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Deformation Analysis of Gasoline Storage Tanks

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Abstract: This paper aims to study the deformations of the five tanks implanted in a Terminal located in the region of Pará, Brazil. Initially, the results of eight standard penetration tests (SPT), carried out around the construction area of the tanks, were analyzed to define a representative geological-geotechnical profile and estimate of geotechnical parameters of the local subsoil. The vertical deformations imposed by the construction of the tanks were predicted numerically from the PLAXIS 2D computational program, which performs stress-strain analysis using the finite element method. From the prediction of the settlements, it was possible to estimate the maximum settlements and the angular distortions for the foundations of the tanks, comparing with the admissible values.

Key words: Numerical analysis, storage tanks, settlements and distortions.

1. Introduction

Storage tanks are heavy boiler equipment, subject to approximately atmospheric pressure and intended mainly for the storage of oil and its derivatives. The construction of a storage tank is normally regulated by the American Standard API 650 [1] "Welded Steel Tanks for Oil Storage" from the American Petroleum Institute (API). In Brazil, is also used the NBR 7821 standard [2] "Welded Tanks for Oil and Derivatives Storage (in portuguese), published by the Brazilian Association of Technical Standards (ABNT).

Settlement is the main cause of foundation deformation of liquid storage tanks. Excessive settlement can affect the structural integrity of the storage tank and lead to a significant potential risk. In order to ensure safety, during the operation of liquid storage tanks, it is necessary to carry out regular inspection and maintenance [3].

According to Reference [4], settlement is a base effect that occurs in newly built tanks or existing tanks. API 653 standard divided settlements into two types: immediate settlement and consolidation settlement. Immediate settlement usually occurs at the base of the new tank as an effect of foundation compaction during hydrostatic testing. Consolidation settlement occurs at the base of the existing tank, and is caused by differences in soil properties, which can last for years. The main types of settlements according to [1] are: (a) uniform settlement, (b) planar (differential) settlement, (c) non-planar settlement, (d) edge settlement, (e) bottom settlement near the edges, and (f) bottom settlement remote from edge, as shown in the Fig. 1.

According to Reference [5], differential settlement around the foundation ring below the side of a vertical cylindrical storage tank is a particularly severe form of settlement and can cause distortion and excessive stresses in the tank side. The main structural effect of foundation inclination is overturning, which is the effect caused by the weight of the liquid content of the tank on the side of the tank. This paper aims to numerically analyze the behavior of 5 tanks, looking for settlements and distortions associated with their execution.

2. Method and Materials

The five tanks, located in the region of Pará, Brazil, are 13.36 m in diameter and 14.40 m high, as shown in Table 1. The tanks will be built to store gasoline, which

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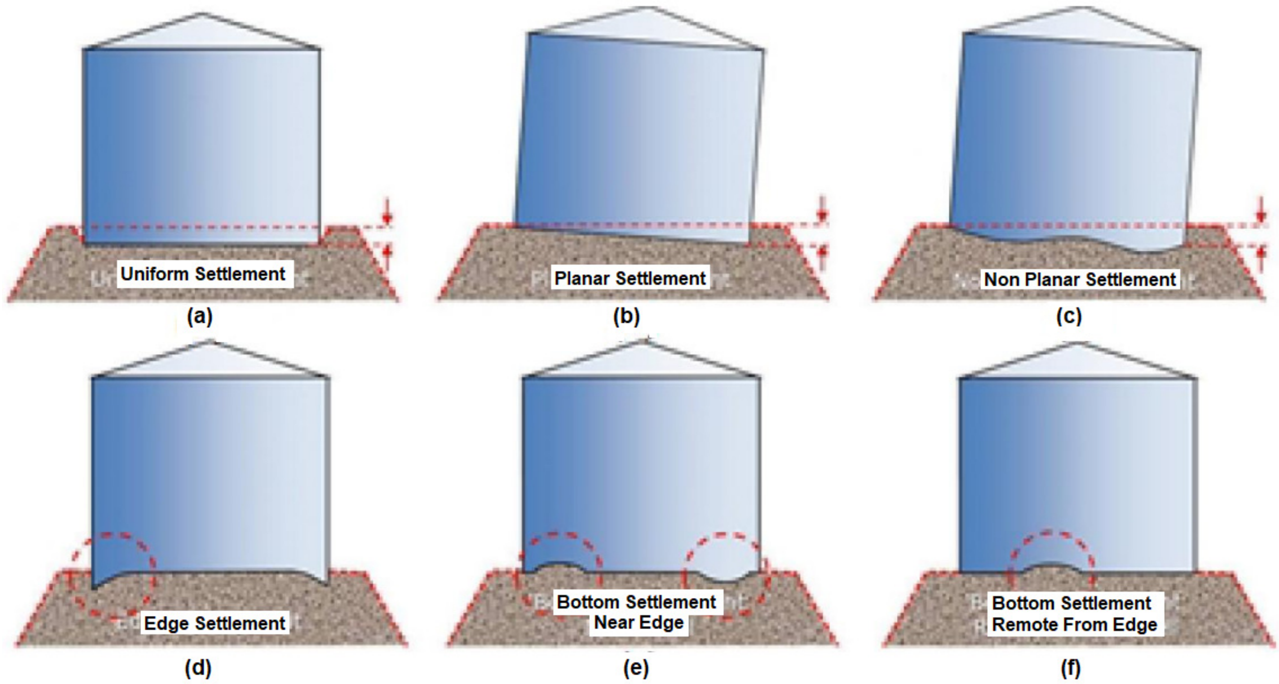


Fonte: Wisnugroho e Sutomo, 2018

Fig. 1 Settlements in cylindrical vertical tanks [1]

Table 1 General data of the tanks。

Nominal capacity (m^3)	Nominal diameter (m)	Nominal height (m)
2,019	13.36	14.40

has a specific weight of 0.75 kN/m^3. However, in the test phase, the tanks will be filled with water, whose specific weight is equal to 9.81 kN/m^3.

The layout of the tanks is shown in the Fig. 2. The distance between the TQ-01 and TQ-02, TQ-02 and TQ-03, and TQ-04 and TQ-05 tanks is 11.82 m. Between the TQ-03 and TQ-04, and TQ-02 and TQ-05 tanks it is 16.74 m. Each tank transmits an overload of around 160 kPa to the foundation soil.

Initially, the results of the 8 standard penetration tests, carried out around the tanks, were analyzed to define a representative geological-geotechnical profile of the local subsoil.

The vertical deformations (settlements) imposed by the construction of the tank were predicted numerically from the computational program PLAXIS, which performs stress-strain analyzes using the finite element method.

2.1 Geotechnical Investigations

Fig. 2 shows the location of standard penetration tests with SPT measurements.

The standard penetration test (SPT) is an in-situ dynamic penetration test designed to provide information on the geotechnical engineering properties of soil. This test is the most frequently used subsurface exploration drilling test performed worldwide. The test procedure is described in [6] and [7]. The test provides samples for identification purposes and provides a measure of penetration resistance (N_{SPT}) which can be used for geotechnical design purposes.

The SPT results basically indicate the presence of 3 distinct lithologies:

(1) Superficial layer of heavily altered phyllite, with an average thickness of 2.0 m, and an average N_{SPT} of 6 blows.

(2) Altered phyllite layer, with variable thickness between 4.0 m and 6.0 m, and average N_{SPT} of 12 blows.

(3) Lower layer of clayey silt, with N_{SPT} in the order of 30 blows. The water level was not detected.

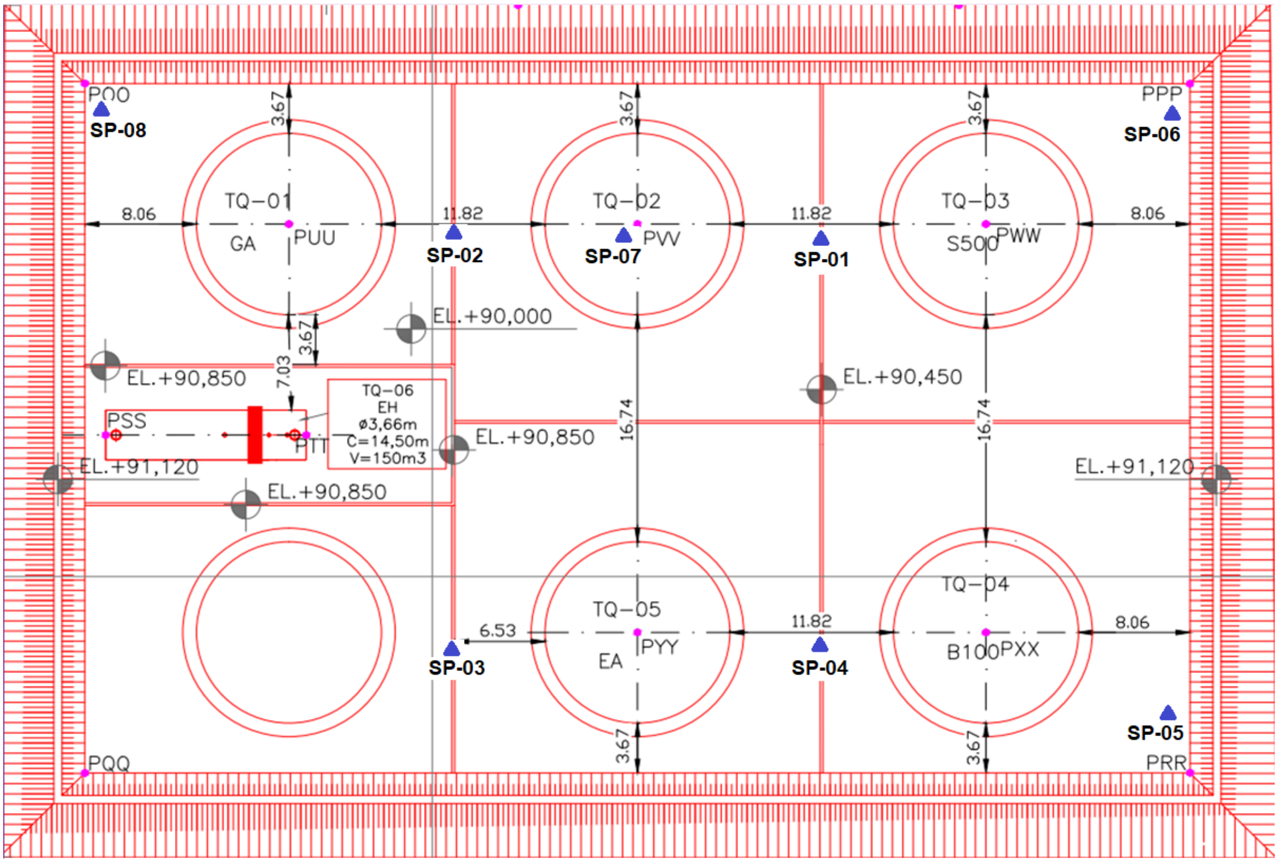


Fig. 2 Layout of tanks and standard penetration tests location

2.2 Adopted Methodology

In the absence of laboratory tests, the representative geotechnical parameters of the materials were defined from correlations with the N_{SPT} values [8]:

$$E = \alpha . q_c \tag{1}$$

$$q_c = K . N_{SPT} \tag{2}$$

Where: K and α are empirical coefficients (Table 2 and Table 3)。

Table 4 presents the geotechnical parameters adopted for the representation of materials.

Table 2 Coefficient α [8]

Soil	
Sand	3
Silt	5
Clay	7

Table 3 Coefficient K [8]

Soil	K
Sand	0,90
Silty Sand	0,70
Clay Sand	0,55
Sandy Silt	0,45
Silt	0,35
Sandy Clay	0,30
Clay Silt	0,25
Silty Clay	0,20

Table 4 Geotechnical parameters adopted in the analyzes.

Soil	γ (kN/m^3)	N_{SPT}	E (MPa)
Phyllite greatly altered	18	6	9.0
Phyllite altered	19	12	18.0
Clay Silt	20	30	40.0

Fig. 4 and Fig. 4 present the geometries adopted in the numerical analyses. It should be noted that:

Each tank transmits an overload of 160 kPa on the ground surface, represented by a distributed load with a width equal to the diameter of the tank.

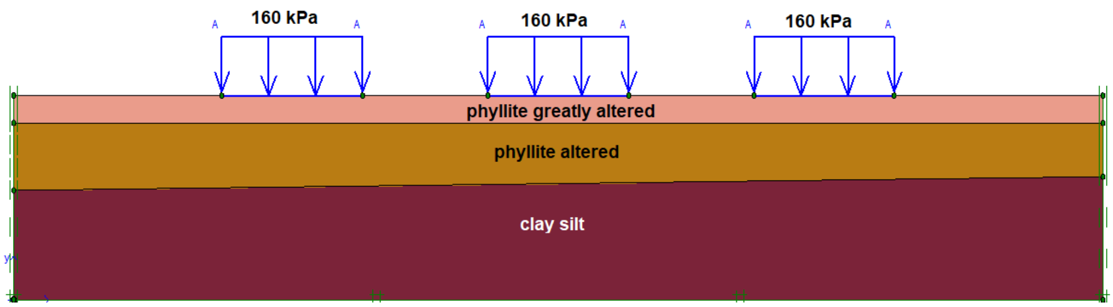


Fig. 3 Line formed by the TQ-01, TQ-02 and TQ-03 tanks.

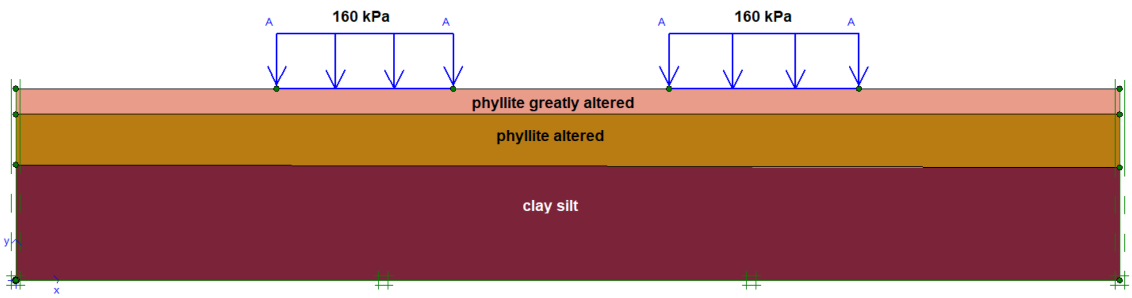


Fig. 4 Line formed by TQ-03 and TQ-04 tanks

Two lines of tanks were analyzed:

- Line formed by the TQ-01, TQ-02 and TQ-03 tanks, spaced 11.82 m (Fig. 4).
- Line formed by the TQ-04 and TQ-05 tanks, spaced 16.74 m (Fig. 4).

3. Results and Discussions

The project specifies the following limit values based on the experience of the projects and the existing standards:

- Maximum distortion: 1:240
- Maximum edge settlement: 300 mm.
- Maximum differential settlement: 175 mm.

3.1 Line formed by TQ-01, TQ-02 and TQ-03 tanks

Maximum vertical displacement = 7.1 cm

Fig. 5 presents the deformed configuration of the finite element mesh, magnified by 50 times. There is a non-uniform distribution of settlements at the base of the tanks, with maximum values of 7.1 cm on the axis of the tanks.

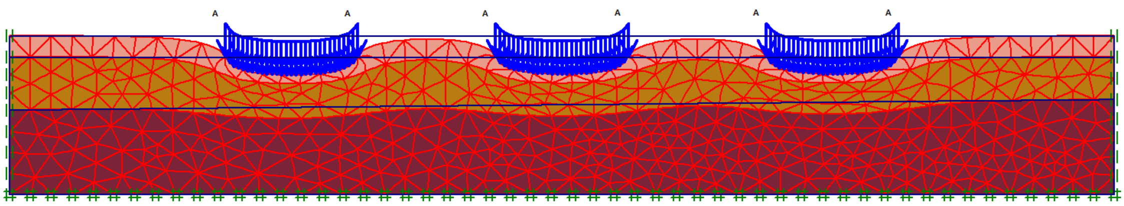
Fig. 6, shows the settlement basins under the tanks, and the

Table 5 presents the expected settlements at the different points indicated in this Figure. The predicted settlement is maximum on the tanks' symmetry axes (6.9 cm to 7.1 cm), and minimum on the edges (4.3 cm to 4.4 cm), leading to a maximum distortion of 1:250, in TQ-01 and TQ-02 tanks.

The distortion is calculated by the equation:

$$\varphi = \frac{\rho_{axis} - \rho_{edge}}{d/2} \qquad (3)$$

Where: ρ_{axis} = settlement on tank axis; ρ_{edge} = settlement on the edge of the tank and d = tank diameter.



Maximum vertical displacement = 7.1 cm

Fig. 5 Deformed configuration: tanks TQ-01, 02 e 03.

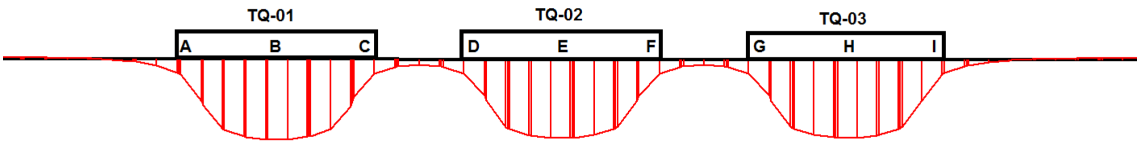
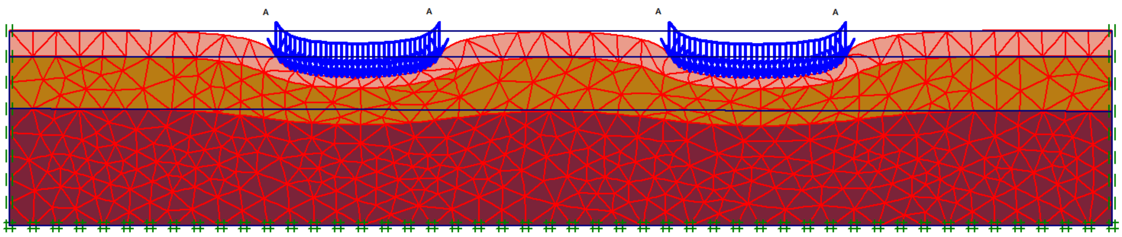


Fig. 6 Settlement Basins: tanks TQ-01, 02 e 03.

Table 5 Summary of results

Tank	Point	ρ_{axis} (cm)	ρ_{edge} (cm)	Distortion (φ)
	A	-	4,4	
TQ-01	B	7,1	-	1:250
	C	-	4,4	
	D	-	4,3	
TQ-02	E	7,0	-	1:250
	F	-	4,3	
	G	-	4,3	
TQ-03	H	6,9	-	1:260
	I	-	4,3	

Subtitle: ρ_{axis} = settlement on tank axis; ρ_{edge} = settlement on tank edge.



Maximum vertical displacement = 7.0 cm

Fig. 7 Deformed configuration: TQ-03 and TQ-04 tanks.

Based on the values estimated and in accordance with the recommendations:

- Maximum distortion: 1:250
- Maximum edge settlement: 44 mm.
- Maximum differential settlement: 27 mm.

5.2 Line formed by TQ-03 and TQ-04 tanks

Fig. 7 shows the deformed configuration of the finite element mesh, increased by 50 times, referring to the TQ-03 and TQ-04 tanks. There is a non-uniform distribution of settlements at the bottom of the tanks, with maximum values of 7.0 cm on the tank axis, and 4.4 cm on the edges, leading to a maximum distortion of 1:260, in both tanks.

Once again, distortion values and maximum acceptable displacements are observed:

- Distortion = 1:260
- Maximum estimated edge settlement: 44 mm.
- Maximum differential settlement: 26 mm.

6. Conclusions

The present paper presented the numerical analysis of the deformations resulting from the execution of 5 gasoline storage tanks.

The analyzes were performed with the Plaxis finite element program and evaluated the differential settlements and distortions were within the limits established by the standard.

The results indicated distortions of the order of 1:250, below the admissible, not compromising the structure of the tank.

In tank designs, numerical analyses appear as an important tool for assessing the integrity of the structure.

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