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THE EFFECT OF SOIL DENSIFICATION ON THE ATTENUATION OF THE PHENOMENON OF SOIL LIQUEFACTION IN A PORT PROJECT IN MOROCCO

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Abstract: Morocco, which is in a seismically active zone, is currently experiencing a significant development in terms of the realization of development and infrastructure projects. Therefore, reflection on soil liquefaction problems during project design is essential. The densification of soils by vibro compaction is a recent process of soil treatment, its effect is to improve the geo mechanical characteristics of the soil in this case the relative density and subsequently the reduction of the potential for liquefaction, it is a technique soil improvement in the mass, it is closely linked to the grain size of the soil to be treated, its percentage of fines less than 10% (going to 0.08 mm <10%), this technique gives the treated soil sufficient cohesion to avoid large increases in pore pressures during the earthquake. This article aims, through the study of a real case, to evaluate the effectiveness of vibro compaction to improve the relative density of the soil and consequently the reduction of the risk of liquefaction of the treated soil. The work focuses on the analysis of the SPT tests carried out before treatment and on the CPT tests of control of the vibro-compactge works carried out after execution. This study showed that this process generates an effect of improvement of the relative density and reduction of the compaction by inducing a reduction of the risk of liquefaction.

Keywords: treatment, Liquefaction, SPT, CPT, Vibro compaction, relative density

ВЛИЯНИЕ УПЛОТНЕНИЯ ПОЧВЫ НА ОСЛАБЛЕНИЕ ЯВЛЕНИЯ ЕЁ РАЗЖИЖЕНИЯ В ПОРТОВОМ ПРОЕКТЕ В МАРОККО

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Аннотация : Марокко, находящееся в сейсмически активной зоне, в настоящее время переживает значительное развитие с точки зрения реализации девелоперских и инфраструктурных проектов. Поэтому важно учитывать проблемы разжижения почвы при разработке проекта. Уплотнение грунтов путем виброуплотнения - это новейший процесс обработки грунта, его эффект заключается в улучшении геомеханических характеристик грунта, в данном случае относительной плотности и, как следствие, снижении потенциала разжижения, это метод улучшения грунта в масса, она тесно связана с размером зерен обрабатываемого грунта, его процентная доля мелких частиц менее 10% (до 0,08 мм <10%), этот метод придает обработанному грунту достаточную связность, чтобы избежать значительного увеличения пор. давления во время землетрясения. Данная статья направлена на изучение реального случая, чтобы оценить эффективность виброуплотнения для улучшения относительной плотности грунта и, следовательно, снижения риска разжижения обрабатываемого грунта. Основное внимание в работе уделяется анализу испытаний СПД, проведенных до обработки, и испытаний CPT контроля виброуплотняющих работ, проведенных после выполнения. Это исследование показало, что этот процесс дает эффект улучшения относительной плотности и уменьшения уплотнения, вызывая снижение риска разжижения.

Ключевые слова: обработка, сжижение, КПТ, СРТ, вибропрессование, относительная плотность

1. INTRODUCTION

Carrying out projects on predominantly sandy land in seismic zones requires consideration of the liquefaction phenomenon in order to avoid unforeseen damage (Seed, 1971[2]; Robertson & Wride, 1998[3]; Boulanger & Idriss , 2008 [4]). To meet this need, the evaluation of the liquefaction potential by appropriate methods therefore becomes an important step in the design of projects in order to decide on possible treatment methods, depending on the nature of the ground treated. Our studied case is the soils of Nador in the North – East of Morocco. this soil consists of sandy deposits presenting a risk of liquefaction. after having confirmed the seismic risk by the exploitation of the SPT tests carried out on the materials in place, the vibro-compaction was carried out to fight against the phenomenon of liquefaction. The vibrations generate a temporary phenomenon of liquefaction of the ground surrounding the vibrator. In this state, the inter granular forces are almost cancelled, and the grains rearrange themselves in a denser configuration presenting better mechanical characteristics. The purpose of this article 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 the liquefaction treatment process by vibro-compaction and in particular the relative density of the soil, and this through the exploitation of a companion of the CPT tests carried out after treatment of the materials.

2. PRESENTATION OF THE SITE

The site object of our study is located in the North-East of Morocco, it is the city of Nador which is known to the Mediterranean. The site is made up of permeable sandy deposits. At this location, the characterization of the soil's susceptibility to liquefaction is essential. the location of the study area is shown in figure 1.

Figure 1. Location of the study area

2.1 Geological setting

The study area 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 strip of a powerful Quaternary; both belonging to the Middle Quaternary.

Around the site There is a set of characteristic reliefs, formed by intermediate substrates : 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 887m. It is a complex stratovolcano formed from a variety of volcanic,

basic and intermediate rocks. To the north, the Cap des Trois Fourches massif, resulting mainly from pyroclastite lava volcanism, and a set of metamorphic rocks. It culminates at 433m at the top of the tarjat.

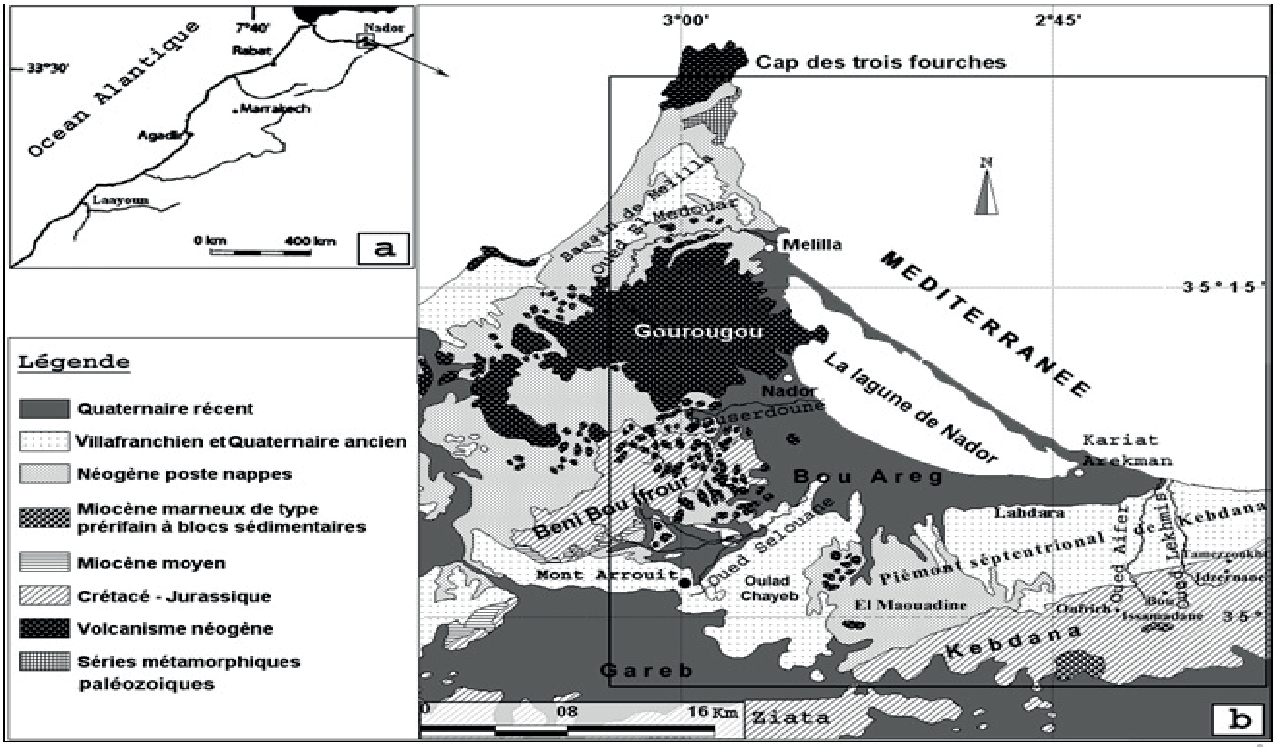

Figure 3. Extract from the geological map of the study area

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.

3. CONTEXT AND GEOTECHNICAL RECONNAISSANCE

to assess the state of compactness of the soil, an SPT test was carried out. the test result is shown in Table 1..

Table 1. SPT test result

Depth(m)	Number of shots
1.5	9
3.5	25
5.5	17
9.5	2
11.5	12
13.5	13
15.5	17
17.5	24
19.5	40
21.5	68
23.5	> 50
25.5	>50
27.5	>68
29.5	77
31.5	78
33.5	>80
35.5	>77
37.5	>83
39.5	>95
41.5	>99

The lithological section shows that the terrain of this area consists mainly of sand-based sediments up to a depth of 21.50 m. Note however the presence of a layer of alluvium between 21.50 and 22.50 m. The bedrock is made up of volcanic tuff and greyish marls up to a sounding depth of 44.30 m.

the sands encountered are loose to moderately compact, except between the depth of 19.30 m and 20.30 m where there is a dense layer of sand.

4. SOIL LIQUEFACTION RISK ASSESSMENT

In the presence of groundwater, the resistance to liquefaction of the soil is evaluated by applying the NCEER method, developed by Youd and Idriss[5], The risk of soil liquefaction is given by the safety factor F.S:

$$F.S = CRR/CSR \qquad (1)$$

With: CSR: cyclic stress ratio.

CRR: cyclic resistance ratio. According to euro code 8[6], and RPS 2000 version 2011 [7], liquefaction occurs if the CRR/CSR ratio < 1.25 (2)

4.1. Cyclic Stress Ratio (CSR) Assessment

Seed and Idriss 1971[8] formulated the following equation for the calculation of the cyclic stress ratio CSR

$$CSR = \frac{\tau_{av}}{\sigma'_{v0}} = 0.65\left(\frac{\alpha_{\max}}{g}\right)\left(\frac{\sigma_{v0}}{\sigma'_{v0}}\right)r_d \qquad (3)$$

Where τ_{av} is the average cyclic shear stress; $\alpha_{\max}$ is the maximum horizontal acceleration at the ground surface; g = 9.81 m² / s is the acceleration due to gravity; σ_{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) [8]:

$$r_d = 1 - 0.00765z \quad z \leq 9{,}15m \qquad (4)$$

$$r_d = 1.74 - 0.0267z \quad 9{,}15m < z \leq 23m \qquad (5)$$

4.2. 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:

$$CRR = CRR7.5 * CM \qquad (6)$$

With CM correction factor, determined according to Annex B of EN 1998-5[6], based on surface wave amplitude M

Table 2. CM correction factor, determined according to Annex B of EN 1998-5[6]

M	CM
5.50	2.86
6.00	1.20
6.50	1.69
7.00	1.30
8.00	0.67

4.3 Evaluation of Safety Factor

The standard penetration test is the most commonly used test. It consists of determining the number of strokes N necessary to sink a corer to a depth of 30 cm, while taking reworked samples indicative of the different layers crossed. This method uses the normalized standard penetration index N1.60cs For a magnitude of 7.5 an approximation of CRR is given by the formula established by Idriss and Boulanger (2006) [9-11]

$$CRR_{7.5} = \mathrm{EXP}\left[\frac{(N1)_{60cs}}{14.1} + \left(\frac{(N1)_{60cs}}{126}\right)^2 - \left(\frac{(N1)_{60cs}}{23.6}\right)^3 + \left(\frac{(N1)_{60cs}}{25.4}\right)^4 - 2.8\right] \quad (7)$$

$$\boldsymbol{(N1)_{60cs} = (N1)_{60} + \mathrm{EXP}\left(1.63 + \frac{9.7}{FC+0.1} - \left(\frac{15.7}{FC+0.1}\right)^2\right)} \quad (8)$$

Table 3. Safety factor for SPT-Test

Depth(m)	Nspt	CSR	CRR	FS
1.5	9	0.26	0.52	2.01
3.5	25	0.25	>4.0	>1.5
5.5	17	0.27	0.55	2.08
7.5	17	0.25	0.40	1.56
9.5	2	0.24	0.13	0.55
11.5	12	0.23	0.22	0.97
13.5	13	0.21	0.21	1.00
15.5	17	0.20	0.24	1.20
17.5	24	0.18	0.31	1.69
19.5	40	0.17	1.07	6.29
21.5	68	0.16	>4.0	>1.5
23.5	50	0.14	1.41	>1.5
25.5	50	0.13	1.73	>1.5

The safety factor calculated in table 3 leads to the conclusion that the layers between 9.00 m and 16.00 m are liquefiable.

4.4 Prediction of Seismic-Induced Settlement

Based on the curves of Ishihara and Yoshimine [12], Driss& Boulanger proposed the following empirical relationship:

$\varepsilon v=1.5e^{(-0.025Dr,ini)}$. min {8 ;ɣ max}

Dr,ini= $\sqrt{\frac{N1(60)cs}{46}}$

If Dr,ini ≥ 39.2% ⇒ Fult = 0.032+0.047. Dr,ini - 0.0006.(Dr,ini)²

iF not Fult =+0.9524

If FS < F ult ⇒ymax→ ∞ (9)

If FS >2 ⇒y max= 0

If F ult ≤ FS ≤2 ⇒ ymax= 3.5 (2- FS)($\frac{1-Fult}{FS-Fult}$)

Table 4. Safety factor for SPT-Test

Depth(m)	Nspt	$(N1)_{60cs}$	Dr,ini	SS(cm)
1.5	9	22.51	0.70	1.15
3.5	25	39.08	0.92	0.00
5.5	17	24.76	0.73	0.41
7.5	17	23.18	0.71	0.77
9.5	2	7.46	0.40	8.77
11.5	12	16.70	0.60	2.46
13.5	13	16.27	0.60	2.38
15.5	17	18.73	0.64	1.20
17.5	24	23.42	0.71	0.31
19.5	40	34.19	0.86	0

SS : Seismic-Induced Settlement

The Seismic-Induced Settlement is about 18.00 cm.

5. SOIL TREATMENT BY VIBRO-COMPACTION

According to paragraph 3, there is a risk of liquefaction between 9.00 and 16.00 m depth. The treatment against liquefaction was done by vibro-compaction in the context of the construction of the port of Nador in Morocco, in order to improve the relative density of the materials in place.

To evaluate the effect of soil densification on liquefaction, the results of CPT tests carried out after treatment are used. Given the number of tests carried out which are more than 20 CPT tests after vibro-compaction, we will simply interpret the 7 tests which are located at the points indicated in table 5:

Table 5. Checkpoints of CPT tests after vibro compaction

Point	**X**	**Y**	CPT
1	703413.10	520974.01	CPT1
2	703392.58	520996.46	CPT2
3	307390.42	520953.30	CPT3
4	703454.86	521014.34	CPT4
5	703382.57	521052.02	CPT5
6	703410.14	520933.01	CPT6
7	703398.25	521024.51	CPT7

The determination of the relative density after vibro-compaction can be done by referring to the work of Jamiolkowski (1985) which made it possible to establish a generic correlation applicable to all types of sand and which is formulated in the following form:

$$q_c = C_0 . P_a . e^{C_1 . D_R} . \left(\frac{\sigma'_{v0}}{P_a}\right)^{C_2} \qquad (10)$$

$$D_R = \frac{1}{C_1} . ln\left(\frac{q_c/P_a}{C_0 . \left(\left(\frac{\sigma'_{v0}}{P_a}\right)C_2\right)}\right) \qquad (11)$$

$$\sigma'_{v0} = z . (\gamma_{sat} - \gamma_w) \qquad (12)$$

$\gamma_{sat} = 21\ kPa$
$\gamma_w = 9.81\ kPa$
$P_a = 101.325\ kPa$
q_c : Measured cone resistance

DR = Relative density; σ'_{v0} : Effective vertical stress; C0 : Jamiolkowski coefficient (1985 2001); C1 : Jamiolkowski coefficient (1985 2001); C2 : Jamiolkowski coefficient (1985 2001). This work was supplemented by Jamiolkowski (2001), who proposes new coefficients C0, C1 and C2, re-evaluated:

Table 6. Coefficients C0, C1, C2 determined by Jamiolkowski in 1985 and 2001 for relations 10 and 11.

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 unfavourable in that, for an equal target relative density, they require higher values of qc than those of 1985.
The use of this formula makes it possible to trace the variation of relative density as a function of depth **(Fig3 to Fig9),** and this by exploiting the results of the CPT tests carried out after vibro-compaction.
The value of the relative density required after treatment depends on the requirements of each project, but in general it must be greater than 70%. for the case of treatment of the sand of the port of Nador by vibro-compacting the validation criteria are as follows:
1. The minimum geometric mean of the relative density measured between 0 and 4 meters depth of the CPT must be 70%
2. The minimum geometric mean relative density measured over the entire depth must be 77%
3. The values of the peak resistance qc measured must be evaluated in relation to the conformity curves **Fig: 10**. No section must decrease beyond these curves over more than 50 cm of continuous test depth

For this project the criteria mentioned above are respected for the 7 control tests and consequently the vibro-compaction has made it possible to improve the relative density of the soil and to reduce the risk of liquefaction.

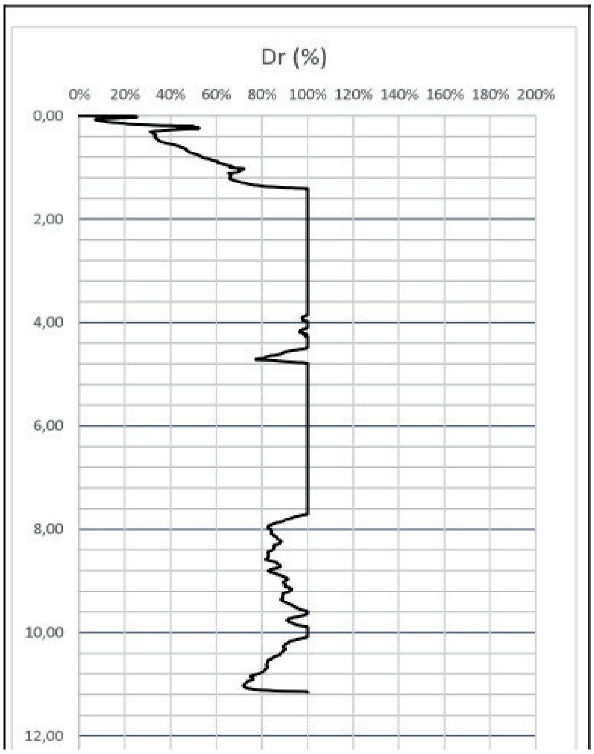

Figure 3. Relative density for CPT1 as a function of depth

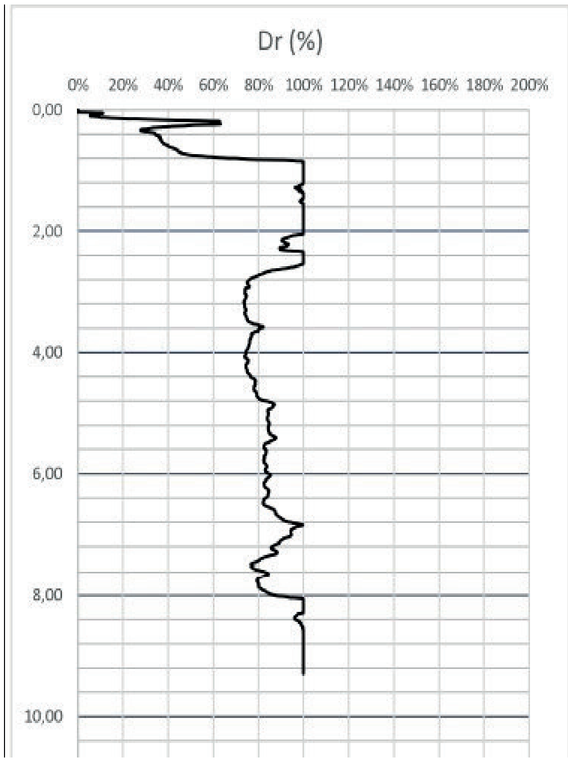

Figure 4. Relative density for CPT2 as a function of depth

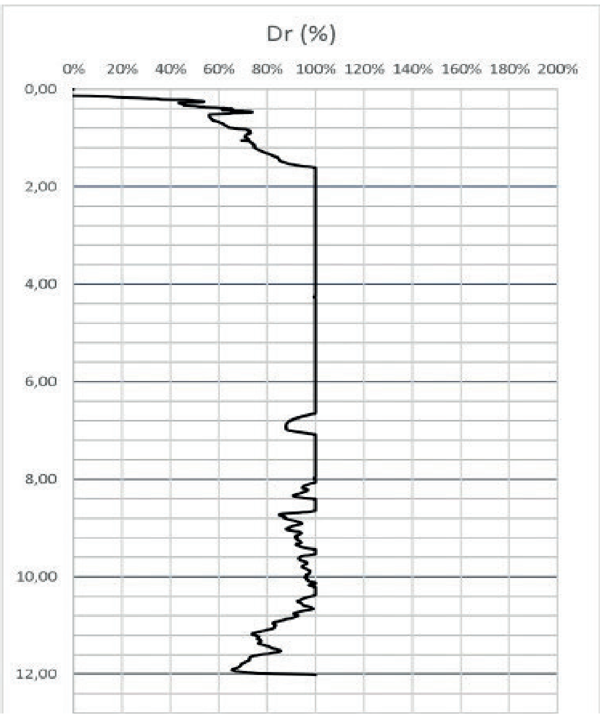

Figure 5. Relative density for CPT3 as a function of depth

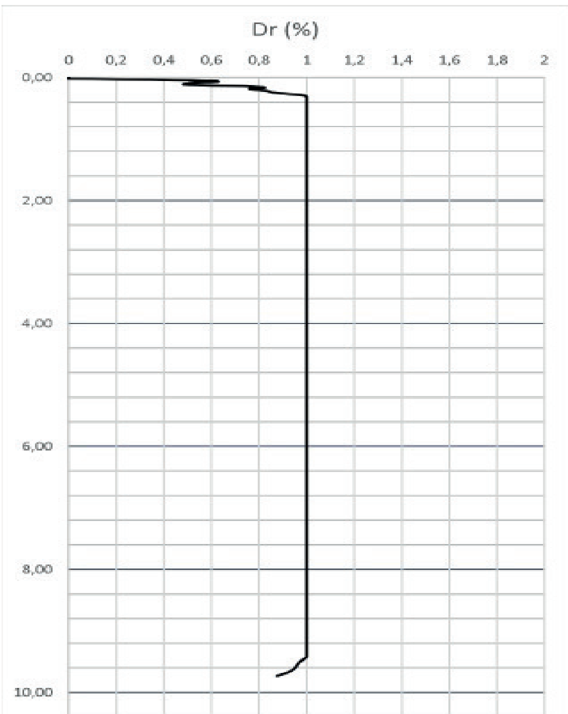

Figure 6. Relative density for CPT4 as a function of depth

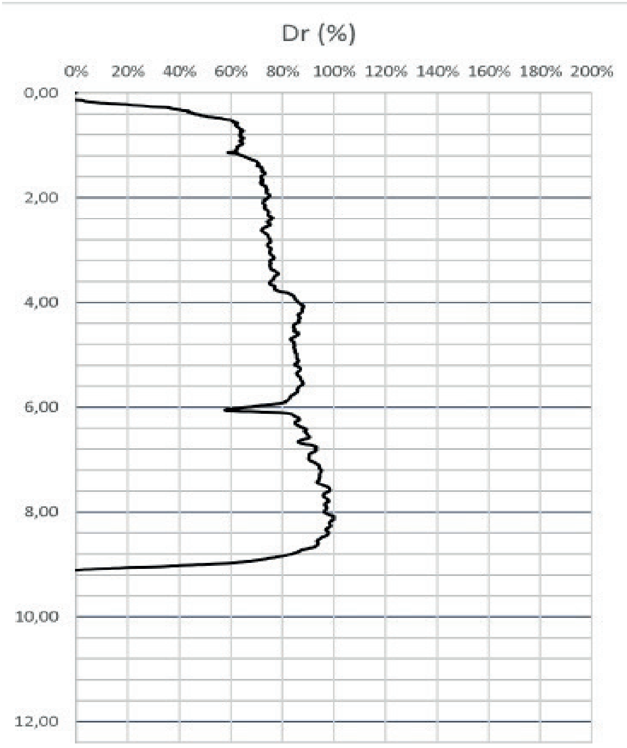

Figure 7. Relative density for CPT5 as a function of depth

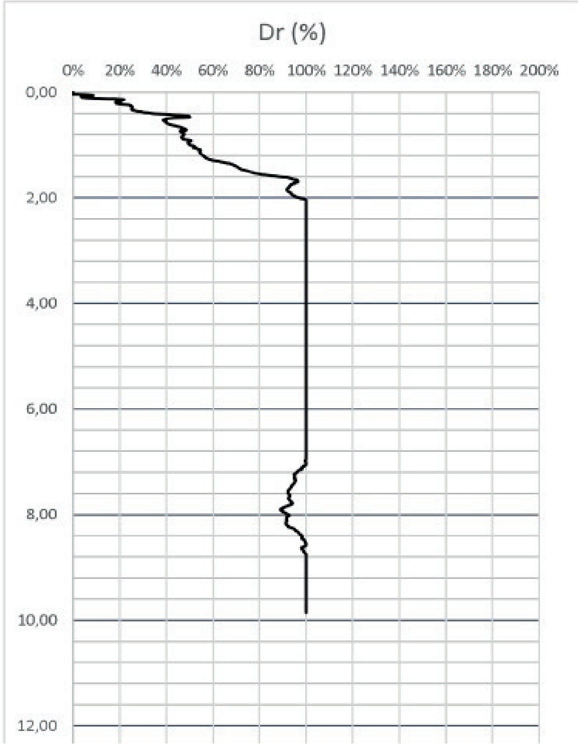

Figure 8. Relative density for CPT6 as a function of depth

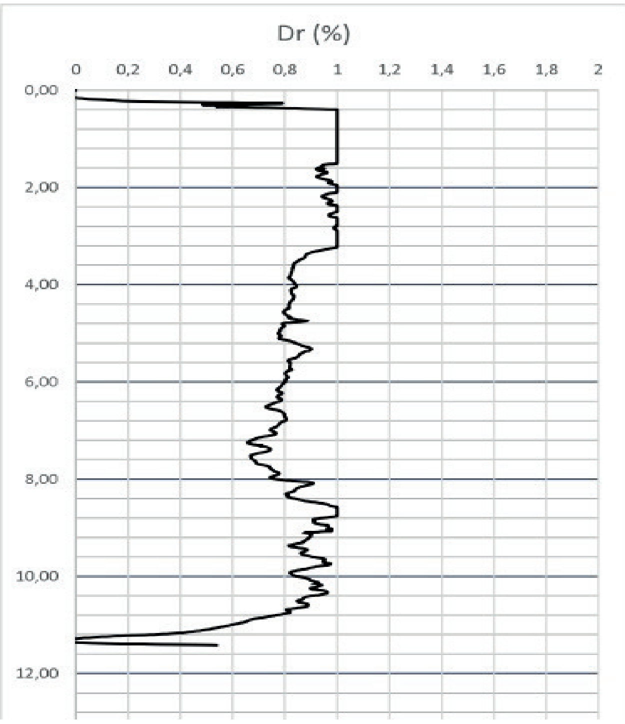

Figure 9. Relative density for CPT7 as a function of depth

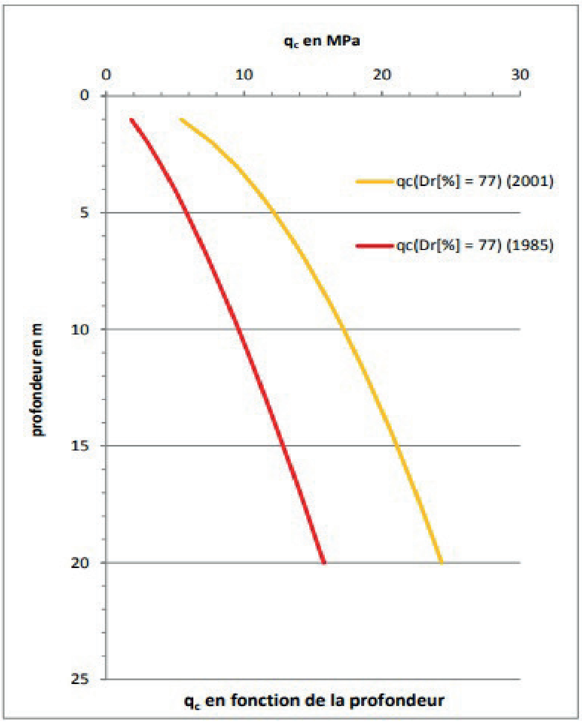

Figure 10. Correlation curves Jamiolowski Dr = 70% and Dr 77%

6. CONCLUSION

in this work we studied the soils of the port of Nador in Morocco, these soils are characterized by the existence of loose sandy deposits to moderately compact presenting a risk of liquefaction between the depths 9 m and 16 m, which was confirmed by the evaluation of the liquefaction potential and the relative density by the exploitation of the SPT tests carried out on the materials on site. the CPT tests carried out on the vibro-compacted materials have made it possible to conclude that the relative density reached after this treatment is satisfactory by inducing an improvement in the geomechanical characteristics of the treated soil and consequently the elimination of the risk of liquefaction during the earthquake

REFERENCES

1. **BZIAZ, M. - BAHI, L. - OUADIF, L. - BAHI, A - MANSOURI, H. - DOUIRI, A. - ABBACH, M**. : Evaluation of post liquefaction settlement and treatment and reinforcement of the soil by stone columns. International Journal of Innovative Research and Scientific Studies 6(1) 2023, pages: 102-114, doi: 10.53894/ijirss.v6i1.1113
2. **Seed B., Idriss I.M., 1971**. Simplified procedures for evaluating soil liquefaction potential. PROC.JSME, ASCE, Vol 97,SM9,PP 1249-1273.
3. **Robertson P.K., Wride C., 1998**. Evaluating cyclic liquefaction potential using the cone penetration test. Canadian Geotechnical Journal: 442-459.
4. **Idriss, I. M., & Boulanger, R. W. (2008).** Soil Liquefaction during Earthquakes. In Earthquake Engineering Research institute (Vol. 1). https://doi.org/10.1109/MIA.2007.322261
5. **T.L. Youd and I. M. Idriss,** "Liquefaction resistance of soils: Summary report from the 1996 NCEER and 1998 NCEER/NSF workshops on evaluation of liquefaction resistance of soils," *Journal of Geotechnical and Geoenvironmental Engineering,* vol. 127, pp. 297-313, 2001.Available at: https://doi.org/10.1061/(asce)1090-0241(2001)127:4(297).
6. **EN 1998-5, "(English): Eurocode 8**: Design of structures for earthquake resistance – Part 5: Foundations, retaining structures and geotechnical aspects [Authority: The European Union Per Regulation 305/2011, Directive 98/34/EC, Directive 2004/18/EC]. Retrieved from: https://www.phd.eng.br/wp-content/uploads/2014/11/en.1998.5.2014.pdf," 2004.
7. **RPS, "The RPS 2000 seismic building regulations**, 2011 version, department of quality and technical affairs, ministry of housing and urban policy in Morocco. Retrieved from: https://www.academia.edu/33259147," 2000.
8. **S.S.C. Liao and R.V. Whitman**, A catalog of liquefaction and Non-liquefaction occurrences during earthquakes, department of civil engineering. Cambridge, MA: Massachusetts Institute of Technology, 1986.
9. **Idriss and R. Boulanger,** "Semi-empirical procedures for evaluating liquefaction potential during earthquakes," Soil Dynamics and Earthquake Engineering, vol. 26, pp. 115-130, 2006.Available at: https://doi.org/10.1016/j.soildyn.2004.11.023.
10. **I.M. Idriss and R.W. Boulanger**, "Soil liquefaction during earthquakes," Monograph MNO-12, Earthquake

Engineering Research Institute, Oakland, CA, 2612008.

11. **I.M. Idriss and R.W. Boulanger**, SPT - based liquefaction triggering procedure, centre for geotechnical modeling, department of civil and environmental engineering. California: Universitu of California, Davis, 2010.
12. **K. Ishihara and M. Yoshimine**, "Evaluation of settlements in sand deposits following liquefaction during earthquakes," Soils and Foundations, vol. 32, pp. 173-188, 1992.Available at: https://doi.org/10.3208/sandf1972.32.173.
13. **I.M. Idriss and R.W. Boulanger**, "Semi-empirical procedures for evaluating liquefaction potential during earthquakes," presented at the 11th International Conference on Soil Dynamics and Earthquake Engineering, and 3rd International Conf. on Earthquake Geotechnical Engineering, Berkeley, USA: 32–56), 2004

СПИСОК ЛИТЕРАТУРЫ

1. **BZIAZ, M. - BAHI, L. - OUADIF, L. - BAHI, A - MANSOURI, H. - DOUIRI, A. - ABBACH, M**. : Evaluation of post liquefaction settlement and treatment and reinforcement of the soil by stone columns. International Journal of Innovative Research and Scientific Studies 6(1) 2023, pages: 102-114, doi: 10.53894/ijirss.v6i1.1113
2. **Seed B., Idriss I.M., 1971**. Simplified procedures for evaluating soil liquefaction potential. PROC.JSME, ASCE, Vol 97,SM9,PP 1249-1273.
3. **Robertson P.K., Wride C., 1998**. Evaluating cyclic liquefaction potential using the cone penetration test. Canadian Geotechnical Journal: 442-459.
4. **Idriss, I. M., & Boulanger, R. W. (2008).** Soil Liquefaction during Earthquakes. In Earthquake Engineering Research institute (Vol. 1). https://doi.org/10.1109/MIA.2007.322261
5. **T.L. Youd and I. M. Idriss,** "Liquefaction resistance of soils: Summary report from the 1996 NCEER and 1998 NCEER/NSF workshops on evaluation of liquefaction resistance of soils," *Journal of Geotechnical and Geoenvironmental Engineering,* vol. 127, pp. 297-313, 2001.Available at: https://doi.org/10.1061/(asce)1090-0241(2001)127:4(297).
6. **EN 1998-5, "(English): Eurocode 8**: Design of structures for earthquake resistance – Part 5: Foundations, retaining structures and geotechnical aspects [Authority: The European Union Per Regulation 305/2011, Directive 98/34/EC, Directive 2004/18/EC]. Retrieved from: https://www.phd.eng.br/wp-content/uploads/2014/11/en.1998.5.2014.pdf," 2004.
7. **RPS, "The RPS 2000 seismic building regulations**, 2011 version, department of quality and technical affairs, ministry of housing and urban policy in Morocco. Retrieved from: https://www.academia.edu/33259147," 2000.
8. **S.S.C. Liao and R.V. Whitman**, A catalog of liquefaction and Non-liquefaction occurrences during earthquakes, department of civil engineering. Cambridge, MA: Massachusetts Institute of Technology, 1986.

9. **Idriss and R. Boulanger,** "Semi-empirical procedures for evaluating liquefaction potential during earthquakes," Soil Dynamics and Earthquake Engineering, vol. 26, pp. 115-130, 2006. Available at: https://doi.org/10.1016/j.soildyn.2004.11.023.
10. **I.M. Idriss and R.W. Boulanger**, "Soil liquefaction during earthquakes," Monograph MNO-12, Earthquake Engineering Research Institute, Oakland, CA, 2612008.
11. **I.M. Idriss and R.W. Boulanger**, SPT - based liquefaction triggering procedure, centre for geotechnical modeling, department of civil and environmental engineering. California: Universitu of California, Davis, 2010.
12. **K. Ishihara and M. Yoshimine**, "Evaluation of settlements in sand deposits following liquefaction during earthquakes," Soils and Foundations, vol. 32, pp. 173-188, 1992.Available at: https://doi.org/10.3208/sandf1972.32.173.
13. **I.M. Idriss and R.W. Boulanger**, "Semi-empirical procedures for evaluating liquefaction potential during earthquakes," presented at the 11th International Conference on Soil Dynamics and Earthquake Engineering, and 3rd International Conf. on Earthquake Geotechnical Engineering, Berkeley, USA: 32–56), 2004