delaunay’s method, you then select the contour for which the element mesh will be created.
3. Kang’s method: Generates the mesh near the emitters according to Kang’s method and outside of these contours according to Delaunay’s method.

#### 4.2 Evaluation of Loads and Combinations of Actions

##### 4.2.1 Permanent Actions

The different permanent loads applied to the buffer tank are:

1. The weight of the buffer tank
2. The weight of the bridge and stairs
3. Soil pressure: The buffer tank is buried 1.5 m. The soil pressure \( P \) exerted on the walls is given by Equation (12):

\[
P = K_0 \times \gamma_s \times h
\]

where, \( \gamma_s \): the unit weight of soil, \( h \): height of the buried part of the buffer tank, \( K_0 \): earth pressure coefficient (Mayne and Kulhawy 1982; Radoslaw and Michalowski 2005)
4. Weight of the soil applied to the edge of the buffer tank raft given by Equation (13):

\[
P = \gamma_s \times h
\]
4.2.2 Variable Actions

The different variable loads applied to the buffer tank are:

1. The pressure due to overloading of a truck on the soil. This load applies once along the axis X and once along the Y axis, and the choice of the loading side is taken into account according to the installation plan. The pressure is given by Equation (14):

\[ P = K_0 \times q \]  

(14)

where, \( K_0 \): earth pressure coefficient, \( q \): Truck traffic overloads \( (q = 1000 \text{ daN/m}^2) \)

2. Variable loads due to the maintenance of the installations and possibly the loads on the staircase and the footbridge.

3. Hydrostatic pressure of the water on the interior walls and the bottom slab of the buffer tank given by Equation (15):

\[ P = \rho \times h \]  

(15)

where, \( \rho \): the density of water \( (\rho = 1000 \text{ daN/m}^3) \), \( h \): the level of water in the buffer tank.

4.2.3 Temperature Actions

The thermal gradient \( \Delta T \) was calculated according to the standards of fascicle 74 (Fascicle No. 74 1998). The thermal gradient in service applied to the panels exposed to a temperature difference between the two faces of the buffer tank (inside face in contact with the water, external face sunny) is given by Equation (16):

\[ \Delta T = \frac{(T_e - T_i) \times C_{tu} \times e}{\lambda} \]  

(16)

where, \( T_e \): the outside temperature, \( T_i \): the temperature of the liquid, \( e \): the wall thickness, \( \lambda \): the thermal conductivity.

The heat transmission coefficient \( C_{tu} \) is expressed by Equation (17):

\[ C_{tu} = \frac{1}{\frac{h_e}{\lambda} + \frac{1}{h_i} + \frac{e}{\lambda}} \]  

(17)

where, \( h_e \): the heat transfer coefficient outside the wall, \( h_i \): the heat transfer coefficient inside the wall, \( e \): the wall thickness, \( \lambda \): the thermal conductivity.

The moment created by the thermal gradient was calculated according to the standards of fascicle 74 (Fascicle No. 74 1998). The determination of the moment is given by Equation (18):

\[ M_t = \alpha \times \Delta T \times \frac{E \times I}{e} \]  

(18)

where, \( \alpha \): the coefficient of thermal expansion of concrete, \( E \): the elasticity modulus of concrete, \( I \): the moment of inertia, \( e \): the wall thickness.

4.3 Waterproofing of the Buffer Tank

To ensure the waterproofing of the buffer tank, PVC water stop was embedded in the concrete joints, acts as a continuous watertight diaphragm to prevent any seepage of water in construction joints which are subject to hydrostatic pressure. PVC water stop is designed for expansion or contraction joint; meanwhile, it can accommodate lateral and transverse movements which make it capable to suit the moving joints. The main usage is to prevent the passage of liquids in concrete joints in many different projects such as Dams, Tunnels, Water & Wastewater Treatment Plants, and other liquid retaining structures. The PVC water stop is extruded form an elastomeric plastic material including high grade polyvinyl chloride, special resin and some chemical additives such as plasticizers and stabilizers. The high material makes PVC water stops unsurpassed with a variety of features and benefits. The Physical Properties of PVC Water stops are shown in Table 1.

Table 1. Physical properties of PVC water stops

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>Unit</th>
<th>Nominal value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness</td>
<td>Shore A</td>
<td>&gt; 65</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>MPa</td>
<td>≥ 12</td>
</tr>
<tr>
<td>Elongation</td>
<td>%</td>
<td>300</td>
</tr>
<tr>
<td>Tensile modulus</td>
<td>MPa</td>
<td>≥ 5.5</td>
</tr>
<tr>
<td>Brittleness tempera-</td>
<td>°C</td>
<td>&lt; -38</td>
</tr>
<tr>
<td>Bibulous rate</td>
<td>%</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>Air aging (70 ± 1°C)</td>
<td>%</td>
<td>≥ 95</td>
</tr>
<tr>
<td>Ozone Resistance</td>
<td>-</td>
<td>No failure</td>
</tr>
</tbody>
</table>

5 RESULTS AND DISCUSSION

5.1 Pressuremeter Test PMT

Figure 4 gives the results of the PMT for the two pressiometric soundings SP1 and SP2 at depths of 20m. The pressiometric module \( E_m \) and the net limit pressure \( P_l^e \) have been determined every one meter. The results show that the net limit pressures vary from 9.3 bar to 29.5 bar and that the pressiometric modules oscillate between 88 and 677 bar. We note that the mechanical characteristics are good, well correlated with the facies encountered. The values of \( E_m \) and \( P_l^e \) make it possible to classify this soil in category II throughout the investigated columns.

5.1.1 Calculation of \( P_l^e \) and \( E_m \) According to PMT Results

The \( P_l^e \) and \( E_m \) were determined by calculation using Eq. (1) respectively for the layers encountered in the first and second drill holes SC1 and SC2.

The results presented in Figure 5 show the profile of the site predicted by the two drill holes SC1 and SC2. The thicknesses of the soil layers to be taken into account were determined by an average cross-section of the profile between SC1 and SC2. According to the soil stratigraphy, we note that the soil is characterized, after having passed a layer of topsoil of 1.00 m of thickness, by a layer of fine sand locally clay and gypsum of beige to brown color up to 2.30 m. A second layer of fine clay sand, very rich in gypsum of 5.10 m thickness arrives to the depth of 7.40 m. The lithological column of the ground ends with a layer of fine gray clay sand of beige to yellowish color which starts from 13.00 m deep and extends until the end of the exploration.
5.1.2 Permissible Soil Stress According to the Bearing Capacity of the Soil

The permissible soil stress \( q_{soil} \) was calculated from the results of PMT using the Equation (5) and (6). The equivalent net pressure \( P^* \) and the soil pressure factor \( K_p \) are given in Table 2 depending on soil class. The following parameters were taken into account in the calculation:

1. The unit weight of soil \( \gamma = 18 \text{ KN/m}^3 \);
2. The factor of safety \( F_s \) is equal to 2 in ultimate limit state (ULS) and equal to 3 in serviceability limit state (SLS);
3. The width of the foundation \( B = 14.00 \text{ m} \);
4. The length of the foundation \( L = 14.50 \text{ m} \).

Table 3 summarizes the calculation of the permissible soil stress \( q_{soil} \) according to the bearing capacity of the soil. A maximum settlement value \( (St = 10 \text{ mm}) \) was chosen for the
According to the Figure 6, the \( \lambda \)-soil stress was taken equal to 9.55 bar for the case of a general calculation. According to the results obtained, the permissible soil stress was taken equal to 2.00 bar for the case of a general raft anchored from 2.00 m of natural ground level (NGL). It is noted that the maximum soil reaction is less than 1978) takes into account the mod-

d.dimensions of the wafer (Baguelin et al. 1978). For non-homogeneous soils, a weighting of the pressuremeter modulus of the different layers has to be done. For the deviatoric term, the weighting is approximately done according to the relative distribution of the deviatoric stress from a linear elastic calculation. The definition of the different modulus in depth is given in Figure 6.

\[ E_c = E_1 = 279.38 \text{ bar}. \]

\[ E_d = \frac{3.2}{E_1 + 0.85E_2 + \frac{1}{E_{3,5}}} = \frac{3.2}{279.38 + 0.85 \times 318.81 + \frac{1}{353}} = 316.76 \text{ bar} \]

For non-homogeneous soils, a weighting of the pressuremeter modulus of the different layers has to be done. For the spherical settlement term, only the modulus of the first layer under the foundation has to be computed. For the deviatoric term, the weighting is approximately done according to the relative distribution of the deviatoric stress from a linear elastic calculation. The definition of the different modulus in depth is given in Figure 6.

\[ E_c = E_1 = 279.38 \text{ bar}. \]

\[ E_d = \frac{3.2}{E_1 + 0.85E_2 + \frac{1}{E_{3,5}}} = \frac{3.2}{279.38 + 0.85 \times 318.81 + \frac{1}{353}} = 316.76 \text{ bar} \]

Table 2. Equivalent net pressure \( P_i^* \) and soil pressure factor \( K_p \) depending on soil class

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Soil class</th>
<th>Equivalent net pressure ( P_i^* ) (MPa)</th>
<th>Soil pressure factor ( K_p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clays, Silts, Chalks</td>
<td>A</td>
<td>&lt; 0.7</td>
<td>0.8 ( 1 + 0.25 \left( \frac{0.6 + 0.4B}{L} \right) \frac{D_1}{B} )</td>
</tr>
<tr>
<td>Clays, Silts</td>
<td>B</td>
<td>1.2–2.0</td>
<td>0.8 ( 1 + 0.35 \left( \frac{0.6 + 0.4B}{L} \right) \frac{D_1}{B} )</td>
</tr>
<tr>
<td>Clays</td>
<td>C</td>
<td>&gt; 2.5</td>
<td>0.8 ( 1 + 0.50 \left( \frac{0.6 + 0.4B}{L} \right) \frac{D_1}{B} )</td>
</tr>
<tr>
<td>Sands</td>
<td>A</td>
<td>&lt; 0.5</td>
<td>[ 1 + 0.35 \left( \frac{0.6 + 0.4B}{L} \right) \frac{D_1}{B} ]</td>
</tr>
<tr>
<td>Sands, Graves</td>
<td>B</td>
<td>1.0–2.0</td>
<td>[ 1 + 0.50 \left( \frac{0.6 + 0.4B}{L} \right) \frac{D_1}{B} ]</td>
</tr>
<tr>
<td>Sands, Graves</td>
<td>C</td>
<td>&gt; 2.5</td>
<td>[ 1 + 0.80 \left( \frac{0.6 + 0.4B}{L} \right) \frac{D_1}{B} ]</td>
</tr>
<tr>
<td>Chalks</td>
<td>B</td>
<td>1.0–2.5</td>
<td>1.3 [ 1 + 0.27 \left( \frac{0.6 + 0.4B}{L} \right) \frac{D_1}{B} ]</td>
</tr>
<tr>
<td>Marl Limestone-marl</td>
<td>A</td>
<td>1.5–4.0</td>
<td>[ 1 + 0.27 \left( \frac{0.6 + 0.4B}{L} \right) \frac{D_1}{B} ]</td>
</tr>
<tr>
<td>Rocks</td>
<td>B</td>
<td>&gt; 4.5</td>
<td>[ 1 + 0.27 \left( \frac{0.6 + 0.4B}{L} \right) \frac{D_1}{B} ]</td>
</tr>
</tbody>
</table>

Table 3. Calculation of the Permissible soil stress \( q_{soil} \) according to the bearing capacity of the soil

<table>
<thead>
<tr>
<th>Dimensions of the foundation</th>
<th>Soil parameters</th>
<th>Permissible soil stress ( q_{soil} ) (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( B ) (m)</td>
<td>( L ) (m)</td>
<td>( B_0 ) (m)</td>
</tr>
<tr>
<td>14.00</td>
<td>14.50</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Table 4. Rheological factor \( \alpha \) for different soil types and different ranges of \( E_M/p_l \) (Baguelin et al. 1978)

<table>
<thead>
<tr>
<th>Type</th>
<th>Peat</th>
<th>Clay</th>
<th>Silt</th>
<th>Sand</th>
<th>Gravel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overconsolidated or very dense</td>
<td>-</td>
<td>&gt; 16</td>
<td>1</td>
<td>2/3</td>
<td>&gt; 12</td>
</tr>
<tr>
<td>Normally consolidated or nearly dense</td>
<td>1</td>
<td>9 to 16</td>
<td>2/3</td>
<td>8 to 14</td>
<td>1/2</td>
</tr>
<tr>
<td>Overconsolidated, altered, disturbed or loose</td>
<td>1</td>
<td>7 to 9</td>
<td>1/2</td>
<td>5 to 8</td>
<td>1/2</td>
</tr>
</tbody>
</table>

Table 5. Shape factors \( \lambda_c \) and \( \lambda_d \) for different soil types and different ranges of \( E_M/p_l \) (Baguelin et al. 1978)

<table>
<thead>
<tr>
<th>( L/B )</th>
<th>Circle</th>
<th>Square</th>
<th>2</th>
<th>3</th>
<th>5</th>
<th>&gt; 20</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \lambda_c )</td>
<td>1.00</td>
<td>1.10</td>
<td>1.20</td>
<td>1.30</td>
<td>1.40</td>
<td>1.50</td>
</tr>
<tr>
<td>( \lambda_d )</td>
<td>1.00</td>
<td>1.12</td>
<td>1.20</td>
<td>1.78</td>
<td>2.14</td>
<td>2.65</td>
</tr>
</tbody>
</table>

The determination of the equivalent modules \( E_C \) and \( E_d \) were calculated from the results of PMT using Equations (3) and (4). \( E_C \) is equal to the pressuremeter modulus of the first layer under the foundation and \( E_d \) takes into account the modulus in depth with the weighting according to Equation (4).
the Permissible soil stress ($1.0015 \text{ bar} < 2 \text{ bar}$).

### 5.2 Reaction Modulus $K$

The reaction modulus $K$ was calculated from the results of PMT using the Equation (11) to be introduced into the ROBOT software. The calculation result gave a value of 2000 t/m$^3$.

### 5.3 The Meshing Methods

A convergence study was developed to choose the right mesh for the buffer tank. The principle of this study is to apply a force on a panel and to make a comparison with the displacement results using the ROBOT software, for several types of mesh: (0.5; 1; 1.5; 2; 2.5; 3; 3.5).

Figure 8 shows the application of a linear load of 100 KN/m on the reinforced concrete wall of 50 cm thickness and on an internal wall panel of 25 cm thickness embedded in the three edges. According to the results presented in Figure 9, it is noted that, for a mesh length equal to 0.50 m, the displacement remains constant. Similarly, for the internal wall panel, the displacement remains constant for a mesh length equal to 0.25 m (Figure 10).

According to these results, a 0.5 m/0.5 m mesh was chosen as the appropriate choice for panels with a thickness of 50 cm and a mesh size of 0.25 m/0.25 m as the appropriate choice for panels with a thickness of 25 cm (Figure 11).

---

![Figure 6](image.png)

**Figure 6.** Subdivision in layers of thickness $B/2$ for equivalent modulus

<table>
<thead>
<tr>
<th>Dimensions of the foundation</th>
<th>Shape factors</th>
<th>Equivalent modules</th>
<th>Permissible soil stress $q_{soil}$ (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B$ (m)</td>
<td>$L$ (m)</td>
<td>$B_0$ (m)</td>
<td>$D$ (m)</td>
</tr>
<tr>
<td>14.00</td>
<td>14.50</td>
<td>0.60</td>
<td>2.10</td>
</tr>
</tbody>
</table>

![Figure 7](image.png)

**Figure 7.** Determination of the permissible soil stress $q_{soil}$ by the robot software

---

![Table 6](image.png)

**Table 6.** Calculation of the Permissible soil stress $q_{soil}$ according to the soil settlement

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![Figure 8](image.png)

---

![Figure 9](image.png)

---

![Figure 10](image.png)

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![Figure 11](image.png)

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5.4 Evaluation of Loads and Combinations of Actions

The different permanent and variable loads applied to the buffer tank were calculated from the different equations. The weight of the stairs, guardrail and duckboard are respectively 150 daN/m$^2$, 30 daN/m$^2$ and 30 daN/m$^2$. The soil pressure $P$ exerted on the walls was calculated by Equation (12). The value is equal to 1350 daN/m$^2$. For the weight of the soil applied to the edge of the buffer tank raft, the value calculated by equation (13) is equal to 2700 daN/m$^2$.

For the temperature actions, the thermal gradient $\Delta T$ for the wall and the floor were calculated by Equation (16). The values are respectively 16.28°C and 19.54°C. The moment $M_l$ created by the thermal gradient $\Delta T$ was calculated by Equation (18). For a panel for example of dimension (12.5 m * 4.8 m * 0.5 m) linearly embedded at the edges and stressed at a thermal gradient $\Delta T = 16.28^\circ$C, the moment $M_l$ is equal to 45.87 KN.m. The different loading cases (permanent loads and variable loads) applied on the different components of the buffer tank have been introduced into the ROBOT software as shown in Figure 12.

The combinations of actions were carried out according to the rules of BAEL91-revised 99 (DTUP 18-702 1999). It gives the combinations of actions to be taken into account in the different construction phases with the appropriate weighting coefficients:

1. The action $Q$ essentially comprises the action due to the liquid for which the following coefficients have been retained: $\psi_0 = \psi_1 = \psi_2 = 1$
2. The determining action $T$ for a tank is generally the
Figure 12. Permanent and variable loads introduced by the robot software
temperature gradient assumed to be associated with the presence of the liquid. For this action, the following coefficients have been retained: \( \psi_0 = \psi_1 = \psi_2 = 0.6 \).

### 5.5 Reinforcement of the Buffer Tank

The calculation of the reinforcements was carried out by the ROBOT software, which gives the results in the form of steel sections in \( \text{cm}^2/\text{m} \) (calculates the upper and lower bars along the local axes \( x \) and \( y \)) for each finite element subjected to stress.

The arrangement of the bars of the reinforcement for the different elements of the buffer tank (Figure 13) is chosen as follows:

![Figure 13. Disposition of the lower and upper reinforcement bars](image)

1. \( X[-] \): lower reinforcement bars in the \( X \) direction (main bars)
2. \( X[+] \): upper reinforcement bars in the \( X \) direction (main bars)
3. \( Y[-] \): lower reinforcement bars in the \( Y \) direction (perpendicular to the main bars)
4. \( Y[+] \): upper reinforcement bars in the \( Y \) direction (perpendicular to the main bars)

The position of the lower and upper bars in the panel is taken in accordance with the direction of the \( Z \) axis of the local mark of the panel.

#### 5.5.1 Reinforcement of the Bottom Slab

Figure 14 show the values of the steel section for the lower reinforcement bars for the bottom slab. We note a maximum steel section value of 7.99 \( \text{cm}^2 \) for the lower reinforcement bars. The choice adopted is therefore \#8\#16/m in the \( X \) and \( Y \) directions which gives a steel section of 10.10 \( \text{cm}^2 \). The maximum spacing between the bars is equal to 20 cm.

The values of the steel section for the upper reinforcement bars for the bottom slab are given in Figure 15. We note a maximum steel section value of 15.63 \( \text{cm}^2 \) for the upper reinforcement bars. The choice adopted is therefore \#8\#16/m in the \( X \) and \( Y \) directions which gives a steel section of 16.08 \( \text{cm}^2 \). The maximum spacing between the bars is equal to 12.5 cm.

#### 5.5.2 Reinforcement of the Wall

Figure 16 show the values of the steel section for the reinforcement bars for the exterior wall. We note a maximum steel section value of 4.86 \( \text{cm}^2 \) for the vertical reinforcement bars. The choice adopted is therefore \#5\#12/m in the \( X \) direction which gives a steel section of 5.65 \( \text{cm}^2 \). The maximum spacing between the bars is equal to 20 cm.

Bars with a diameter of 12 mm and a length of 1.00 m were made to ensure the overlapping. The height of the bar above the upper level of the bottom slab is 0.50 m with a maximum spacing of 20 cm.

For the horizontal reinforcement bars, the maximum steel section value is 5.54 \( \text{cm}^2 \). The choice adopted is therefore \#5\#12/m in the \( Y \) direction which gives a steel section of 5.65 \( \text{cm}^2 \). The maximum spacing between the bars is equal to 20 cm.

Figure 17 shows the values of the steel section for the reinforcement bars for the interior wall. We note a maximum steel section value of 17.97 \( \text{cm}^2 \) for the vertical reinforcement

![Figure 14. Steel section for the lower reinforcement bars for the bottom slab in the X and Y directions](image)
Figure 15. Steel section for the lower reinforcement bars for the bottom slab in the $X$ and $Y$ directions

Figure 16. Steel section for the reinforcement bars for the exterior wall

Figure 17. Steel section for the reinforcement bars for the interior wall
bars. The choice adopted is therefore 8Φ14/m in the X direction which gives a steel section of 12.31 cm\(^2\). The maximum spacing between the bars is equal to 12.5 cm. 

Bars with a diameter of 14 mm and a length of 1.00 m were made to ensure the overlapping. The height of the bar above the upper level of the bottom slab is 0.60 m with a maximum spacing of 12.5 cm. 

For the horizontal reinforcement bars, the maximum steel section value is 13.98 cm\(^2\). The choice adopted is therefore 7Φ14/m in the Y direction which gives a steel section of 10.71 cm\(^2\). The maximum spacing between the bars is equal to 12.5 cm. 

A reinforcement to the right of the bearings by 7Φ14/m was made over a length of 2.00 m from the inside of the wall.

6 CONCLUSION

The present paper has presented a few results of an experimental study conducted on a buffer tank for the water treatment plant at the level of “Oued Noumer”. The Pressuremeter test PMT was used to achieve a quick measure of the in-situ stress-strain relationship of the soil. The modeling of the structure was carried out using the ROBOT software. The test results were analyzed to identify the different soil parameters. The following conclusions have been drawn from the investigation:

1. The pressiomeric module \(E_m\) and the net limit pressure \(P_r^0\) have been determined by two pressiomeric soundings SP1 and SP2.
2. The profile of the site was predicted using two drill holes SC1 and SC2 at depths of 20.00 m.
3. The soil exhibits a good Permissible soil stress \((q_{soil} = 2.00\text{ bar})\) according to the bearing capacity and the settlement.
4. The reaction modulus \(K\) of the soil was calculated from the results of PMT to be introduced into the ROBOT software \((K = 2000 \text{ t/m}^3)\).
5. A PVC water stop was embedded in the concrete joints of the buffer tank to prevent any seepage of water in constructions joints which are subject to hydrostatic pressure.
6. The meshing method was used to model the structure of the buffer tank. A 0.5 m/0.5 m mesh was chosen as the appropriate choice for panels with a thickness of 50 cm and a mesh size of 0.25 m/0.25 m as the appropriate choice for panels with a thickness of 25 cm.
7. The reinforcement of the different elements of the buffer tank was determined in the form of steel sections in cm\(^2\)/m using the ROBOT software.

7 NOMENCLATURE

- \(q_{soil}\) Permissible soil stress, bar
- \(q_e\) Rupture stress, bar
- \(q'\) Average effective stress applied to the soil by the foundation, bar
- \(\sigma'_{0}\) Initial effective stress at the level of the foundation base, bar
- \(\gamma\) Unit weight of soil, KN/m\(^3\)
- \(B\) Width of the foundation, m
- \(L\) Length of the foundation, m
- \(B_0\) Reference width, m
- \(D\) Founding depth, m
- \(S_f\) Final settlement, m
- \(S_c\) Spherical settlement, m
- \(S_d\) Deviatoric settlement, m
- \(e\) Wall thickness, m
- \(\lambda_c\) Shape factor -
- \(\lambda_d\) Shape factor -
- \(\alpha\) Rheological factor -
- \(K_0\) Earth pressure coefficient -
- \(K\) The reaction modulus t/m\(^3\)
- \(q\) Truck traffic overloads daN/m\(^2\)
- \(\Delta T\) The thermal gradient \(\circ\)C
- \(T_c\) Outside temperature \(\circ\)C
- \(T_i\) Liquid Temperature \(\circ\)C
- \(\lambda\) Thermal conductivity W/m\(^2\)C
- \(h_c\) Heat transfer coefficient outside the wall m\(^2\)C/W
- \(h_i\) Heat transfer coefficient inside the wall m\(^2\)C/W
- \(C_{tu}\) Heat transmission coefficient w/m\(^2\)C
- \(\alpha\) Coefficient of thermal expansion of concrete -
- \(E\) Elasticity modulus of concrete N/m\(^2\)
- \(I\) Moment of inertia m\(^4\)

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REFERENCES


International, West Conshohocken, United States.