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DETERMINATION OF VIBRO - COMPACTION PARAMETERS BY MAKING A TEST BOARD IN A PORT SITE IN MOROCCO

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Abstract

Vibro-compaction is a recent technique for treating soils in the mass, thus improving its mediocre geo mechanical properties. In addition, this treatment makes it possible to minimize the risk of liquefaction, it is closely linked to the grain size of the soil to be treated. The soil underlying the construction project of the port of Nador in Morocco requires treatment to improve its characteristics and in particular to minimize the risk of liquefaction, given that Morocco is in a collision zone, near the border between the two African-Eurasian plates that are seismically active (earthquake in the city of Al Hoceima in 2004 in Morocco). The purpose of this work is to test the different parameters of vibro-compaction (mesh, vibration frequency, height of passes, duration of compaction) necessary to obtain the objectives set for the work (relative density ≥ 77 %), through the carrying out of an embarkation test on the substitute sands of the main breakwater of this Port. The in situ control tests (CPT) of the main dam, which were carried out by the substitution sand, made it possible to confirm the results of the test bench. These results stipulate on the one hand that the vibro-compaction mesh of 4.00 m is the most optimal and on the other hand that the relative density is an important parameter of liquefaction control.

Keywords:

Vibro compaction;
Liquefaction;
Relativedensity;
CPT;
Loosesand.

1 Introduction

Several methods allowing the reinforcement and the treatment of the grounds (vibro compaction, stone columns, gravel drains, Static Horizontal Compaction, rigid inclusion…) which allows the reduction of the risk of the potential of liquefaction and consequently the possibility of using these grounds for the development of various projects. The land planned for the construction of the main breakwater of the port of Nador in northern Morocco contains poor quality materials requiring dredging and substitution. The most suitable and effective method for the treatment of these substituted materials is vibro-compaction, which is one of the processes for improving the geo-mechanical characteristics of the soil, it belongs to the field of deep soil treatment. The choice of this technique of improvement in the mass is closely linked to the particle size of the materials to be treated, its percentage of fines must be less than 10 % (passing to 0.08 mm). It applies mainly to non-cohesive aggregates soils, such as sands and gravels. The vibrations generate a temporary phenomenon of liquefaction of the ground surrounding the vibrator. In this state, the intergranular forces are almost canceled, and the grains rearrange themselves in a denser configuration presenting better mechanical characteristics.

The purpose of this work is to describe the technique as it is carried out today and to discuss the parameters to be defined and controlled to ensure the effectiveness of this process, it is articulated around two axes:

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1) To carry out a test board at the start of work in the materials replaced after dredging with the aim of validating the meshing of the vibro-compaction points, depending on the performance to be obtained

2) Exploit the results of the work control after execution of the vibro-compaction of the materials substituted from the main dike to draw interesting conclusions and recommendations that will be beneficial for similar projects.

2 Presentation of the study site (the port of the city of Nador)

Our case study is located in the northeast of Morocco in the city of Nador. The project site has a foundation clearly overgrown with permeable sandy deposits. At this location, the seismic risk can cause the liquefaction of the sands of the structure. This is why it is important to characterize the susceptibility of the soil to liquefaction. Thus, the risk can be controlled and the foundation will be qualified.

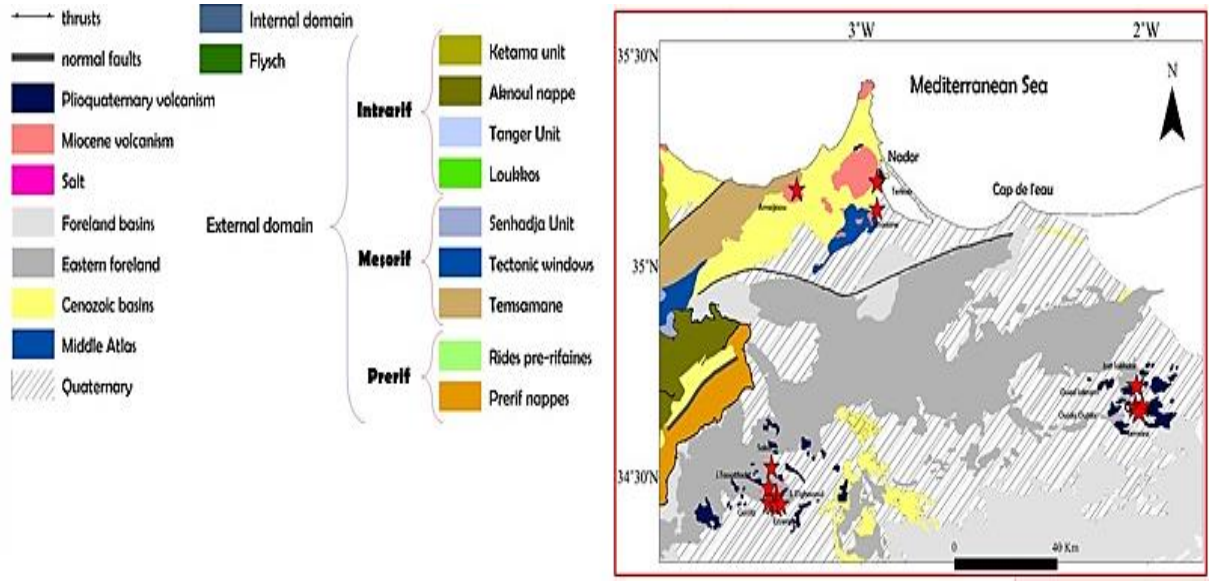


Fig. 1: Structural map of the north of Morocco.

2.1 Geological setting

The area where the project is located is part of the Eastern Rif, and presents geological formations characterized by an Upper Miocene and a Lower Pleistocene belonging to the Villafranchian. These lands consist mainly of pink silts with a gravelly bed, and a small band of a powerful Quaternary; both belonging to the Middle Quaternary. Around the site there is aset of characteristic reliefs, formed by intermediate substrates:

1) To the east, the Volcanic Massif of Gourougou, located at the eastern limit of the site. It is 25 km long along the E-W axis, and 15 km wide along the N-S axis. It culminates at 887 m. It is a complex stratovolcano formed from a variety of volcanic, basic and intermediate rocks.

2) To the north, the Cap des TroisFourches massif, resulting mainly from pyroclastite lava volcanism, and a series of metamorphic rocks. It culminates at 433 m at the top of tarjat

The study area is located for the most part outside the watershed of the Kertwadi. The flows in the commune of Iaazanene are also distributed with the basins of the Ighzer N'tiyawadi and the Ighzer Tighazinewadi which flow directly into the sea. The Bouhouawadi, for its part, joins the Kertwadi at about 2 km from the mouth. Note also the presence of other valleys or chaâbas which detach themselves from the sub-basins and flow directly towards the shore.

2.2 The seismicity of the region

The province of Nador is part of the Rif chains, this region is the seat of a very active instrumental seismic activity, which has been verified and validated by a set of studies which have highlighted the existence of numerous active structures in the within the Rif chains. The area planned for the port of Nador project and the watershed to which it belongs are located at the north-eastern

end of the high Rif ranges, at the bay of Bettoya. It is obviously in the northern zone with medium seismicity. In addition, the Nador region is part of zone No. 3 according to the RPS 2000 revised in 2011, and therefore a maximum acceleration of 0.2 g is considered

2.3 Characteristics of the materials to be treated

In general the particle size curves of the soils to be treated make it possible to locate the treatment zones. Four schematic zones are illustrated in Fig. 2. It is:

1) Zone A and B: The particle size zones of the soils in this zone are best suited for compaction by vibro compaction. The fine particle content remains below 10 %.

2) Zone C: Vibro compaction is possible, but the presence of fines reduces its effectiveness. Zone D: Vibro compaction does not apply.

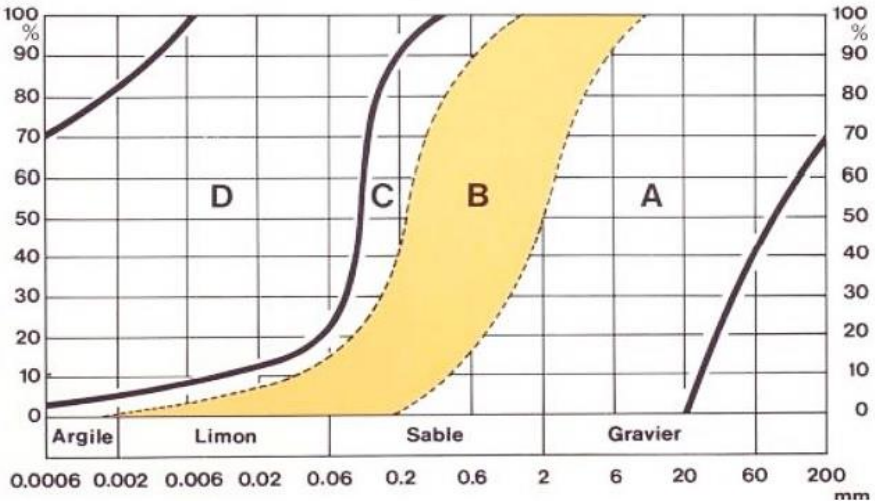


Fig. 2: Particle size zones of soils where vibro compaturation is recommended, Reiffsteck, 2008, [2].

Vibro compacted granular materials are characterized by their shear strengths (friction angle).

Table 1: Characteristics of vibro-compacted sand.

Material	Total density γ [kN/m^3]	Saturated density γ_{sat} [kN/m^3]	Friction angle ϕ' [°]
Uncompacted substitute sand	16	18	32
Substitute vibro-compacted sand	18	20	37

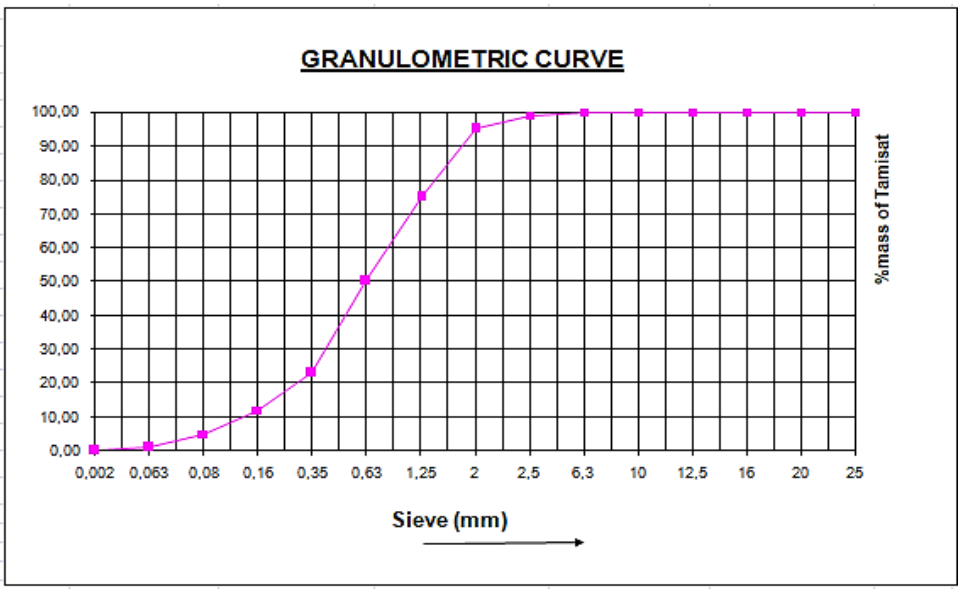


Fig. 4: The particle size curve of the treated material.

3 Methodology

3.1 Vibro-compaction validation criteria

The in situ tests which are adapted to the site conditions and which will be used to check the effectiveness of this method of treatment is the CPT. they can either be used directly to evaluate the liquefaction potential by calculating the safety factor Seed and Idriss [3], Youd and Idriss [4], Robertson and Wride [5], safety factor *S.F* > 1.5 or used in the correlation of Jamiolkowski (1985) [6], to determine the relative density. The minimum density required after vibro-compaction must be greater than 77 %, *Dr* ≥ 77 %.

3.1.1 Validation of the test board by determining the relative density

The work of Jamiolkowski (1985) made it possible to establish a generic correlation applicable to all types of sand and which is formulated in the following form

$$q_c = C_0 . P_a . e^{C_1 . D_R} . \left(\frac{\sigma'_{v0}}{P_a}\right)^{C_2} , \quad (1)$$

$$D_r = \frac{1}{C_1} . ln\left(\frac{{}^{q_c}/_{P_a}}{C_0 . \left(\left(\frac{\sigma'_{v0}}{P_a}\right) C_2\right)}\right) , \quad (2)$$

$$\sigma'_{v0} = z . (\gamma_{sat} - \gamma_w), \quad (3)$$

where y_{sat} = 21 kN/m^3, y_w = 9.81 kN/m^3, P_a = 101.325 kPa, P_a - atmospheric pressure, z – depth, q_c - measured cone resistance, D_r - relative density, σ'_{v0} - effective vertical stress, C_0 - Jamiolkowski coefficient (1985 2001), C_1 - Jamiolkowski coefficient (1985 2001), C_2 - Jamiolkowski coefficient (1985 2001).

The relationship is valid for fine sands without fines f_c = 1-3 %, purely siliceous (no carbonates) for which each of the parameters C_0, C_1 and C_2 have been rigorously determined in the laboratory (large scale compression chambers) for 206 samples in total, from 10 different origins. Average coefficients C_0, C_1 and C_2 are proposed which correlate well with all the samples. This work was supplemented by Jamiolkowski (2001), who proposes new coefficients C_0, C_1 and C_2 re-evaluated:

Table 2: Coefficients C_0, C_1, C_2determined by Jamiolkowski in 1985 and 2001 for relation (1) and (2).

Jamiolkowski	1985	2001
C_0	11.79	17.68
C_1	2.93	3.1
C_2	0.72	0.5

The 2001 coefficients are more unfavorable in that, for an equal target relative density, they require higher values of q_c than those of 1985.

This formula has been represented on a graph for the relative densities 70 % and 77 %, on this graph we can directly transfer the value of the point resistance q_c from the in situ CPT test.

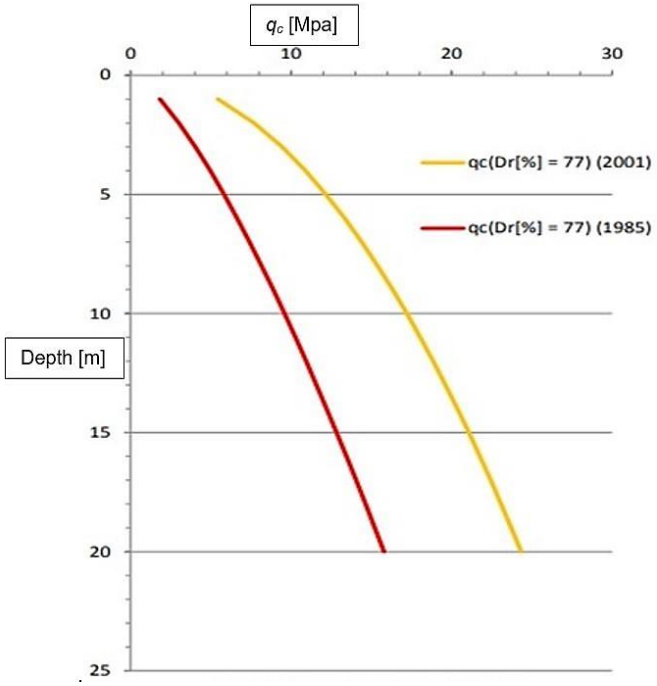


Fig. 4: Correlation curves Jamiolowski D_r = 70 % and D_r = 77 %, q_c depending on the depth.

The 2001 coefficients are more unfavorable insofar as, for an equal target relative density, they require higher values of q_c than those of 1985. As mentioned above, the proposed correlation does not take into account the presence of carbonates in the sands, which means that, at equal relative density, the measured qc is significantly lower (between 1.3 and 1.8 times). Thus, we propose to retain the target q_c values from the Jamiolkowski 2001 correlation, occasionally authorizing slightly lower values (to take into account the presence of carbonates), but without falling below the values from the Jamiolkowski correlation 1985.

The values of q_c measured must therefore be above the orange curve, tolerating a few lower values which must nevertheless be

3.1.2 Validation of the test board by determining the security factor

In the presence of groundwater, the resistance to liquefaction of the soil is evaluated by applying the NCEER method, developed by Youd and Idriss [3]. The risk of soil liquefaction is given by the safety factor *S.F*:

$$F.S = CRR/CSR, \quad (4)$$

with *CSR* - cyclic stress ratio, *CRR* - cyclic resistance ratio.

According to euro code 8 [7], and RPS 2000 version 2011 [8], liquefaction occurs if the

$$CRR/CSR < 1.25. \quad (5)$$

3.1.2.1 Cyclic stress ratio (CSR) assessment

Seed and Idriss 1971 [3] formulated the following equation for the calculation of the cyclic stress ratio *CSR*.

$$CSR = \frac{\tau_{av}}{\sigma'_{v0}} = 0.65 \left(\frac{\alpha_{\max}}{g}\right)\left(\frac{\sigma_{v0}}{\sigma'_{v0}}\right) r_d \,, \quad (6)$$

where τ_{av} is the average cyclic shear stress, α_{max} is the maximum horizontal acceleration at the ground surface, g = 9.81 m² / s is the acceleration due to gravity,$\sigma_{v0}$is the initial vertical total stress, σ'_{v0} is the initial effective vertical stress, r_d is the stress reduction factor.

The stress reduction coefficient is expressed as a function of depth by the following equations (Liao and Whitman 1986) [9]:

$r_d = 1 - 0.00765z,\ \ z \leq 9.15$ m, (7)

$r_d = 1.74 - 0.0267z,\ 9.15$ m $< z \leq 23$ m, (8)

3.1.2.2 Evaluation of cyclic resistance ratio (CRR)

The determination of cyclic soil resistance can be carried out using data obtained from in-situ tests (Standard penetration test, Cone penetration test, shear wave velocity measurement). To incorporate the effect of earthquake magnitude (duration of earthquake or number of cycles), an MSF magnitude correction factor that adjusts the CRR value to an earthquake magnitude of 7.5 will be added in the following equation which becomes as follows:

$CRR = CRR7.5 * CM,$ (9)

with *CM* correction factor, determined according to Annex B of EN 1998-5 [7], based on surface wave amplitude *M*.

Table 3: *CM* correction factor, determined according to Annex B of EN 1998-5[7].

M	*CM*
5.50	2,86
6.00	2,20
6.50	1,69
7.00	1,30
8.00	0,67

Robertson's CRR7.5 estimation (Robertson and Wride 1998) [5] seems more difficult than the other two methods. The evaluation steps are summarized in Fig. 3. This method is limited by a normalized tip strength of less than 160 and uses another criterion (liquidity limit and moisture content) to evaluate liquefaction if I_c is greater than or equal at 2.6.

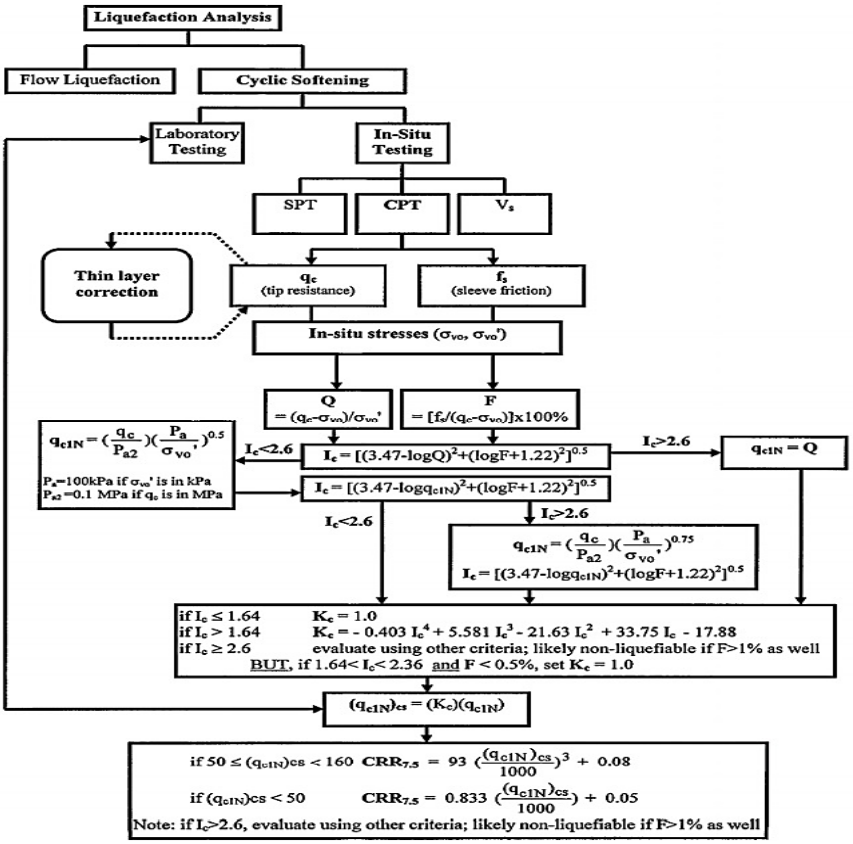


Fig. 5: Method of Robertson and Wride 1998.

3.2 Geotechnical and altimetry investigations before treatment

After dredging, a substitution was made. After bathymetry, it was observed that the roof of the substitution was located at an average elevation between -26.60 m and -28.60 m with an average of -27.60 NGM (general sea level).In order to know the initial state of compactness of the sands to be compacted, 9 tests were carried out before vibro-compaction. These 9 preliminary drillings gave quite similar results:

1) From 0.00 to 6.00 m, q_c variable from 4 to 10 MPa in general with peaks higher than 10 MPa
2) From 6.00 to 13.50 m, q_c variable from 10 to more than 20 MPa
3) The soundings were stopped between 10.00 and 14.00 m. It is noted that according to these results for most of the CPT surveys carried out before treatment, the criterion mentioned in paragraph 3.1 is not met. Average q_c values per borehole vary from 11 MPa to 16 MPa. Treatment by vibro-compaction is therefore necessary.

3.3 Realization of the test board

The vibro-compaction was carried out by vibrator type S340/30, with 2 tubes of 10 ml or 1 tube of 10 ml and 2 tubes of 5 ml each, the upper part of the vibrator consists of a tube head.

Test boards will be produced at the start of the work with the aim of validating the meshing of the vibro-compaction points, depending on the performance to be obtained. For each of the zones, the test boards will make it possible to prepare the mesh plans of the compaction points for each construction phase.

The acceptance criteria for the vibro-compaction works will be based on the relative density of 77 % to be obtained after compaction, measured under the conditions to be established during the execution studies, validated by the Project owner



Barge Kemal Kurdas *Grue Sumitomo Hitachi SCX 1500*

Fig. 6: Vibro-compaction machine.



Fig. 7: Vibrator before being submerged.



Fig. 8: Vibrator lying on barge.

Vibro-compaction was tested in the free test area to adjust different kinds of parameters before starting the test board. During vibro-compaction, the following working parameters were recorded in real time.

1) Depth [m] of the vibrator as a function of time.
2) Instant electrical consumption of the vibrator A as a function of time.

Furthermore, the compactness obtained can be appreciated through the instantaneous electrical consumption of the vibrator motor, which increases in proportion to the density of the ground treated. In this case, a compaction stopping criterion on the amperage requested by the vibrator is set.

Vibro-compaction was carried out on 106 bridges. The information relating to the vibro-compaction points carried out is summarized in Table 4.

Table 4: The vibro-compaction point information for the test board.

Mesh	Dimensions	Landing	Duration of stages	Max amperage	Parameters retained
A	3,20 m x 3,20 m	0,50 m	25 sec	280 A	25 sec / Landing or stabilization at 250 A
B	3,60 m x 3,60 m	0,50 m	55 sec	350 A	55 sec / Landing or stabilization at 250 A for 3 sec
C	3,00 m x 3,00 m	0,50 m	25 sec	280 A	25 sec / Landing or stabilization at 250 A
D	3,40 m x 3,40 m	0,50 m	30 sec	280 A	25 sec / Landing or stabilization at 250 A
E	3,80 m x 3,80 m	0,50 m	1 min 05 sec	350 A	1 min 05 sec or stabilization at 250 A for 3 sec
F	4,50 m x 4,50 m	0,50 m	1 min 15 sec	350 A	1 min 15 sec or stabilization at 250 A for 3 sec
G	3,60 m x 3,60 m	0,50 m	25 sec	350 A	25 sec / Landing or stabilization at 250 A for 3 sec
H	3,80 m x 3,80 m	0,50 m	25 sec	350 A	25 sec / Landing or stabilization at 250 A for 3 sec
J	4.00 m x 4.00 m	0,50 m	25 sec	350 A	25 sec / Landing or stabilization at 250 A for 3 sec

3.3 Geotechnical and altimetry investigations after treatment

After vibro-compaction 6 CPT tests were carried out by mesh after 7 days, 14 days and 21 days. The curves of values measured as a function of depth are almost always above the Jamiolkowski 2001 criteria. The average score of the test board points after vibro-compaction is -28.14 mZH, to be compared to the initial level at -27.60 mZH. This therefore corresponds to an induced settlement of 0.54 m on average over average treatment depths of 12.45 m, or 4.4 % of the treated volume. Given the relatively large initial compactness, the induced settlements are therefore satisfactory and attest to the effectiveness of vibro-compaction.

4 Analyse and discussions

We calculated the global average of the q_c for each mesh, the result is presented in Table 5.

Table 5: The averages at 7, 14 and 21 days of the surveys carried out.

Mesh		CPT1, 7J	CPT2, 7J	CPT1, 14J	CPT2, 14J	CPT1, 21J	CPT2, 21J
A3,20	Depth [m]	12,02	8,65	9,48	7,67	2,79	7,4
	average q_c [MPa]	25,78	18,41	26,32	24,76	28,37	14,66
B3,6	Depth [m]	5,89	7,21	3,51	1,84	7,75	6,66
	average q_c [MPa]	32,47	42,6	28,55	22,75	36,19	42,04
C3,00	Depth [m]	4,11	8,42	3,47	8,33	7,12	7,61
	average q_c [MPa]	8,15	19,61	13,21	24,6	25,66	31,31
D3,40	Depth [m]	7,14	9,2	6,7	6,25	7,38	8,57
	average q_c [MPa]	24,38	27,18	24,76	19,75	37,31	36,1
E3,80	Depth [m]	7,81	7,57	6,5	7,58	9,98	9,51
	average q_c [MPa]	54,54	23,54	23,3	23,77	38,36	47,51
F4,50	Depth [m]	2,77	6,4	8,26	9,3	9,12	9,31
	average q_c [MPa]	26,01	14,95	23,58	24,52	35,25	37,65
G3,60	Depth [m]	7,34	6,01	7,71	7,9	7,09	6,32
	average q_c [MPa]	20,13	21,38	40,39	41,06	29,25	18,22
H3,80	Depth [m]	8,2	7,06	9,38	8,12	10,02	7,14
	average q_c [MPa]	27,52	19,27	36,66	43,9	28,78	18,74
J4,00	Depth [m]	10,77	9,76	8,42	9,97	9,09	9,21
	average q_c [MPa]	24,41	18,33	29,04	33,92	23,11	35,84

Table 6: global average of the q_c for each mesh.

Period	The average of q_c
7 day	24.92 MPa
14 day	28.04 MPa
21 day	31.35 MPa

The overall mean of the q_c all surveys combined, is 28.10 MPa. The vibro-compaction therefore made it possible to double the average values of q_c. According to Jamiolkowski's exponential correlation, at constant depth, the average relative density has therefore increased by $\ln(2)/C_1 = 0.22$, or 22 percentage points.

Note: The averages calculated relate to the thicknesses of backfill for which the control CPTs did not reach refusal: the averages over the total thickness of the substitution are therefore much greater in reality.

By considering mesh groups, we obtain the following averages:

Table 7: q_c at 7 days, 14 days and 21 days for each mesh group.

Mesh groups	7 days	14 days	21 days
C, A, D	20,59 MPa	22,23 MPa	28,90 MPa
B, E, F	32,35 MPa	24,41 MPa	39,50 MPa
G, H, J	21,84 MPa	37,49 MPa	25,66 MPa

The various data analyzed show that:

1) The criteria are achieved very satisfactorily for all the meshes tested and the procedures applied.

2) Independently of the meshes tested, the profiles of q_c are generally no longer measurable beyond 8 m (often even well before), due to excessive compactness (refusal of the survey tool).

2) As the pore pressures generated during vibro-compaction dissipate over time, it can be seen that the average values increase significantly between the soundings carried out at 7 days and at 21 days (by approximately 25 to 30 %).

3) Meshes tested with long dwell times (B and E in particular) give better results which would be acceptable for relative densities of 85 to 90 %, but this is not the desired objective. These long bearings are not recommended for the type of vibrator used in this type of terrain, because they would be too stressed in terms of power and subject to repeated breakdowns.

5) It can be seen that the large meshes treated in strong current (G, H, and J) give equivalent or even better results than the small meshes treated in weak current (C, A and D). The average q_c can be summarized on the following graph Fig. 8 , which confirms this observation:

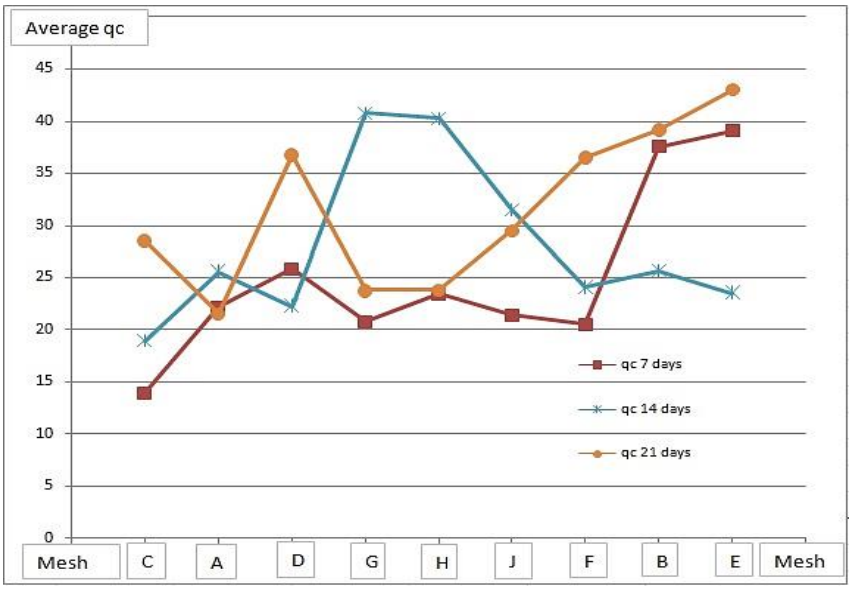


Fig. 9: Average q_c at 7 days, 14 days and 21 days for all CPT tests.

The results after 7 days on meshes G, H and J give very satisfactory results: see Fig. 9.

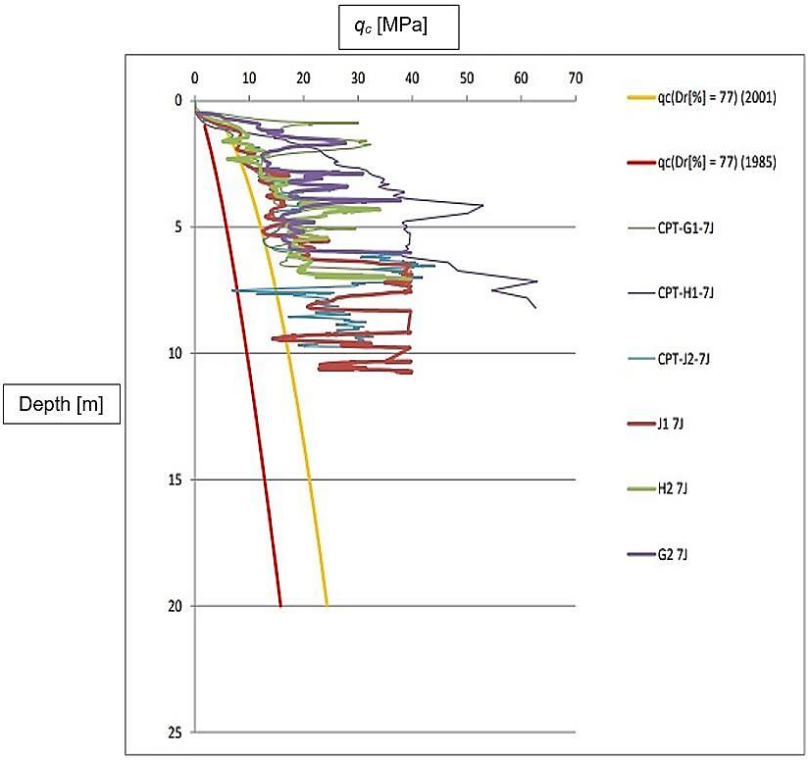


Fig. 10: Results after 7 days on meshes G, H and J.

5 Conclusion

The results of the test board led to the conclusion that the meshes (B and E in particular) tested with long bearing times (55 s to 1.00 m 15 s) can give relative densities of 85 to 90 %, whereas for the meshes tested with duration of coulter bearings (25 sec), it is noted that the large meshes treated in strong current (G, H, and J) give equivalent or even better results than the small meshes treated in weak current (C, A and D). For the conditions of this site linked to the general work schedule and the equipment used for the vibro-compaction, it is advisable to work with H (3.80) or J (4.00) mesh, given that they provide satisfactory results with sufficient margin in relation to the criteria.

Finally, the treatment of substitute materials by vibro-compaction respecting the following parameters:

1) The vibro-compaction will be carried out using the S 340/30 vibrator positioned on a 150 t or 12 t crane and installed on a KEMAL KURDAS or/and DANIS KOPER barge.

2) The retained mesh of the vibro-compaction points is 4.00 m.

3) Peak consumption: 25 seconds per step of 0.50 m or stabilization at 250 A for 3 seconds Max peak amperage 350 A.

Allows the improvement of the relative density and the elimination of the risk of liquefaction of the sand. The settlement induced after vibro-compaction is 0.54 m on average over average treatment depths of 12.45 m, or 4.4 % of the treated volume

Vibration compaction methods, their technologies, parameters and characteristics are of regional importance. The effect of the time interval between compaction and tests is important.

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