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Risk Analysis of Soil Liquefaction from the Characterization of Their Geotechnical Parameters by Statistical Approach-Case Study: Soils of the Plain of Sebou in the Region of Kenitra Morocco

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Abstract: This study aims to analyze the risk of soil liquefaction of plain Sebou in the region of Kenitra-Morocco. However, it is necessary first to characterize the geotechnical parameters of soils in question. The interest of this work is to identify, quantify and take into account the variability for a better estimate of the geotechnical risk, especially the risk of liquefaction. A study of the lithological distribution of soils is performed. Then, a statistical analysis of physical and mechanical parameters is realized in order to look for possible correlations between the main parameters. This simple descriptive analysis is followed by a multidirectional statistical study: a Principal Component Analysis (PCA) and an Ascending Hierarchical Classification (AHC). The analysis and interpretation of geotechnical parameters allowed to identify with more precision four types of compressible soils With mechanical properties ((Cc) the compression index of soil, (e0) the initial void ratio) the following: Vase and silty vase: high compressibility of the soil with a mean Cc of 0.263 and e0 of 0.773. Clay and silty-clay: high compressibility- an average compressibility of the soil with a mean Cc of 0.206/0.151 and e0 of 0.671/0.637. Clayey silt: high mean compressibility of the soil with a mean Cc of 0.152 and a mean e0 of 0.558. Silty sand and clean sands: low mean compressibility of the soil with a mean Cc of 0.13 and a mean e0 of 0.521. All soils in the plain of Sebou are below the level of the water table. The analysis of these results shows that the SPT value is always greater than 0 between 0 and 10 m for the upper layers of sand and greater than 10 between 10 m and 20 m.

Key words: Risk · Soils · Liquefaction · Geotechnical · Mechanical and physical characteristics · Multidimensional statistics

INTRODUCTION

Civil engineering projects are dedicated to the realization of efficient and economical works in a short time which requires an acceptable risk increasingly low. Geotechnical studies are highly important in such projects. Thus, a good estimate of the risk associated with geotechnical parameters has become a major issue since most of the new structures are located on sites with difficult conditions.

So as to make these structures safe, identifying the main physical and mechanical characteristics of these soil types and optimizing how to recognize each characteristic were necessary.

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It includes:

- A study of correlation between some physical and mechanical parameters;
- A data analysis (PCA) of each soil so as to determine the various parameters that explain the new factorial axes;
- The Ascending Hierarchical Classification method (AHC), helping to reveal homogeneous classes by taking into consideration the physical and mechanical parameters of the different samples;
- A statistical treatment of compressibility parameters of compressible soils such as compressibility index (Cc), swelling of the soil, void ratio (e0) and consolidation pressure.
- Once the geotechnical soil parameters have been characterized, we analyze the risk of soil liquefaction by examining SPT drilling and laboratory tests carried out in the study area.

The interest of this work is to identify, quantify and take into account the physical and mechanical characteristics of soils for a better estimate of the geotechnical risk (liquefaction, settlement, stability...), in an area with sub-arid to sub-humid climate.

Presentation of the Site of Study

The Morphological and Geological Context: The area of study is bounded by the hills of Lalla Zohra to the north, by Maamora plain to the south, by the hills of Bou Draa and Bel Ksiri to the east and by the Atlantic Ocean to the west. A large closed basin, whose center is occupied by Sebou and Beht rivers, is situated at less than 10 meters of altitude even if edges do not exceed a few hundred meters.

Towards the sea, the basin is also closed by the dune Sahel wide of 5 to 25 Km and high of about 30 to 50 meters. The numerical model of the ground, introduced by the Figure 1, shows well the dominance of low-lying lands.

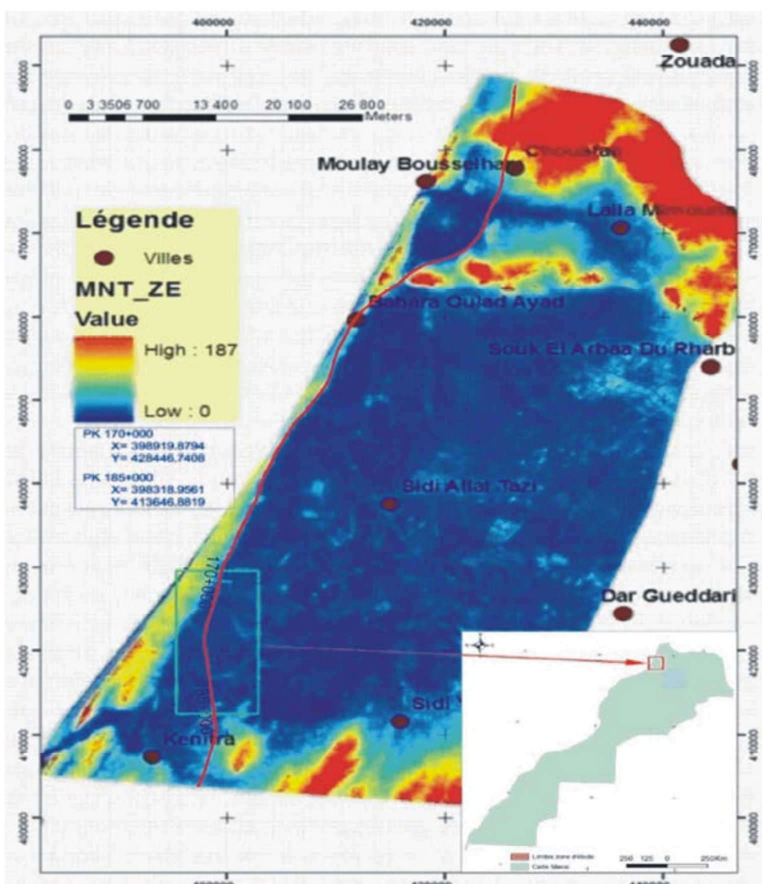

Fig. 1: Localization of the zone and digital elevation model of the zone of study

From a geomorphologic point of view, the zone of study crosses several geomorphologic sets: The sandy formations of Maamora in the bypass of the city of Kenitra, the Gharb plain with alluvial deposits of the Sebou river and the dune coastline beyond the plain of Sebou.

The geological study constitutes a primordial and an essential stage for any geotechnical synthesis. Not only it allows to define well the lithology, the structure and the geological history of the region but it also allows delimiting the geographical spread of the different lithological facies and their distribution modes.

On the whole, the Gharb basin, asymmetrical and hardly subsident since its formation in the middle of Miocene, knew in the course of its evolution several fluctuations of sea level linked to the neotectonic movements. The latter were translated in the coastal zone by faults and by a regular uprising of Meseta, resulting from an isostatic readjustment [1-8]. These variations are, in most cases, due to tectonic activity and to sedimentary provisions. The effect of the short-term sea level fluctuations is added to the long-term tectonic movements.

Problematic: The Tangier-Kenitra segment is strategic nationally. It connects the two cities of Tangier and Kenitra both experiencing a demographic and an economic increase in recent decades.

Morocco has adopted the realization of a High Speed rail Line (HSL) Tangier-Kenitra. This line is within the scope of a Moroccan project developed in 2005 by ONCF which aims to build 1500 Km high-speed rail lines in less than two decades. As it was reported earlier, the region is a part of the Gharb plain known geologically by a subsidence phenomenon in addition to the presence of surface packing soils. However, the HSL infrastructure is very sensitive to the compaction phenomenon. Thus, the main problem is to analyze the risk of soil liquefaction and seek appropriate solutions. To achieve this goal, a campaign was conducted geotechnical investigations in the region. It consists of the characterization of physical and mechanical properties of soils.

MATERIALS AND METHODS

The geological and geotechnical investigations necessary to the design of the site are conducted in two steps: The APS Phase (preliminary design) and the APD phase (before detailed design).

A total of 289 static penetrometers, 89 core holes, 11 holes with SPT tests and coring, 20 holes with Vane tests were conducted to determine these heterogeneities.

To characterize the soils of the region and for a further exploit of the database, we decided to make a multidirectional statistical treatment (PCA and HCA) and also look for correlations between the different parameters.

The campaign of reconnaissance concluded that a simplified model of five layers is appropriate: Silt and silty mud, clay and silty clay, clayey silt, silty sand, sand and sandstone.

Results and Discussion

Correlation Between Geotechnical Parameters: The method used to determine the correlation between geotechnical parameters of the soil is the principal component analysis (PCA). The principle of PCA is well described by several authors [9, 10]. This method is often used in the fields of geosciences [11-13]. It is a factorial method that allows building factors considered either as new independent variables or uncorrelated statistically which facilitate the study of links between initial variables. The main objective is to extract, in a condensed form, the largest possible information contained in the data, whether related to links between variables or between individuals (tests). Correlation matrices lead to determining the positive and negative correlations. Correlation between parameters was determined (Table 1).

According to the previous table, the parameter Wl is always positively correlated with IP while γd is negatively correlated with the two parameters Cc and e0.

Principal Component Analysis (PCA): The principal components analysis method (PCA) was conducted on 13 parameters and 181 people in total. It shows that the first three principal axes absorb 72% of the total variance. They absorb respectively 37%, 22.7% and 12.4% (Table 2).

We note that many variables are dependent, even weakly. The highly significant correlations appear for physical parameters (for example R = -0.859 between W% and γd is weakly significant when considering the mechanical parameters (eg R = 0.488 between Cc and Cs), but also between physical and mechanical parameters (eg R = 0.42 between W% and Cc) (Table 3).

Table 1: Correlation between the geotechnical parameters of the five types of soils

	Wl		γd	
Type of soil	Positive correlation	Negative correlation	Positive correlation	Negative correlation
Mud	IP		Ic	Wn, Cc, e0
Clay	IP		Ic,	Wn, Cc, e0
Sandy clay	IP, Ic, Pc		Ip, Ic, Pc	Wn, e0
Argillaceous Silt	IP, Ic	Wn		Wn, Cc, e0
Muddysand	IP, Ic			Wn, Cc, e0

With: (Wn) water content, (Ip) plasticity index, (WI) liquidity limit, (Ic) consistency index, (e0) void ratio, (γd) specific weight, (Cs) swelling index and (Pc) consolidation pressure

Table 2: analysis of the first three principal axes (ACP)

	F1	F2	F3
Eigen value	3.697	2.271	1.24
Variance percentage	36.974	22.71	12.404
cumulative percentage	36.974	59.684	72.089

Table 3: Correlation matrix for the parameters used

	X	Y	Z	Prof/TN	gh	gd	Wn	WL	IP	Cc	Cs	Pc	e0
X	1	0.501	-0.098	-0.069	-0.148	-0.151	0.106	-0.021	0.007	0.165	0.099	-0.099	0.104
Y		1	0.190	-0.187	0.062	0.113	-0.129	0.124	0.206	-0.069	-0.037	0.060	-0.115
Z			1	0.096	0.071	0.152	-0.165	0.096	0.143	-0.152	-0.122	0.203	-0.100
Prof/TN				1	-0.045	0.027	-0.056	-0.181	-0.229	0.005	-0.026	0.032	0.030
gh					1	0.760	-0.360	-0.172	-0.166	-0.572	-0.224	0.162	-0.679
gd						1	-0.870	-0.181	-0.085	-0.611	-0.252	0.312	-0.667
Wn							1	0.166	0.025	0.483	0.220	-0.310	0.484
WL								1	0.912	0.294	0.483	0.283	0.288
IP									1	0.229	0.432	0.276	0.238
Cc										1	0.521	-0.134	0.762
Cs											1	0.162	0.393
Pc												1	-0.231
e0													1

We note first that the positional parameters have a moderate impact on other parameters.

Further, physical parameters are strongly correlated. The pole% W / Ip / Wl is inversely correlated with the density and with Ic to a lesser extent. These physical parameters are not correlated with the mechanical ones as soil stress is not related to their physical and mechanical characteristics. This confirms that the phenomenon of soil consolidation is related to loading conditions specific to the site.

Projection on the Factorial Plan F1F2 (59.68%) (Figures 2-3): The projection of individuals on the first factorial plan with its first two principal components absorbs 59.68% of the total variance. Individuals are more or less grouped except some who are excluded and seem specific.

The F1 axis is positively correlated with the variables gd and gh while it is negatively correlated with the variables CC, e0 and more or less Wn.

The F2 axis is more or less correlated positively with the variables Wl and IP and it is negatively correlated with no variable.

Projection on the Factorial Plan F1F3 (45.84%) (Figures 4-5): The second factorial plan F1-F3, absorbs 45.84% of the global information. So, it is important to analyse the contribution of the third factorial axis.

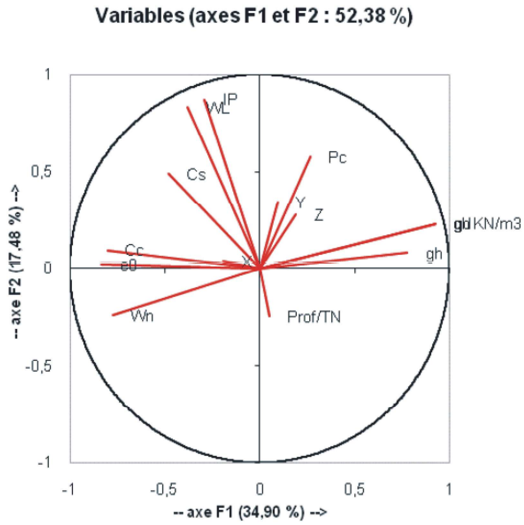

Fig. 2: Correlation circle of variables

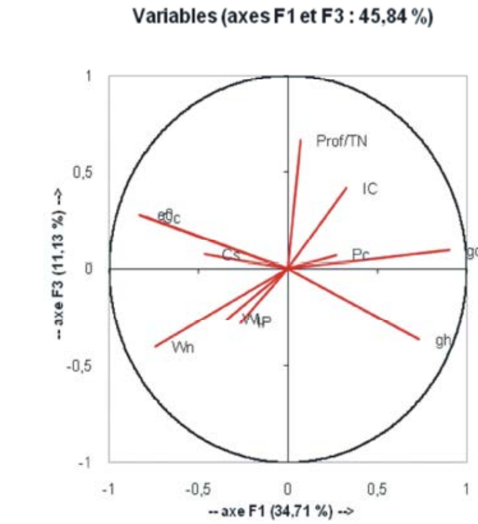

Fig. 4: Correlation circle of variables

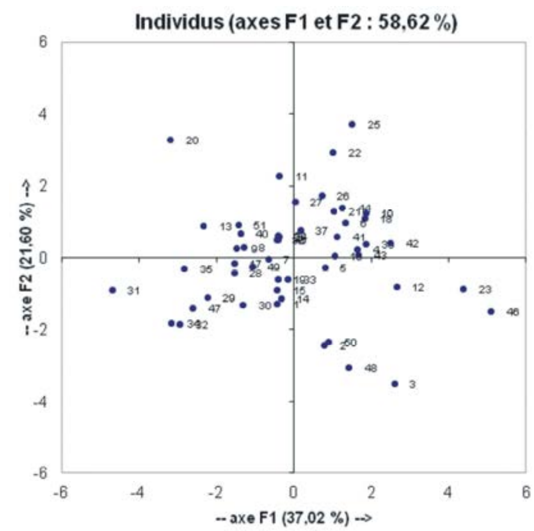

Fig. 3: First factorial plan (F1F2) of individuals

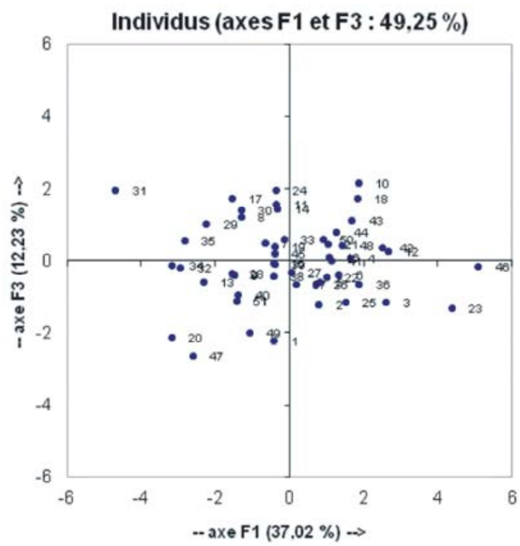

Fig. 5: Second factorial plan (F1F2) of individuals

The axis F3 absorbs only 11,13% of the total variance. In addition, we note that only the depth is more or less positively correlated with this axis F3. The F1 axis shows the same previous correlations.

The principal components analysis take into account neither the position of points in space, neither the degrees of similarity between the parameters. To overcome this, we started to use the Ascending Hierarchical Classification method (AHC).

Ascending Hierarchical Classification: The AHC Classification allowed to reclassify individuals in 4 classes more or less homogeneous. The level of dissimilarity was of 35.7% (Figure 6).

The analysis of the level index resulting from the CHA has shown that, for a number of four classes, the interclass inertia is smaller. The spatial distribution of these classes was done and the four sub-areas defined are well represented on the longitudinal geotechnical profile.

The Compressibility of Soil Identified in the Area of Study: After the characterization of different types of soil in the area of study, a treatment of the parameters of compressibility is necessary to estimate approximately the soil settlement. The Table 4 summarizes the mean values of compressibility tests according to the lithology, without taking into account the depth of layers. The associated coefficients of variability

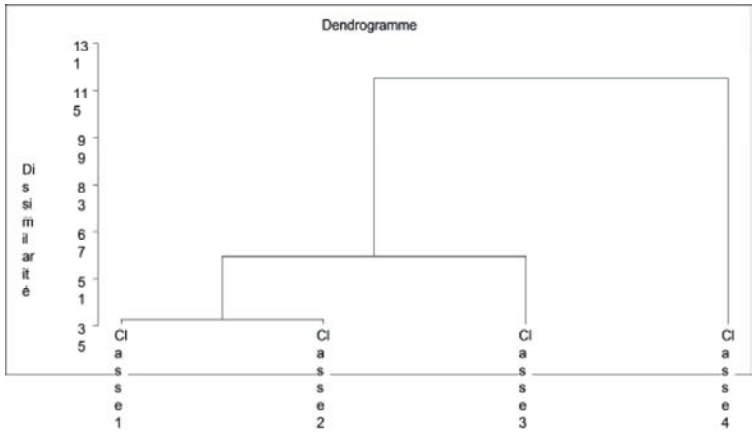

Fig. 6: Level of dissimilarity – Ascending hierarchical Classification

Table 4: average oedometric properties

	Mean/Coefficient of variability			
Lithologies (a number of tests)	Cc	Cs	e0	Pc (kPa)
Mud (35)	0,26 / 48.79%	0,07 / 43.45%	0,77 / 30.79%	150,51 / 51.14%
Clay (88)	0,21 / 42.45%	0,06 / 61.76%	0,67 / 30.88%	190,86 / 66.29%
Silty clay (25)	0,15 / 40.46%	0,04 / 54.29%	0,64 / 24.94%	190,6 / 66.73%
argillaceous silt (19)	0,15 / 33.74%	0,03 / 57.22%	0,56 / 16.78%	119,42 / 71.29%
Muddy sand (17)	0,13 / 63.45%	0,02 / 65.60%	0,52 / 29.08%	92,12 / 63.51%

With: (Cc) the compression index of soil, (e0) the initial void ratio and (Pc) consolidation pressure.

show well the changeability of values while oedometric means gives information about the compressibility of the site.

The Table above Highlights the Following Points:
Vase: parameters show high compressibility of the soil with a mean Cc of 0.263 and e0 of 0.773.

Clay, parameters show a relatively high compressibility of the soil with a mean Cc of 0.206 and e0 of 0.671.

Silty clay: parameters show an average compressibility of the soil with a Cc of 0.151 and a mean e0 of 0.637 which remains high. Consequently, these soils can compress significantly.

Silts, parameters show a high mean compressibility of the soil with a mean Cc of 0.152 and a mean e0 of 0.558.

Silty sands and clean sands: the parameters show a low mean compressibility of the soil with a mean Cc of 0.13 and a mean e0 of 0.521.

Risk of Soil Liquefaction: The rupture of an embankment after liquefaction of the soil is a combination of three specific events:

- The presence of a soil susceptible to liquefaction by its very nature and its saturation: It is the qualitative potential,
- The ability of the soil to lose any strength due to seismic loading: It is the potential related to the solicitation,
- Destabilization of soil sufficient to cause failure of the embankment or slope debris.
- The liquefaction of a soil is the total loss of shear strength by increasing the pore pressure. This increase is accompanied by deformations whose amplitude can be limited or virtually unlimited.

Liquefaction occurs when determined soil types affected by earthquakes develop significant interstitial pressure quickly (without drainage) resulting in a loss of tensile strength and thus the ground breaking, which behaves as if it were a liquid.

This causes the collapse of foundations, slope failure and landslides.

Soils that may lose much of their resistance to dynamic loads are thin and poorly consolidated sands and silts and poorly graded sands.

One of the conditions for the liquefaction is that the level of the water table is near the surface and the degree of compaction is low with less than 15-20 SPTN30 values.

According to the observations made in areas in which occurred liquefaction phenomena, we can establish that causes of liquefaction are:

- Earthquakes of magnitude 5.5 or greater, with greater than or equal to 0.2g acceleration.
- Below 15 m depth, no phenomenon of liquefaction happens.
- In the majority of cases where liquefaction was observed, the water table was shallow, less than 3 m
- With a level of groundwater exceeds 5 m depth liquefaction risk is very low.

Properties of Liquefiable Soil and Qualitative Potential of Liquefaction: The properties that characterize liquefiable soils are:

Sands:

- Degree of saturation of 100%.
- Average diameter D50: 0.05 <D50 <1.5 mm.
- Coefficient of uniformity Cu = d60/d10 <15.
- Percentage of fines (passing 80 µ) of less than 10%.
- Low degree of compactness, that is to say, N <10 to 10m depths <and N <20 for depths> 10m.

Clays:

- D15> 0.005 mm
- Liquid limit LL <35%
- Moisture content > 0.9 LL

The evaluation of the qualitative potential of liquefaction is defined according to Eurocode 8 (art. 4.1.4 of EN 1998-5) [14].

The evaluation of liquefaction potential must be done when the sub-grade consists of thick layers or thick lenses of loose sand, with or without fine silt or clay and situated below the level of the water table and when the level of the latter is close to the ground surface.

Non-Liquefiable Soils and Exclusion Criteria: The risk of liquefaction is overlooked when α.S <0.15 (α is the ratio of the calculated value of the ground acceleration, ag in the acceleration of gravity g and when, at the same time, one of the conditions below is true:

- The sands which contain clay (passing 5µ) that exceeds 20% proportion, with a plasticity index IP> 10;
- Sands containing silt (passing 80µ) in excess of 35% when the proportion and number of strokes normalized SPT N1 (60)> 20.

The sands are said "clean sands", with a value normalized SPT N1 (60)> 30.

Risk of Significant Liquefaction

Evaluation Forms Depending on SPT Values: The methodology to be applied is the one proposed by Eurocode 8 (EN 1998-5) [14].

If the risk of liquefaction can not be neglected, a liquefaction assessment can be done by correlating the SPT measurements and seismic shear stresses.

According to Eurocode, seismic shear stress can be evaluated using the following expression:

$$\tau_e = 0.65.\alpha.\text{s}.\sigma'_{v0}$$

Applicable for 20 m depths with:

σ'_{v0}: Total land stress.

α is the ratio of the ground acceleration ag with the gravitational acceleration g

S: the characteristic parameter of the soil class.

The risk of liquefaction can be estimated also from the method of Seed and Idriss (1971) according to the Eurocode 8 (EN 1998-5) [14].

Under this method, the soil will liquefy if the ratio of cyclic shear stress CSR (cyclic shear stress ratio) produced by an earthquake is higher than the shear strength of the soil in place:

$$CSR = \frac{\tau_{\text{cm}}}{\sigma'_{\text{v}}} = 0.65\frac{\sigma_{\max}}{\sigma'_{\text{v}}}\frac{\alpha_{\max}}{g}l'_a$$

With

τcm = Average cyclic shear
σv = Total stress
σ'v = Effective stress
amax = Maximum horizontal acceleration
g = Gravity acceleration
yd = Reduction factor with depth (yd=1-0.015.z,.z with z = depth)

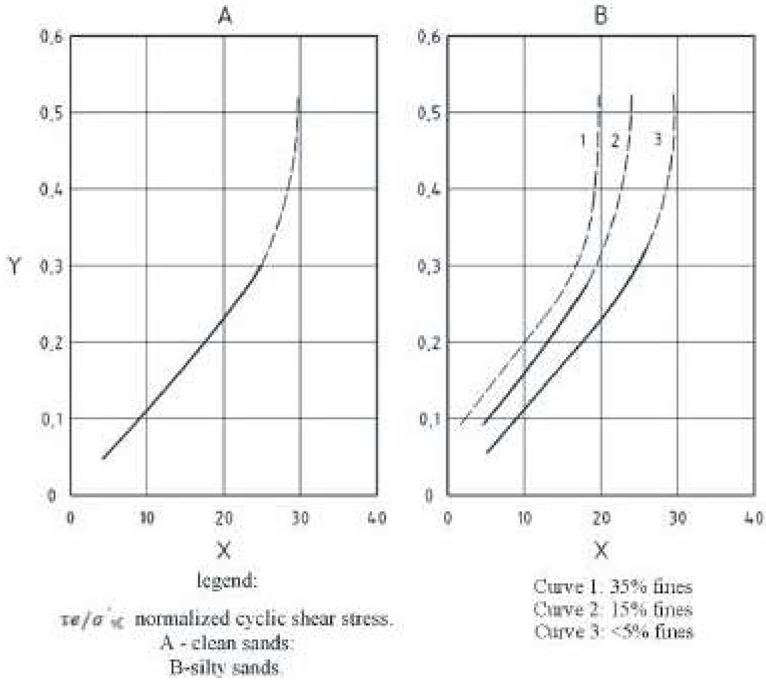

Fig. 6: Relationship between stress ratios producing liquefaction and N1 values ??(60) for clean sands and silty for earthquakes of magnitude MS = 7.5

The method of Seed and Idriss was reviewed by Youd and Idriss (2001).

To estimate the risk of liquefaction, it is necessary to calculate the cyclic shear (CSR) exerted by the earthquake on the ground and the soil's ability to resist said effort (CRR).

CSR is defined in the same way as in the original method of Seed and Idriss, with the particularity of altering the value of νd:

- νd = 1.0 to 0.00765 z for z ≤ 9.15 m
- νd = 1.174 to 0.0267 to 9.15 m z <z ≤ 23m

CRR can be calculated from the penetration test with CPT or from SPT, or the speed of transverse waves Vs, the CPT is one that offers the best results.

Charts and Graphs Used with SPT Values: Empirical diagrams, based on SPT index are provided from EN 1998-5 to check the risk of liquefaction and to determine the value based on the type of soils (clean sands and silty sands).

The diagrams shown in Figure 7 in Appendix B for clean sands and silty sands (Excerpts of EN 1998-5) are for earthquakes with a magnitude of 7.5.

The value of the penetration index SPT to take into account is the standard N1 (60).

This value, N1 (60), can be obtained from the following expression:

$$(N1)60 = N \bullet CN \bullet CE \bullet CB \bullet CR \bullet CS$$

With:

- N = number of strokes of the SPT.
- CN = (100 / σ'_{v0}) x 0.5. (CN must not exceed 1.7) with σ'_{v0} (kPa) is the effective stress of soils at the depth at which the SPT measurement was performed. CN is usually between 0.5 and 2.
- EC depends on the impact energy of the test. For the "Donet" type 0.5 <EC <1.2 for the "automatic" type 0.8 <EC <1.3 and the "safety" type 0.7 <EC <1.7.
- CB indicates the influence of the diameter of the probe. It is equal to 1.0 for 65mm<Ø<115mm.
- CR varies with the depth of the prob (L), for L <3 m, CR = 0.75; for 4m <L <6m 10m And For CR = 0.85 <L <30m, CR = 1 0.
- CS = 1.0 for collections of standard samples.

For less than 3 m deep, measured MSE values should be reduced by 25%

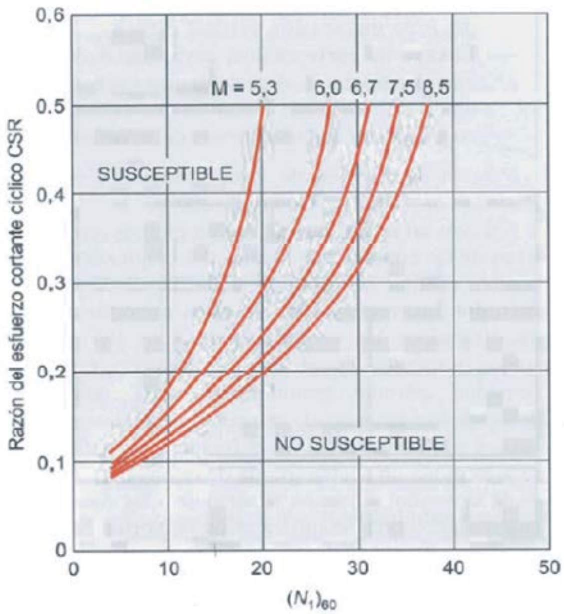

Fig. 8: Abacus 1-risk of soil liquefaction based on (N1) 60 and the value of the cyclic shear CSR

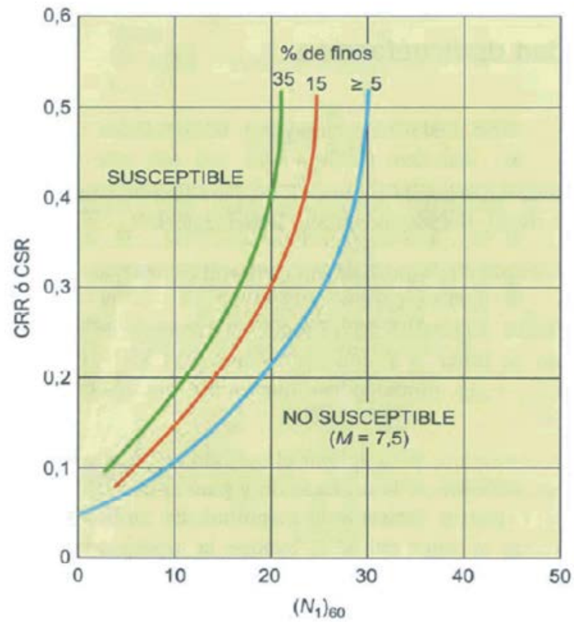

Fig. 9: Relationship (N1) 60 CRR or CSR.

Table 4: CM factor

*M*s	*CM*
5.5	2.86
6.0	2.2
6.5	1.69
7.0	1.3
8.0	0.67

In applying the criteria to different magnitudes of MS = 7.5, where MS is the magnitude of the surface waves, the ordinates of the curves in Figure B.1 must be multiplied by the CM factor shown in Table 4.

Having calculated the value of τ_e in the previous expressions and a value of (N1) 60 and considering Figure 8 it is possible to decide whether liquefaction is possible for several magnitudes of earthquakes.

With the method of Seed and Idriss, it is the following diagram that is applicable to assess the risk of liquefaction in different magnitudes of earthquakes:

The graph (Figure 9) above defines the relationship between CSR and CRR or the value of (N1) 60 indicating the boundary between soil liquefaction risk or not for an earthquake of magnitude 7.5 and the percentage of fine <80μ.

Risk Assessment of Liquefaction on the Plain of Sebou Parameters Used for the Seismic Risk Assessment of Liquefaction: For the preliminary analysis of the risk of soil liquefaction, a review SPT boreholes and identification tests made in laboratory were carried out on the sector including plain Sebou.

Following the methodology described above, the risk calculations of liquefaction have been made, according to the criteria of Eurocode and also Seed and Idriss. The magnitude used is 6.5.

The choice of this magnitude is based on the different seismic events occurred in Morocco from 1900 to the present. On seismic loading, characteristics considered are those from the study of seismic hazard along the route of the LGV KT (December 2009) and also the note of reply related to the same report (March 2010) conducted by the Scientific Institute of Rabat [15].

In this study, an acceleration map was published, which classifies the sector in three areas between 0.13g and 0.16g. With these criteria the liquefaction risk can not be overlooked because the α = 1.5 x 0.16 = 0.24 therefore greater than 0.15 for a soil class C.

Soil Characteristics of the Sebou Ground Towards the Risk of Liquefaction: Compressible soils of the plain of Sebou mostly clayey and inter-bedded with lenses or layers of silty sand or little silty located entirely below the level of the water table

Soils of the Plain Sebou: SPT values characteristics were measured in the following surveys:

SPT survey X	Y	Depth in m	SPT value between 0 and 10 m	Nature of materials	SPT value between 10 m and 20 m	Nature of materials
398 893	428 256	20	11 - 18	clayey sand	26 - 67	gritty sand
428 256	424 160	12	14 - 18	Clay and silty sand 5 m by 5 m	38 - 50	gritty sand and sandstone beyond 10 m
397 864	423 673	12	7-10 to 7 m - 23 m between 7 and 10 m	Sandy and clay up to 7 m --- Compact and compact sandy clay up to 10 m	23 to 11 m - 31 to 12 m	Silty sand and clay compact
397 697	422 994	20	40 to 5 m-12 m 18 to 12	Sand-clay 5 m to 12 m	30 - 40	compact clay
397 534	422 008	12	9 - 15	Silty sand and clay 3m and silts up to 10 m	21	compact clay
397 504	421 509	12	9 to 5 m - 16 to 9 m	Silty clay up to 5 m - clay up to 9 m	20 - 22	compact clay
397 507	421 062	12	11-17 up to 8 m-37 to 10 m	3 m of sand-silt and clay-sand up to 8 m to 10 m	18	compact clay
398 051	416 241	40	From 10 to 11 up to 5 m-10 to 6-9 m	Silty sand up to 5 m - mud up to 10 m	9	Mud and sandy mud up to 20 m
398 092	415 843	50	6 - 8	Silts and silty mud	22 to 13 m - 7-8 to 20 m	10-13 m sand-silt-sand silt and mud up to 20 m
398 143	415 346	20	22 -24	sandy clay	15 10 m 15 m - 38 to 50 to 20 m	10 m to 15 m sand - 15 m 20 m sand compact gritty

All soils in the plain of Sebou are below the level of the water table.

The analysis of these results shows that the SPT value is always greater than 0 between 0 and 10 m for the upper layers of sand and greater than 10 between 10 m and 20 m.

In these surveys, particle size analysis showed that these sands had a passing more than 15% 80μ.

These sands are not liquefiable according to potentiality criteria described in Section 4-6.1, but the risk is not excluded under the criteria of Section 4-6.2.

For these sands encountered in the study area,, application of the Eurocode chart is required. For SPT (60) = 9 and for a sand with 15% fines (curve 2), we obtain a cyclic shear stress of 0.15 for an earthquake magnitude 7.5.

For an earthquake of magnitude 6.5, the value of cyclic shear is 0.15x1.69 = 0.25. The seismic shear stress = 0.65. S. = 0.65x 0.16 x1.6 = 0.0166.

These sands will not liquefy for an earthquake of magnitude 6.5.

Clays with an SPT value lower than 10 have a plasticity index greater than 15 and liquidity limit greater than 35. So, they are non-liquefiable.

CONCLUSION

This work shows the importance of having a full view of all geotechnical recognitions campaigns.

The analysis and interpretation of geotechnical parameters allowed to identify with more precision 4 types of compressible soils (Silt and silty mud, clay and silty-clay, clayey silt, silty sand) with the following characteristics: Obtained from PCA Results: The correlation matrices were used to determine the positive and negative correlations between γd WI with other parameters. PCA showed that the first three factorial axes (F1, F2 and F3) absorbed more than 72%. The CHA divided the sample into four different classes with physical and mechanical characteristics more or less homogeneous.

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