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Tangier Mediterranean Port: geological & geotechnical study & assessing the risk of earthquake-related liquefaction using the Cone Penetration Test (CPTU)

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Abstract:
The geological basement of the Tangier Mediterranean port (southeastern Gibraltar coast) is here studied to locate sand-saturated levels, in order to assess the risk of earthquake-induced liquefaction. Geological and geotechnical field analyses based on cone penetration tests (CPTU) lead to the four following results: (i) the high-risk area is reduced and is situated between CPT22 and 25, (ii) clayey silty sands prone to earthquake-related liquefaction directly occur beneath the protecting structures, (iii) the distant earthquake source is more fatal for the ground beneath the studied port, than the earthquake from a close source, and (iv) the load applied by the building can reduce the potential of liquefaction, but remains efficient only for the first 3m depth.

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1. Introduction

The Tangier Med port occurs in the northernmost part of Morocco, precisely in the southeastern segment of Gibraltar-sea coast, i.e., between the cities of Ksar Sghir and Fnideq. The site of the Tangier Med port is crossed by the mouth of the Rmel river. The geological foundations are alternations of sandstones and pelites of the flyschs unity of Tisirène, metric sandstone banks dominate the right bank of the port, whereas on the left bank, pelites dominate. This work aims to: i) synthesize the available geotechnical and geological data coming from this zone since the starting year 2002 of this port; and then, ii) to assess the risk of earthquake-related liquefaction using the cone penetration method.

2. Geological and geotechnical study

2.1 Geotechnical campaigns and realized surveys

The site of the Tangier Mediterranean port has been the subject of several campaigns of geotechnical surveys (location map in Figure 1) staggered in time and conducted by several laboratories (LPEE, FUGRO, SeaCore, GTEC) (Tab.1). So, several surveys and tests were carried out. All the data are used in this study.

Table 1. Table showing the geotechnical surveys conducted in Tangier Med port

Campaign	***Laboratory and date***	***Types of tests***
Preliminary recognitions	*LPEE, Morocco-2003*	*core drillings*
Recognitions of the site of the port	*FUGRO, France – 2004*	*core drillings + CPT**
Recognition of protective structures	*SEACORE, United Kingdom–2005*	*core drillings + CPT +SPT***
Full Lands	*LPEE, Morocco – 2004*	*core drillings + CPT + pressuremeters*
Container quay	*LPEE, Morocco – 2005/2006*	*core drillings + pressuremeters*
Container quay	*GTEC, Belgium -2005*	*CPT*
Full Lands complementary	*LPEE, Morocco -2005*	*core drillings + CPT + pressuremeters*
Full Lands (TC1)	*FUGRO, France – 2006*	*core drillings + SPT*

*Nota: * CPT: Cone Penetration Test; ** SPT: Standard Penetration Test.*

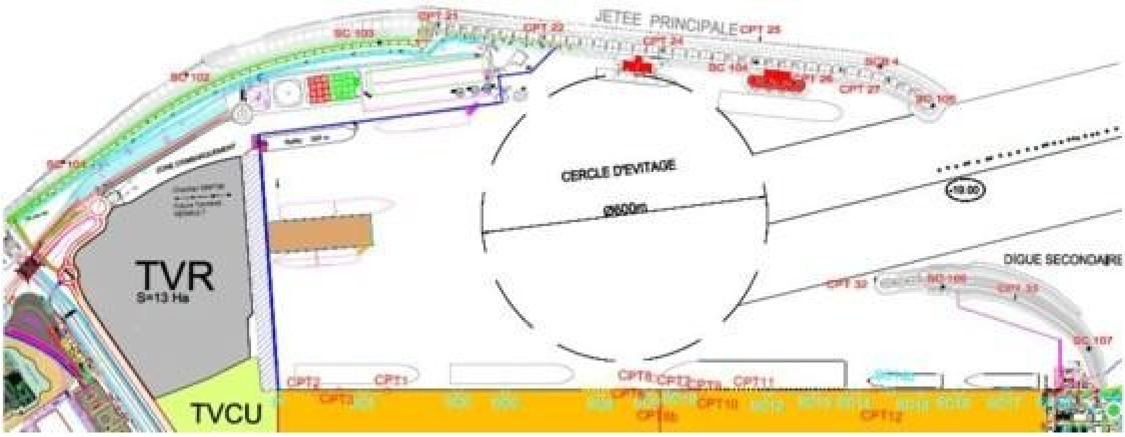

Figure 1. Surveys location map.

2.2 <u>Realization of the bedrock (substratum) map</u>

The data of the various campaigns treated by SURFER and COVADIS software allowed to establish a map of the bedrock (substratum) and the corresponding block diagram (figure 2). These show the presence of three valleys whose size is variable and correspond to R'Mel river, Chaâba river, and a small stream.

It is noteworthy that the substratum dives brutally towards the open sea. The overlapping of the map with the mass plan of the port (figure 2) allows to locate these valleys, it shows that they cross the embankment, exactly in the location of the container quay, and run along the axis under the influence of the seawall protecting structures.

2.3 <u>Geological sections</u>

Three geological sections were established on the site supporting the main structures of the port (Figure 3), precisely, i) the protection structures (seawalls), ii) the embankment, iii) and the container quay. These sections are intended to evidence the compositional nature of the corresponding geological basement, and hence to highlight the problems related to their structural susceptibility. These sections show the existence of a thick layer of sand and silty sand (yellow and orange figure 4) in the protecting structure zone (seawalls) (AOULAD MANSOUR, 2007; AOULAD MANSOUR *et al.*, 2011). A typical section shows, from top to bottom:

- clean sands, 15 m thick, with an average of 87% sand, 12% silt and 1% clay,
- silty clayey sands, whose thickness reaches 6.3 m and composed of 39% sand, 33% silt and 28% clay with a plasticity index IP of 16.2% (average value of the layer);
- clayey silts in the form of a thin lens, identified only in SCB4 drilling. They consist of 34% sand, 52% silt and 14% clay; the IP of this formation is 10%;
- gravelly channels, 1 to 4 m thick;
- sandy silts with 40% sand, 39% silt and 21% clay; the IP is 14.3%;

- massive sandstone-pelite bedded alternation, with conspicuous altered bed surfaces.

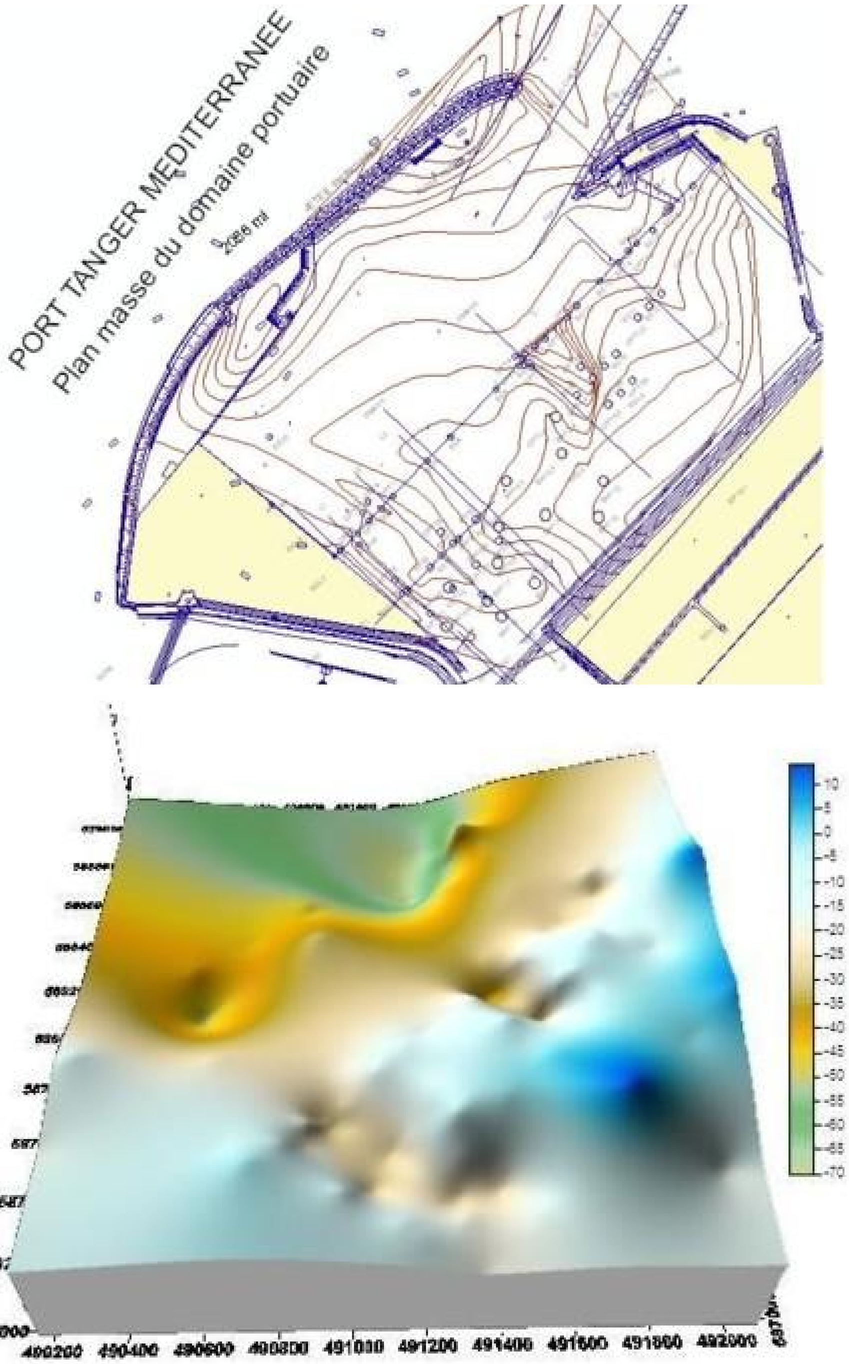

Figure 2. Map and block diagram of bedrock performed respectively under Covadis and Surfer.

Figure 3. Location of geological sections.

The sandy beds are constantly saturated, which enhance their permeability. Thus, they can be identified, together with the pelitic intercalations, as bearing a potential risk of earthquake-related liquefaction. In the area of the container quay, the valley detrital discharge resulted in the accumulation of more than 30m of sands, silty sands and clayey silts unsuitable for the foundation of the platform. Because this poorly consolidated to soft material can generate unacceptable settlement (AOULAD MANSOUR, 2007; AOULAD MANSOUR *et al*., 2011, it was dredged to bedrock, and substituted by vibrocompacted adaptated grain size pit materials in order to densify and minimize soil compaction risk under the container quay (Figure 4)

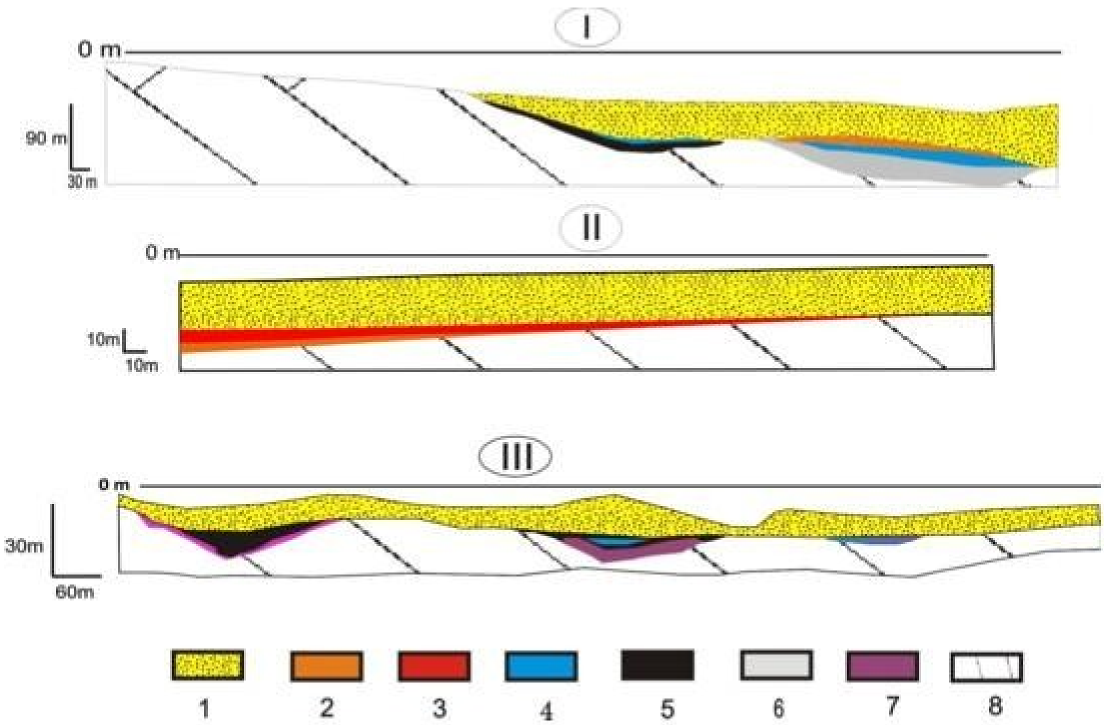

Figure 4. Geologic sections in the influence of the port structures
(I) Main breakwater, (II) Secondary breakwater, (III) Container quay
Legend: 1 Sands, 2 Silty sands, 3 Clayey sands, 4 Alluvium, 5 Sandy silts, 6 Altered bedrock, 7 Marl, 8 Bedrock sandstone-pelite

3. Liquefaction risk analysis

3.1 Study of the seismic hazard

The studies of seismic hazard of Tangier Mediterranean Port is conducted first by a deterministic approach (CHERKAOUI, 2003) and then by a probabilistic approach (GEOTER International Engineering, see MARTIN *et al*. 2004a and 2004b). The first approach is carried out according to French practices for nuclear sites and installations classified for the protection of the environment in order to define the dimensioning earthquakes. The second, in compliance with the principles of Eurocode 8, is intended to calculate the maximum acceleration of the soil at different return periods and levels and to calibrate the levels of sizing with regard to these periods of return.
This study allowed to retain two dimensioning earthquakes, one for close source and one for distant source, corresponding to the SMS (Séismes Majorés de Sécurité) earthquakes of the determinist study. Their characteristics of magnitude and acceleration are respectively 4.7 and 0.24 g, corresponding to a return period of 1975 years for the close source and 8.5 and 0.093 g corresponding to a return period of less than 475 years, for the distant source. The study of liquefaction will be initiated on the basis of these results.

3.2 The CPTU test

The analysis of the risk of liquefaction is conducted from cone penetration tests CPTU. These tests measure the pore pressure in the soil, in addition to the resistance to penetration of the cone and of the local skin friction on the sleeve, located immediately above it.

3.3 The analysis of the risk of liquefaction and the calculation of safety factors

In the absence of Moroccan legislation on the subject, this analysis is performed according to the rules of PS 92 according to the empirical method of YOUD and IDRISS (2001), which includes the following phases:

Phase 1: it is advisable to verify through laboratory tests, realized on samples from cored boreholes or SPT, if situ grounds are potentially liquefiable under seismic requests. The standards of NF P.06-13 consider as liquefaction sensitive all the sandy and silty grounds presenting the following characteristics:

- *degree of saturation close to 100%;*
- *uniform particle size* $Cu = D_{60}/D_{10} < 15$*;*
- *diameter* D_{50} *between 0.05 mm and 1.5 mm;*
- *effective vertical stress less than 0.3 MPa.*

Clay soil with the following characteristics:

- *saturated soil;*
- *diameter D15 > 5µm;*
- *liquidity limit* W_L *<35%:*
- *water content* $W > 0.9W_L$.

In Tangier Mediterranean Port, soil fulfilling these criteria are strictly situated in:

- *the upper fringe of the survey SC 104 (0-4 m) and towards 12,50 m in depth;*
- *towards 10 - 13 m, then in 18 m of depth in the survey SC 105;*
- *towards 0 & 12m of depth in the survey SC 106;*
- *between 7,00 & 12m of depth in the survey SC 108.*

Phase 2: if the formations are proved to be potentially liquefiable, a preliminary study of the "free field" risk of liquefaction, neglecting at first the effect of the structure on the ground must be conducted. Then, the influence of the soil-structure interaction on the liquefaction risk is estimated by calculating the positive influence of a load, provided by the structure, on the ground.

The evaluation of liquefaction risk is based on the calculation of a safety factor *FS*, which is defined as the ratio between the normalized cyclic resistance of the material (CRR), and standard cyclic loading (CSR) induced by the earthquake at the same depth.

$$FS = CRR/CSR \qquad (1)$$

CSR in free field is deducted from the maximum acceleration of the earthquake in the surface, a_{max}, according to the following formula:

$CSR = 0,65\ (a_{max}/g)\ (\sigma_{vo}/\sigma'_{vo})\ r_d$ (2)

a_{max}: earthquake maximum acceleration in the surface,

g: acceleration of gravity (9,81m/s^2),

σ_{vo}: vertical total stress,

σ'_{vo}: vertical effective stress,

r_d: reducing coefficient of stress according to the depth.

For the study of liquefaction, CPTU parameters must be standardized (ROBERTSON & WRIDE, 1998). First, the total resistance of the cone q_t and lateral friction fs are corrected by the effective stress to calculate Q_t and Fr used in the establishment of the charter of the types of soils (SBT) which may be represented by the index Ic (ROBERTSON, 2010).

$Q_t = (q_t - \sigma_{vo})/ \sigma'_{vo}$ (3)

$Fr = (fs/(q_t - \sigma_{vo}))*100\%$ (4)

$I_c = ((3.47-\log Q)^2+(1.22+\log F)^2)^{½}$. (5)

Then q_t is normalized by introducing total and effective stress (σ_{vo} & σ'_{vo}), atmospheric pressure (Pa) and the normalization factor n which is a function of I_c.

This normalization is done using the following formula:

$Q_{tn} = ((qt - \sigma'_{vo})/Pa)\ (Pa/ \sigma'_{vo})^n$ (6)

where n = 0.381 (I_c)+0.05 (σ'_{vo} /pa)-0.15.

For silty sands another corrector coefficient Kc is introduced:

$Qtcn = K_c \times Q_{tn}$ (7)

$K_c = 1$, if $I_c \leq 1.64$

$K_c = 5.581 I_c^3 - 0.403 I_c^4 - 21.63 I_c^2 + 33.75 I_c - 17.88$, if I_c is between 1.64 and 2.50

$K_c = 6\ 10^{-7} (I_c)^{16.76}$, if I_c is between 2.50 and 2.70

The value of the cyclic resistance CRR is calculated from Q_{tn} if I_c is less than 2.70, and from $Qtcn$, if I_c is greater than 2.70.

In practice, the value of *CRR* is always calculated for a reference earthquake of magnitude 7.5, hence the notation $CRR_{7.5}$. To adjust this value to different magnitudes, more reliable and stronger, according to the studied cases, the authors (YOUD & IDRISS 2001) have introduced a weighting factor of the magnitude *MSF*, using the following formula:

$CRR = CRR_{7.5} \times MSF$ *(8)*

MSF is calculated from a nomogram in function of the magnitude.

The risk of liquefaction is considered zero when the safety factor *FS* is greater than 2, unlikely for a value of *FS* between 1.33 and 2, likely for values between 1.33 and 1. For values of *FS* less than 1, the risk is almost certain.

4. Results assessing the risk of liquefaction

Assessing the risk of liquefaction, primarily interests the area of the protection structures (seawalls), where thick formations of sand and silty sand, very sensitive to

liquefaction, have been identified. Beneath the container quay these materials have been dredged and substituted to avoid unacceptable settlement. The calculation of *FS* perpendicular to the main breakwater shows that it is less than 1.3 in the levels below, summarized in Table 2 (eg CPT 25, Figure 5).
In the influence of the secondary breakwater (CPT32, CPT33 and CPT34), all the coefficients are superior to 1,3 and consequently, no risk level has been identified (Figure 6).
Analysis of the results indicates that the distant source earthquake is more favorable to the phenomenon of liquefaction than the near source earthquake.
The load of the structure reduces the liquefaction potential. the only remaining risk areas are the superficial soil (about 3 m), and a few levels of very low thickness.
The critical zone coincides with the CPT 22, 24 and 25 of about 460 m (Figure7).

Table 2. Depth of risk levels at the site of the main breakwater.

	Close source of magnitude=4,7				*Distant source of magnitude =8,5*				
	CPT21	*CPT22*	*CPT24*	*CPT25*	*CPT21*	*CPT22*	*CPT24*	*CPT25*	*CPT27*
Liquefiable levels before construction works	*6 – 6,6* *7,6 – 7,8*	*0,4 – 6* *9,6 –10* *12 –12,2*	*1,2 – 1,8* *2,2 – 2,4* *3,2 – 5*	*0,6 – 2,8*	*0,4– 0,8* *4 – 4,2* *5,2– 5,4* *5,8– 6,8* *7,2– 8,8*	*0,4– 6,2* *8,4 – 8,8* *9,6 – 10,4* *12 – 12,4*	*0,6 – 0,8* *1,2 – 2,4* *3,2 – 5,2*	*0,6 – 2,8* *6,2 – 6,6* *13,8–14* *15,4 - 16,2* *16,6– 16,8* *17,2– 17,4* *18,6 - 19*	*18,6– 19,2* *21,4– 21,8*
Liquefiable levels after construction works	*None*	*0,8 – 3,6* *4,2 – 4,4*	*3,2 – 4,2* *4,6 – 4,8*	*0,6 – 0,8* *1,6 – 2,2*	*6 – 6,6* *7,6 – 7,8*	*0,4 – 6* *8,6 – 8,8* *12 – 12,2*	*1,2 – 2,4* *3,2 – 5*	*0,6 – 2,8*	*None*

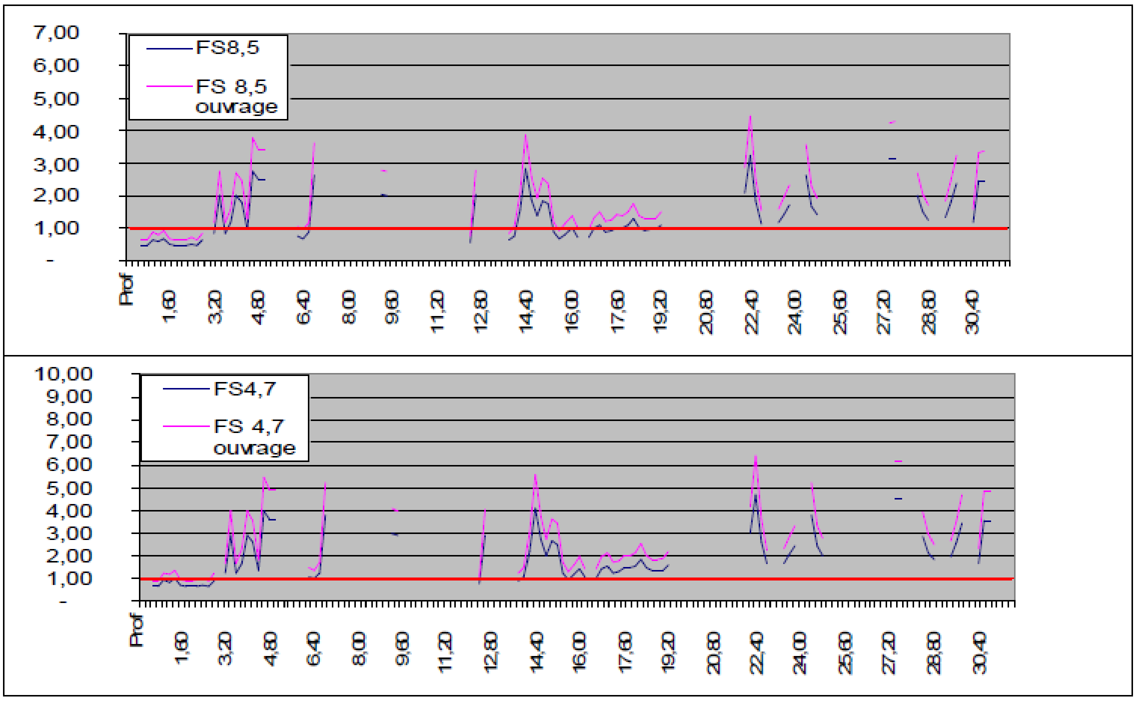

Figure 5. Curves of the results of the analysis of liquefaction, CPT 25 main breakwater (abscissa depth, ordinate FS).

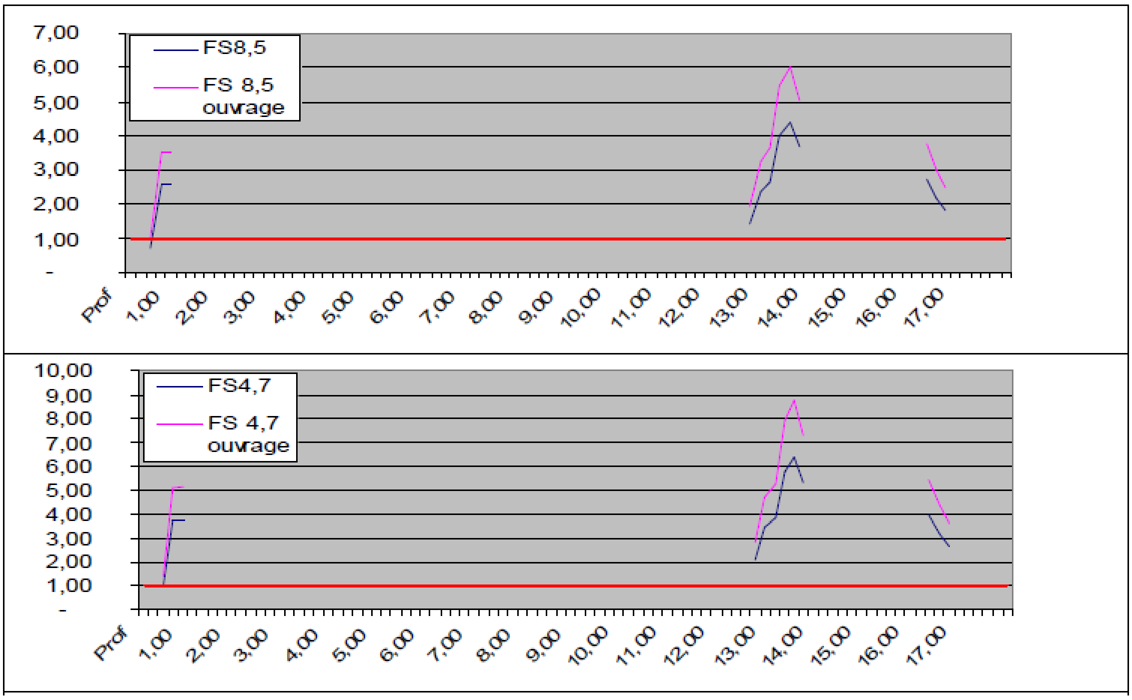

Figure 6. Curves of the results of the analysis of liquefaction, CPT 33 (abscissa depth, ordinate FS).

5. Conclusion

The geological and geotechnical study of the Tangier Mediterranean Port highlights the existence of three unequal valleys, crossing the site of the port, and a dominance of sands and silty sands beneath the protecting structures. Such metastable material is prone to liquefaction under seismic request. The risk analysis conducted on the basis of CPTU and the earthquakes of projects shows that the danger zone is between CPT22 and CPT25, and the distant earthquake is more fatal for the ground. The load applied by the structure can reduce the liquefaction potential, but remains only efficient in the very superficial part of the ground, i.e., no more than 3m deep.

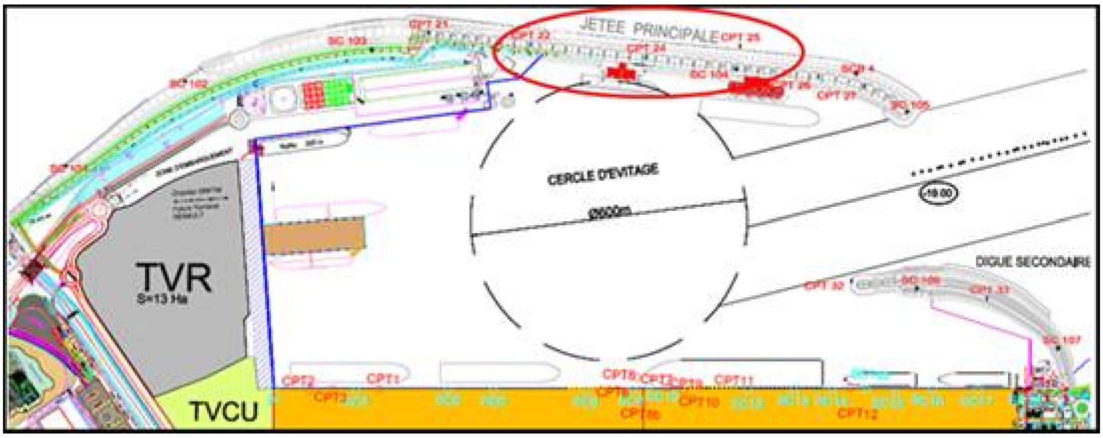

Figure 7. Location of the high liquefaction-risk area.

6. Acknowledgments

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7. References

AOULAD MANSOUR M.R. (2007). *Port Tanger Méditerranée: Etude géologique et géotechnique et évaluation du risque de liquéfaction.* Rapport de projet de fin d'études, Ecole Nationale de l'Industrie Minérale, 92 p.

AOULAD MANSOUR M.R., MIHRAJE A., STITOU MESSARI J.E. (2011). *Port Tanger Méditerranée: Etude géologique et géotechnique et analyse du risque de liquéfaction à partir des essais in situ.* Conférence Méditerranéenne Côtière et Maritime Edition 2, Tanger, Maroc, pp 5-8. http://dx.doi.org/doi:10.5150/cmcm.2011.002

CHERKAOUI T.E. (2003). *Evaluation de l'aléa sismique: port de Tanger-Méditerranée.* Rapport d'étude.

MARTIN C., CARBON D., SECANELL R. (2004a). *Evaluation probabiliste de l'aléa sismique sur le site du port de Tanger Méditerranée.* GEOTER International Rapport GTI/TMSA/0105-50. 27 p.

MARTIN CH., CARBON D. SECANELL R. (2004b). *Annexes -Evaluation probabiliste de l'aléa sismique sur le site du port de Tanger Méditerranée.* GEOTER International Rapport GTI/TMSA/0105-50. 40 p.

ROBERTSON P.K., WRIDE C.E. (1998). *Evaluating cyclic liquefaction potential using the cone penetration test.* Canadian Geotechnical Journal, Ottawa, Vol. 35(3), pp 442-459. http://dx.doi.org/10.1139/t98-017

ROBERTSON P.K. (2010). *Evaluation of flow liquefaction and liquefied strength using the cone penetration test.* Journal of Geotechnical and Geoenvironmental Engineering ASCE, Vol. 136 (6), pp 842-853. http://dx.doi.org/10.1061/(ASCE)GT.1943-5606.0000286

YOUD T.L., IDRISS I.M. (2001). *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 ASCE, Vol. 127 (4), pp 297-313. http://dx.doi.org/10.1061/(ASCE)1090-0241(2001)127:4(297)