SETTLEMENT ANALYSIS OF CRANES USED IN A THERMOELECTRIC POWER PLANT CONSTRUCTION IN AMAZONAS

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Abstract. *With the evolution of civil construction industry, it is increasingly common the use of cranes in works of different sizes, accelerating processes and accomplishing work's financial- physical schedule, each day leaner. Nevertheless, with crane's use, it is possible to verify the occurrence of accidents due to tilting of them, often generating tragedies. There are several reasons to cranes' tilting. In the studied case will be evaluated one of them: differential settlement between crane pads, which can be responsible to contribute to the occurrence of angular distortion above the desirable and allowed for proper use of the equipment. The studied case is the Thermoelectric Plant Mauá 3, in Amazonas, Brazil. Prediction results will be presented for absolute settlement of two crane pads used during the construction of the Plant. Absolute settlement were estimated based on analytical methods of Barata (1984) and Schmertmann et al. (1978) and were compared to the results obtained by numerical method, using Plaxis 2D. Based on these results, were also verified the angular distortions obtained according to different criteria. It was verified whether the cranes met the required specification, determining if the crane's use is safe in the place intended for installation.*

Keywords: *Settlement, Barata Method, Schmertmann Method, cranes.*

1. INTRODUCTION

Considering the fact that a crane tipping brings huge human and financial damages, became very important to make rigorous evaluations regarding the operational safety of the equipment. The main objective of this article is to verify if it is possible to guarantee safety during the use of two cranes (Terex-AC 350 and Terex AC-500) in the construction of UTE Mauá 3 in Manaus, through settlement analysis of crane's pads, evaluating if will be necessary some kind of soil improvement.

Pads of both cranes have a 2,5m x 2,5m plant dimension and are seated in clayey sand soil. Settlements will be estimated based on two analytical methods: Barata Method (1984) and Schmertmann et al. (1978) and by numerical method that is based on the Finite Element Method using the software Plaxis 2D. In each one of these methods, is going to be considered the loads applied in each pads, as well as the distance between them.

Cranes' manufacturer provides for angular distortion (θ) a limit based on the differential settlements between pads of each crane and, because no instrumentation data was provided, manufacturer restriction was used to evaluate their performance in settlement terms. From the analysis made in this article was verified that in general, the greater the load applied, greatter is the settlement verified. Besides that, the greater the distance between pads, lower is θ's value found.

2. EQUIPAMENTS

Several cranes were used in the construction of the Plant. In this study, the Terex AC-350 and Terex AC-500 cranes will be evaluated. Each crane was seated on four metal pads with dimension B (width) = 2,5 m and L (length) = 2,5 m, positioned at the natural ground level. In Figure 1 it is possible to observe these cranes in question, seen in plan, with the respective distances between pads, as well as the load applied in each of them.

The Terex AC-350 crane is a 12-wheel crane that has a maximum lifting capacity of 350 tons when the boom is three meters from the center of mass of the equipment. It is possible to achieve up to 64 meters of boom, reducing its load capacity to 5,8 tons. The Terex AC-500 is a 16-wheeled crane, with a maximum lifting capacity of 500 tons when the boom is three meters from the center of mass of the equipment. It is possible to achieve up to 56 meters of boom, reducing its load capacity to 18,6 tons.

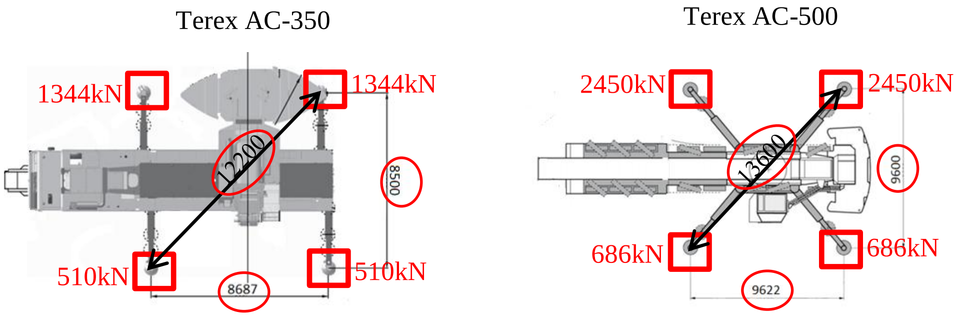

Figure 1. Pad's details and their distances between axis (mm)

3. IN SITU TESTS

Some boreholes positions associated with the Standard Penetration Test (SPT) performed near the location where the cranes were placed are shown in Figure 2, as well as their operating position.

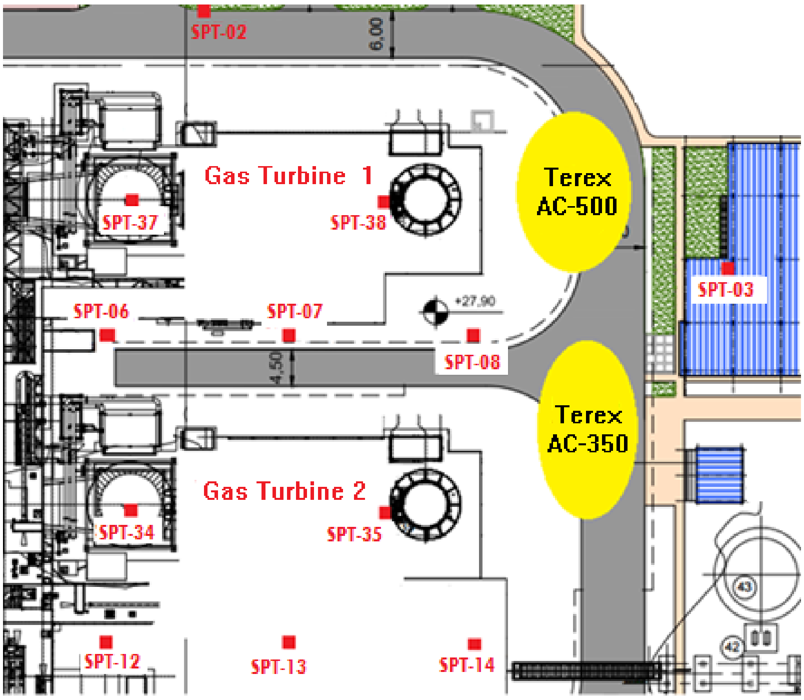

Figure 2. Boreholes positions seen in plan

The most representative boreholes for the TEREX AC-350 crane are the SPT-03, SPT-08, SPT-14 and SPT-35 boreholes. As for the TEREX AC-500 crane, the closest boreholes are SPT-03, SPT-08 and SPT-38. In the present study, the SPT-08 and SPT-3 boreholes for the AC-350 and the SPT-08 and SPT-38 boreholes for the AC-500 was used. The boreholes profiles for SPT-08, SPT-35 and SPT-38 are shown in Figure 3.

It is observed that in all boreholes considered, there is a clayey sand soil predominance and that the water level is on average 18,5 meters deep.

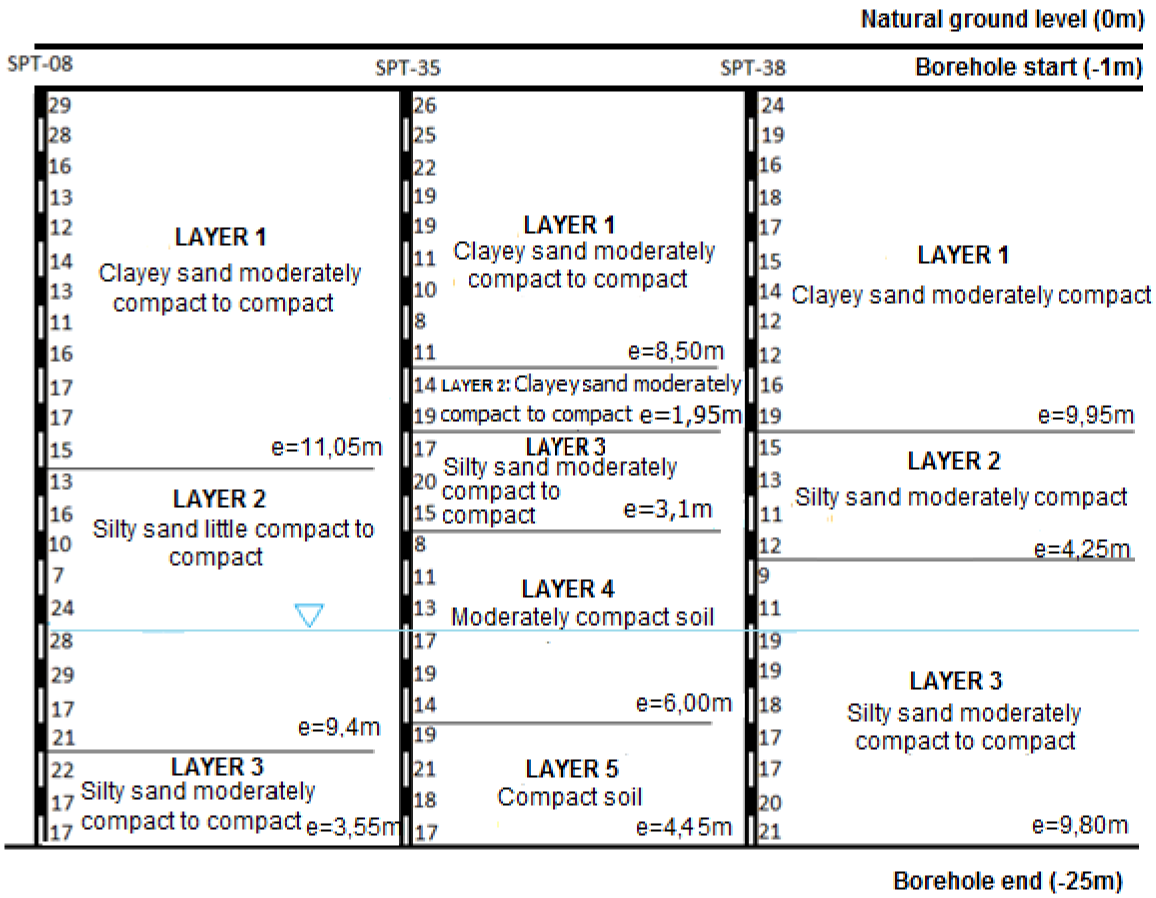

Figure 3. Boreholes profiles SPT-08, SPT-35 and SPT-38 ("e" is the layer thickness)

4. FORECAST OF ABSOLUTE SETTLEMENTS

4.1. Barata Method (1984)

According to Barata (1984 and 1986), this method is applied to settlement prediction of shallow foundations based on fast compressibility soils, such as silty sand and clayey sand in this studied case. Barata (1962, 1966 and 1967) proposed the Eq. (1).

$$r_h = \lambda . c_\Delta . \Delta p . \frac{B}{E_z} . (1 - \mu^2) \quad (1)$$

Where r_h is the foundation's estimated settlement in the seating depth h; λ is the coefficient that considers the effect of foundation's depth, called the Mindlin coefficient; c_Δ is the form factor of the foundation, which takes into account the ratio L / B (ratio of the length and the width of the foundation); Δp is the net stress uniformly distributed at the base of the analyzed foundation; B is the smallest dimension of the foundation or its diameter; And E_Z and μ are respectively the elastic modulus and the soil's Poisson coefficient.

Barata (1984) suggests the adoption of Eq. (2) for estimating the soil elastic modulus, E_Z, the main part of its method. Barata also suggests adopting in Eq. (1) the value of E_z, which is representative of the medium depth of the pressure bulb. In Eq. (2), q_c is the cone resistance measured and the parameter a, named by Barata as Buisman coefficient, depends on the type of soil, and K is the factor which correlates SPT data and cone resistance, as suggested by Danziger (1982), according Eq. (3).

$$E_z = a \times q_c \tag{2}$$

$$q_c = K.\, N_{SPT} \tag{3}$$

Two cases were considered in the settlement analysis through this method: Case A, which uses the estimated elastic modulus E_Z considering the entire depth (25 m) tested in the boreholes for each crane (SPT-8 and SPT-350 for the TEREX AC-350 crane and SPT-08 and SPT-38 for the TEREX AC-500 crane), and Case B, which use the estimated elastic modulus E_Z considering the depth most affected by the load (pressure bulb range).

Values of E_Z used in the settlement estimation of pad's cranes were obtained graphically (depth profile × E_z). The values of E_Z shown in Table 1 refer to the medium depth of pressure bulb which, in this analysis, is equal to 2,5 meters, since the depth reached by the pressure bulb is given by the equation $\alpha.B$, where α is the relationship between the length and width of the foundation (L / B), in this case equal to 1, therefore $\alpha = 2$ and finally $\alpha.B = 2.2{,}5 = 5$ m.

The net stress uniformly distributed in the base of the foundation (Δp) used to settlements estimation was based on the loads applied in each pad. For the AC-350 crane, Δp was equal to 81,6 and 21,5kN / m², for the loads of 510 and 1344kN, respectively. For the AC-500, Δp was equal to 109,8 and 392kN / m² for loads of 686 and 2450kN, respectively.

In addition to the data shown in Table 1, the following boundary conditions were considered in the settlement calculation (i) soil predominantly clayey sand, $a = 1{,}2$ and $k = 5{,}3$ kgf / cm²; (ii) Pads (B= 2,5m and L = 2,5m, where $c_\Delta = 0{,}82$) were seated at the ground level, so there is no inlay, taking to $\lambda = 1$; (iii) pressure transmitted by the pads base was estimated based on information provided by the equipment manufacturer. Using Eq. (1) the settlements shown in Table 2 were obtained.

Table 1. E_z values used to settlement prediction

Borehole	SPT-08				SPT-35			
Terex AC-350 Crane	Terex AC-350				Terex AC-350			
	Case A		Case B		Case A		Case B	
Applied load in each pad (kN)	1344kN	510kN	1344kN	510kN	1344kN	510kN	1344kN	510kN
Ez(kN/m²)=	13000	13456	13000	13456	12900	14655	12900	14655
Borehole	**SPT-08**				**SPT-38**			
Terex AC-500 Crane	**Terex AC-500**				**Terex AC-500**			
	Case A		**Case B**		**Case A**		**Case B**	
Applied load in each pad (kN)	2450kN	686kN	2450kN	686kN	2450kN	686kN	2450kN	686kN
Ez(kN/m²)=	13000	13456	13000	13456	12100	11100	12100	11100

Table 2. Absolute settlement - Barata method (1984)

Crane	Applied Load	Settlement (mm)					
		(SPT-08)		(SPT-35)		(SPT-38)	
		Case A	Case B	Case A	Case B	Case A	Case B
AC-350	510 kN	11,7	11,3	11,8	10,4	*	*
	1344 kN	30,9	29,8	31,1	27,4	*	*
AC-500	686 kN	15,8	15,2	*	*	16,9	18,5
	2450 kN	56,3	54,3	*	*	60,4	65,9

4.2. Schmertmann et al. Method (1978)

This method was developed to allow the settlements estimation of shallow foundations based on sandy soil. The following expression used to settlement prediction was proposed by Schmertmann (1970).

$$\rho = C_1 \times C_2 \times \Delta p \times \Sigma \frac{I_{ZP}}{E_s} . \Delta z \qquad (4)$$

In equation (4), C_1 is the form factor related to the overhead effect of the foundation, C_2 is the form factor that considers the effect of time ("creep"), I_{ZP} is the influence factor for each sublayers with thickness Δz, which should not be greater than $B/2$ (where B is the smallest dimension of the foundation); E_s is the elastic modulus of each sublayers, being for square foundations, Es = 2,5. q_c (Schmertmann et al., 1978); Δp is the net stress acting on the foundation depth.

The form factors C_1 and C_2 are given by Eq. (5) and Eq. (6).

$$C1 = 1 - 0,5\frac{\sigma'_{vb}}{\Delta p} \quad (5)$$

$$C2 = 1 + log\frac{t}{t_0} \quad (6)$$

Where $\Delta p = p - \sigma'_{vb}$ = net stress in the foundation, σ'_{vb} = effective vertical stress at the foundation base level, t = time to evaluate the settlement and t_0 = reference time, assumed to be 0,1 year. In both cases studied, C_1 and C_2 will be equal to 1, C_1 because the inlay is null, that is, there is no overhead at the pad's base level (σ'_{vb} = 0) and C_2 = 1 because the analysis is made for immediate settlement.

The influence factor for each of the thickness sublayers Δz_i is given by Eq. (7). Its value varies according to the analyzed pad, since it depends on the load applied on it, which varies according to the evaluated crane.

$$I_{z(máx)} = 0,5 + 0,1\sqrt{\left(\frac{p - \sigma'_{vb}}{\sigma'_{vp}}\right)} \quad (7)$$

The net tension uniformly distributed in the base of the foundation (Δp) used is similar to that shown in the previous item (4.1). In the case in question, the pads have L = B = 2,5 m, thus, deformations' distribution of the influence factor for axissimetric condition (L / B = 1) was considered in all analyzes. Table 3 shows the values of $I_{z(máx)}$ considered for each crane, borehole and load acting on the considered pad.

Table 3. $I_{z(máx)}$ values used to settlements analyzes

Analyzed borehole	**SPT-08**		**SPT-35**	
Terex AC-350 Crane				
Applied load in pad	1344kN	510kN	1344kN	510kN
$I_{z(máx)} =$	0,81	0,69	0,81	0,69
Analyzed borehole	**SPT-08**		**SPT-38**	
Terex AC-500 Crane				
Applied load in pad	2450kN	686kN	2450kN	686kN
$I_{z(máx)} =$	0,92	0,72	0,92	0,72

The equation Es = 2.5. q_c (Schmertmann et al., 1978) was used, once that, for the described cranes, the pads are square, as mentioned above. The correlation predicted by Danziger (1982) in Eq. (3) was used to obtain q_c of each sublayers with thickness equal to Δz_i. Thus, it was possible to obtain settlements values, as shown in Table 4.

Table 4. Settlements obtained through Schmertmann et al Method (1978)

Crane	Analyzed load	SPT-08	SPT-35	SPT-38
AC-350	510 kN	4,4 mm	4,7 mm	*
	1344 kN	13,7 mm	14,3 mm	*
AC-500	686 kN	9,3 mm	*	11,2 mm
	2450 kN	37,8 mm	*	24,4 mm

* Settlement value do not apply to evaluated case.

4.3. Plaxis 2D

The Finite Element Method (FEM) is one of the most used numerical tools in current project practice because of its ability to simulate various boundary conditions, incorporating different constructive steps and many constitutive models. In this item, settlements caused by crane's operational loads will be evaluated using the FEM through two-dimensional analysis in the software Plaxis 2D, described by Brinkgreve (2002) as a specific finite element program for analysis of deformations and stability of Geotechnical works.

For analysis in Plaxis 2D some soil parameters must be estimated according to the experience and knowledge of the engineer, because sometime it is not possible to have laboratory tests.

In order to compare the blow counts, N_{SPT} in different countries, it was necessary to standardize the obtained results in SPT test. Researches developed by Palacios (1977) and Schmertmann and Palacios (1979) showed that the blow counts in the test, N_{SPT}, is inversely proportional to the energy reaching the top of the rod composition, at least for N until 50. ISSMFE (1989) established 60% of theoretical potential energy (E^* = 474 J) as the international reference. Then, if the SPT test is performed, the N_{SPT} value must be converted to N_{60}, using Eq. (8).

$$N_{60} = N_{SPT} \frac{E}{E_{60}} \tag{8}$$

In Eq. (8), E is the real energy applied to the sampler, corresponding to N_{SPT}, and E_{60} corresponds to 60% of theoretical potential energy. If the energy E is known, the above expression must be used. If it is not, an estimate of the value of E is necessary. Taking into account an efficiency of the Brazilian test of 72%, Decourt et al. (1989) suggested that in Brazil the Eq. (9) is suggested.

$$\frac{E}{E_{60}} = 1{,}20 \tag{9}$$

For estimation of the soil's elastic modulus, two approaches were used:

a) According to Schnaid (2000) for sandy soils, $\frac{E}{N_{60}} = 3{,}4$. Thus, $E = 3.4.N_{60}$ (MPa). Correlating this expression in Eq. (8) and (9), it is obtained Eq. (10).

$$E = 3{,}4.\ (1{,}2.\ N_{SPT}).\ 10^3 = 4080.\ N_{SPT}\ (em\ kPa) \tag{10}$$

b) According to Freitas, Pacheco and Danziger (2012), it is possible to estimate the elastic modulus of sedimentary sands according to the following expression $E = 8000.\ N_{60}^{0,8}$. Substituting this equation in Eq. (8) and (9), it is obtained Eq. (11).

$$E = 8000.\ (1{,}2.\ N_{SPT})^{0,8} \approx 9256.N_{SPT}^{0,8}\ (em\ kPa) \tag{11}$$

In order to get correct information from the software, it is necessary to feed it with a few more parameters besides elastic modulus. It was used Poisson Coefficient (ν) equal to 0,3 because considering soils with fast compressibility, it is acceptable to use such value in most cases. This study fits the description, since it is a predominantly sandy soil.

In numerical analysis (Plaxis 2D), was considered as soil's specific weight γ_{sat}= 18 kN/m³, taking into account the type of soil found in the available boreholes (in all, clayey sand soil), as well as the lack of the water level at the most relevant depth to settlement analysis (depth of the pressure bulb).

The support pads as already mentioned in item 2 have dimensions of 2,5 m x 2,5 m and thickness of 0,050 m. They were modeled using plate element available in Plaxis 2D (plate). The following plate data must also be provided to the program: (i) Axial stiffness module - *EA* (kN/m); (ii) Flexural rigidity modulus *EI* (kN.m² / m) and (iii) Poisson coefficient (ν). Being E the elastic modulus, *A*, the pad's area and *I* the inertia moment to flexion.

For numerical modeling presented in this article, it was adopted the consideration of plane deformation state. This condition is widely used in analysis of geotechnical works (dams, tunnels, foundations, etc.) and involves the following assumptions about geometry, loading and constitutive parameters: (i) One of the body's dimension is larger than the other two, allowing any cross section to be considered as a "symmetry section" and, consequently, exhibiting no deformations orthogonal to the plane XY shown in Fig. 4a; (ii) The elastic parameters do not vary along the largest dimension of the body and (iii) The loading does not vary along the largest dimension of the body and does not exhibit component in that direction.

The pads dimension in z-axis is 2,5 meters (Fig. 4a). As the plane strain condition considers the pad dimension in z-axis much bigger than the others, the following artifice was used to consider the real pad dimension: The value of *EA* and *EI* was divided by the pad size in the z-axis, which is equal to 2,5 meters.

The axial and flexural stiffness modulus, respectively *E.A* and *E.I*, are estimated, in the studied situation, as shown in the equations: E_{steel} = 210 GPa, B = 2,5 m and e = 0,025 m. Substituting these values into the equations, the expressions shown below will be obtained.

$$E.A = (E_{steel}\,.\,B.\,e)\,/\,2{,}5 = \frac{[210000000\times(2{,}5\times0{,}025)]}{2{,}5} = 525000\ kN/m \quad (12)$$

$$E.I = (E_{steel}\frac{B.e^3}{12})\,/\,2{,}5 = \frac{\left[210000000\times\frac{(2{,}5\times0{,}025^3)}{12}\right]}{2{,}5} = 27{,}3\ kN.m^2/m \quad (13)$$

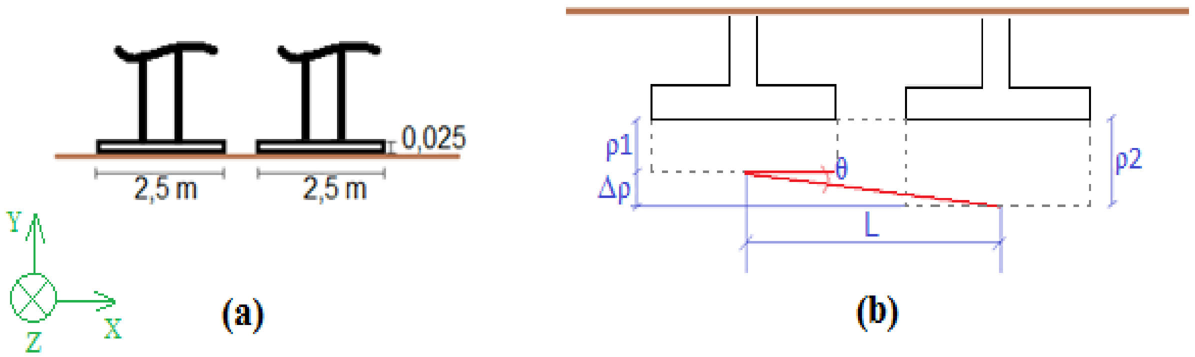

Figura 4. (a) Pads details regarding Plaxis 2D's axis. (b) Pads showing differential settlements

Obtained results. From the considerations made, in previous item, the graphic output with settlements results were obtained for each individual analyzed pad. An example of a graphical result of Plaxis 2D is shown in Fig. 5. Considering each graphical results, it was possible to obtain absolute settlements values as shown in Table 5.

Table 5. Settlements through numerical analyzes (Plaxis 2D)

Crane	Analyzed Load	Isolated pads settlements (mm) "E" through Schnaid (2000)			Isolated pads settlements (mm) "E" through Freitas, Pacheco and Danziger (2012)		
		SPT-08	SPT-35	SPT-38	SPT-08	SPT-35	SPT-38
AC-350	510 kN	7,9	8,4	*	6,2	6,5	*
	1344 kN	20,6	21,9	*	16,1	17,1	*
AC-500	686 kN	10,6	*	12,1	8,3	*	9,3
	2450 kN	37,6	*	43,3	29,3	*	33,1

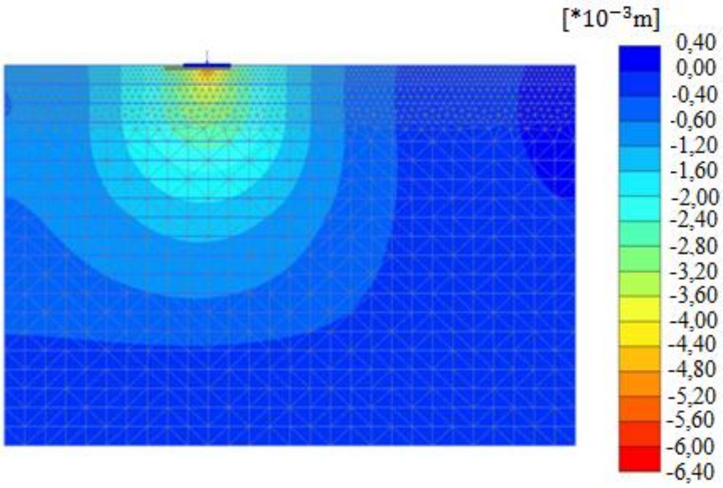

Figure 5. Output example from Plaxis 2D (colors represent settlements intensity in meters)

5. DISTORTIONAL SETTLEMENT ANALYZES

In order to have a better understanding of distortional settlement theory, it is important, first, to introduce the concept of differential settlement.

It is called differential settlement, the difference between absolute settlements of two distinct foundations or two points of the same base. In Figure 4b, the differential settlements is given by $\Delta\rho = \rho 2 - \rho 1$. By introducing the distance between foundation's axes L (Fig. 4b), it is possible to obtain the distortional settlement given by $\rho_{dist} = \Delta\rho / L$. Calculating the tangent of distortional settlement, it is possible to obtain the angle θ relative to it.

According to the cranes' manufacturer, for the equipment studied in the present work (AC-350 and AC-500), the maximum angle, which its tangent is the settlement distortion (θ), must have a maximum value equal to 0,1°, referring to a distortion settlement of 1/573, ensuring the safe use of equipment.

The analyzed cranes have distances between pads as shown in Fig. 1a and Fig. 1b. From the distances and absolute values calculated in previous item, it is possible to calculate the distortional settlement, evaluating if they are according to manufacturer's specification.

5.1. Terex AC-350 Crane

The smallest distance between pads with different loads is 8,50 meters and the longest possible distance between them is 12,2 meters, according to Fig. 1a. Thus, in this item will be made analyzes in order to verify, for each analytical method if, for these distances between pads, the distortion settlement meets the manufacturer's specification, which is a function of the angle θ, already presented above.

Distortional Settlement. Taking into account the settlements shown in Table 5, as well as the smallest and the largest distance between the pads shown in Figure 1a, the distortional settlements and angles θ shown in Table 6 were obtained, considering cases A and B, evaluated in Barata Method (1984), in the Schmertmann et al. (1978) and, through the software Plaxis 2D.

From the results shown in Table 6 considering SPT-08 borehole analysis, it is verified that the settlement method that presented lower values of θ was Schmertmann et al. (1978), with values equal to 0,06 º and 0,04 º in the cases of distance between pads of 8,5 and 12,2 meters, respectively. On the other hand, Barata method (1984), Case A, showed the highest values of θ among all the evaluated, being 0,13 and 0,09 in the cases of distance between pads of 8,5 and 12,2 meters, respectively. From the presented previously, it is possible to verify that θ's values tended to be larger how much smaller is the distance between pads, even in intermediate cases. It is also observed that, on average, in all the methods, θ's values are within the predicted limit given by the manufacturer, equal to 0,1º. With this, it can be concluded that according SPT-08 borehole, it is possible to guarantee safety during crane use in the evaluated soil.

Considering again Table 6, now evaluating the results obtained from SPT-35 borehole in the analysis of AC-350 crane, it is verified that the settlement method that presented lower values of θ was Schmertmann et al. (1978), with values equal to 0,06 º and 0,05 º in the cases of distance between pads of 8,5 and 12,2 meters, respectively. On the other hand, Barata method (1984), Case A, presented higher values of θ among all evaluated, being 0,10º and 0,09º in the cases of distance between pads of 8,5 and 12,2 meters, respectively. It is verified that the values of θ again tended to be higher when is consider a smaller distance between pads, even in intermediate cases. Note that for both distances between pads considered for the SPT-35 borehole, θ's values are within the predicted limit given by the manufacturer, equal to 0,1º. With this, it can be concluded that for this borehole, it is possible to guarantee safety during crane use in the evaluated soil.

Table 6. Settlements AC-350 - Pads distances: 8,50m and 12,20m - SPT-08 and SPT-35

Distance between pads (m)	Analyzed Borehole	Settlement type	Barata Case A		Barata Case B		Schmertmann et al.		Plaxis 2D (E por Schnaid 2000)		Plaxis 2D (E por Freitas et al 2012)	
			Q=1344kN	Q=510kN	Q=1344kN	Q=510kN	Q=1344kN	Q=510kN	Q=1344kN	Q=510kN	Q=1344kN	Q=510kN
8,5	SPT-08	Absolute (mm)	30,9	11,7	29,8	11,3	13,7	4,4	20,6	7,9	16,1	6,2
8,5	SPT-08	Differential	19,1		12,7		9,3		12,7		9,9	
8,5	SPT-08	Distorcional	0,00220		0,00146		0,00107		0,00149		0,00116	
8,5	SPT-08	θ(°)	0,13		0,08		0,06		0,09		0,07	
12,2	SPT-08	Absolute (mm)	30,9	11,7	29,8	11,3	13,7	4,4	20,6	7,9	16,1	6,2
12,2	SPT-08	Differential	19,1		18,5		9,3		12,7		9,9	
12,2	SPT-08	Distorcional	0,00157		0,00152		0,00076		0,00104		0,00081	
12,2	SPT-08	θ(°)	0,09		0,09		0,04		0,06		0,05	
8,5	SPT-35	Absolute (mm)	29,8	11,3	27,4	10,4	14,3	4,7	21,9	8,4	17,1	6,5
8,5	SPT-35	Differential	14,6		11,0		9,6		13,5		10,6	
8,5	SPT-35	Distorcional	0,00168		0,00126		0,00111		0,00159		0,00125	
8,5	SPT-35	θ(°)	0,10		0,07		0,06		0,09		0,07	
12,2	SPT-35	Absolute (mm)	29,8	11,3	27,4	10,4	14,3	4,7	21,9	8,4	17,1	6,5
12,2	SPT-35	Differential	18,5		17,0		9,6		13,5		10,6	
12,2	SPT-35	Distorcional	0,00152		0,00139		0,00079		0,00111		0,00087	
12,2	SPT-35	θ(°)	0,09		0,08		0,05		0,06		0,05	

5.2. Terex AC-500 Crane

The smallest distance between pads with different loads is 9,60 meters and the longest possible distance between them is 13,6 meters, according to Figure 1b. Thus, in this item will be made analyzes in order to verify, for each analytical method if, for these distances between pads, the distortion settlement meets the manufacturer's specification, which is a function of the angle θ, already presented above.

Distortional Settlement. Taking into account the settlements shown in Table 5, as well as the smallest and the largest distance between pads shown in Fig. 1b, the distortional settlements and angles θ shown in Table 7 were obtained, considering Barata Method (1984) (cases A and B), Schmertmann et al. (1978) and software Plaxis 2D.

From the results shown in Table 7 considering SPT-08 borehole analysis, it is verified that the settlement method that presented lower values of θ was Plaxis 2D, using elastic modulus, E, by Freitas et al. (2012) while the highest value of θ were find using Barata Method (1984) Case A. It is verified that, among all the analyzed methods, the only one who presented θ values below the limit given by the manufacturer, was the numerical method Plaxis 2D, using elastic modulus by Freitas et al. (2012). With this, it is possible conclude that considering SPT-08 borehole it is not guaranteed safety in the use of the crane in the evaluated soil. Then, some kind of soil treatment becomes needed, as soil change or reinforcement, for example.

Table 7. Settlements AC-500 - Pads distances: 9,60m and 13,60m - SPT-08 and SPT-38

Distance between pads (m)	Analyzed Borehole	Settlement type	Barata Case A		Barata Case B		Schmertmann et al.		Plaxis 2D (E por Schnaid 2000)		Plaxis 2D (E por Freitas et al 2012)	
			Q=2450kN	Q=686kN	Q=2450kN	Q=686kN	Q=2450kN	Q=686kN	Q=2450kN	Q=686kN	Q=2450kN	Q=686kN
9,6	SPT-08	Absolute (mm)	56,3	15,8	54,4	15,2	37,8	9,3	37,6	10,6	29,3	8,3
9,6	SPT-08	Differential (mm)	40,5		39,2		28,5		27,0		21,0	
9,6	SPT-08	Distorcional	0,00422		0,00408		0,00297		0,00281		0,00219	
9,6	SPT-08	θ(°)	0,24		0,23		0,17		0,16		0,13	
13,6	SPT-08	Absolute (mm)	56,3	15,8	54,4	15,2	37,8	9,3	37,6	10,6	29,3	8,3
13,6	SPT-08	Differential (mm)	40,5		39,2		28,5		27,0		21,0	
13,6	SPT-08	Distorcional	0,00298		0,00288		0,00210		0,00199		0,00154	
13,6	SPT-08	θ(°)	0,17		0,17		0,12		0,11		0,09	
9,6	SPT-38	Absolute (mm)	60,4	16,9	65,9	18,5	24,4	11,2	43,3	12,1	33,1	9,3
9,6	SPT-38	Differential (mm)	43,5		47,4		13,2		31,2		23,8	
9,6	SPT-38	Distorcional	0,00453		0,00494		0,00138		0,00325		0,00248	
9,6	SPT-38	θ(°)	0,26		0,28		0,08		0,19		0,14	
13,6	SPT-38	Absolute (mm)	60,4	16,9	65,9	18,5	24,4	11,2	43,3	12,1	33,1	9,3
13,6	SPT-38	Differential (mm)	43,5		47,4		13,2		31,2		23,8	
13,6	SPT-38	Distorcional	0,00320		0,00348		0,00097		0,00229		0,00175	
13,6	SPT-38	θ(°)	0,18		0,20		0,06		0,13		0,10	

Considering again Table 7, now evaluating the results obtained from SPT-38 borehole, it is verified that the settlement method that presented lower values of θ was Schmertmann et al. (1978), while the highest value of θ were find using Barata Method (1984) Case B. It is verified that the only method who presented θ values below the limit given by the manufacturer (θ=0,1°) was Schmmertmann et al. Method (1978). So, considering SPT-38 borehole, is neither recommended the use of AC-500 crane directly on the natural ground, been more feasible to do some kind of soil treatment (soil change or reinforcement).

6. FINAL CONSIDERATIONS

This Article approached the settlement evaluation of two cranes (Terex AC-350 and Terex AC-500) used in the construction of UTE Mauá 3, in Manaus. Therefore, were considered critical loads per pad for each crane. These analyzes were performed considering isolated pads.

Considering manufacturer’s specification it is concluded that in the AC-350 crane’s case, its safe use would be guaranteed. However, considering the settlements obtained through AC-500 crane’s specification, it is not possible to guarantee safety in its use in the soil analyzed. Even so, the soil’s substitution or soil reinforcement are actions more advisable in this case.

Interestingly, in engineering practice, crane’s settlement analysis is less spread. In general, it is used the soil’s substitution in the region affected by the pads. However, preliminary settlement analysis could show that the practice of soil substitution may, in some cases, be quite conservative, proving that settlement prediction methods become great tools to reduce costs with soil exchange, considering situations where the settlements prove to be admissible with the analyzed structure. Or, otherwise, show that the predicted improvement may not be sufficient, demanding a new procedure for soil improvement, or modification of the foundation design from shallow to deep. Therefore, it is expected that this work has contributed to show the advantages of prediction and encourage the settlement measurement of the crane's pads, allowing the evaluation of crane's performance. It also allows future studies in the same line and more assured practices in the area.

Finally, considering the high loads that pads are submitted, it would be very interesting, as a suggestion for future work, to accomplish a load capacity analysis of the soil submitted to the loads coming from the cranes, in order to analyze the safety in relation to the bearing capacity of soil foundation.

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