SITE SPECIFIC EARTHQUAKE RESPONSE ANALYSIS, CASE STUDY: SEBAOU VALLEY - ALGERIA

N. Mezouer[1], M. Hadid[2] and Y. Bouhadad[1]

[1] *National Earthquake Engineering Research Center (CGS), Algiers, Algeria*
[2] *National Public Works School (ENTP), Algiers, Algeria*
Email: mezouer_n@yahoo.fr

ABSTRACT:

A strong earthquake of magnitude Mw=6.8 struck Boumerdes, eastern Algiers region on May 21st 2003 at 7:44 pm (GMT+1). Many induced effects, mainly sand boiling and lateral spreading, have been observed. We perform in this work a site specific response analysis around the Sebaou Bridge, which suffered some damage. Geotechnical data of the site are gathered (borehole logs with SPT tests results as well as the physical properties of the soil). The ground accelerations recorded during this earthquake are used as bedrock motion which is analytically propagated upward through the soil profile to the free surface. An amplification factor ranging from 1.2 to 1.5 times the base rock acceleration is observed. On the other hand, liquefaction analysis is conducted and the factor of safety against liquefaction is determined for this site. Results give a safety factor less than unity. In order to quantify the liquefaction effect the liquefaction potential index P_L is calculated and it is over 15 in all boreholes what indicates a high liquefaction potential. Also, induced effects due to liquefaction are evaluated and ground displacements (settlement and lateral spreading) are estimated.

KEYWORDS: Boumerdes earthquake, amplification, liquefaction, lateral spreading, settlement.

1. INTRODUCTION

The Algiers-Boumerdes region, located in northern Algeria, a part of the African and Eurasian tectonic plates boundary, was strongly hit, on May 21st, 2003, at 7:44 pm (GMT+1) by a destructive earthquake of magnitude M_w=6.8 (Bouhadad *et al.*, 2004). This is a major earthquake comparable, in terms of impact, to those of Algiers of 1365 and 1716, of Oran 1790 and of Chlef 1954 and 1980 (CRAAG, 1994; Benouar, 1994). The focal mechanism indicates a reverse fault, located offshore, oriented NE-SW and dipping 43° to the southeast (Meghraoui *et al.*, 2004)). This earthquake triggered extensive liquefaction in seaside and in river valleys, particularly along the Sebaou valley. In this work we perform a site response analysis in the Sebaou river valley (Figure 1), near a slightly damaged bridge during this earthquake. The analysis consists of amplified peak acceleration determination, the liquefaction potential assessment and the ground displacement evaluation.

2. GEOETCHNICAL DATA

The used geotechnical data in this work are gathered from 10 boreholes performed at the time of bridge construction study during the seventeenth. Also one other borehole has been performed after the May 2003 earthquake. Location of the boreholes is shown on figure 2. The cross section interpreted from these boreholes is shown on figure 3, while the related data are shown on figure 4. Results of the laboratory analysis results of the taken samples from the boreholes are shown in table 1.

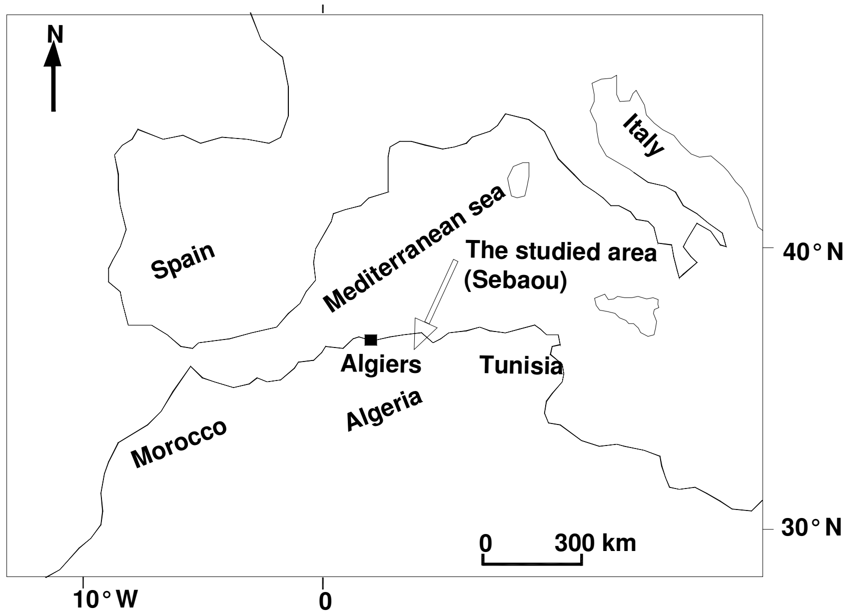

Figure 1 Geographical setting of the studied area (the arrow indicates the position of figure 2)

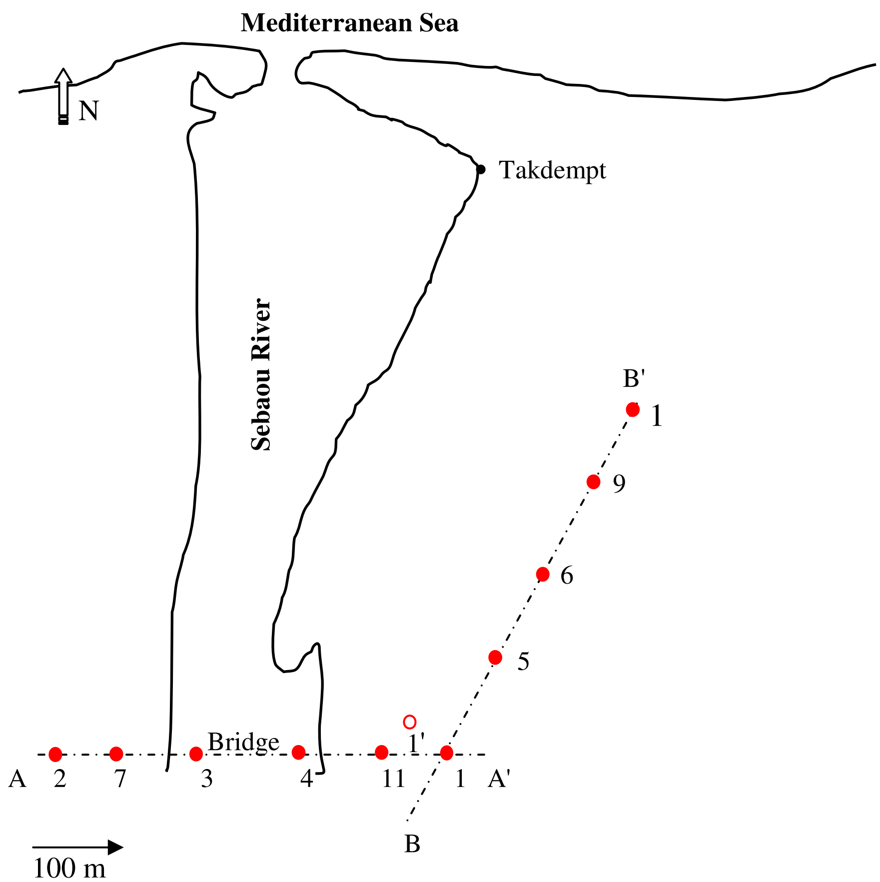

Figure 2 Boreholes location

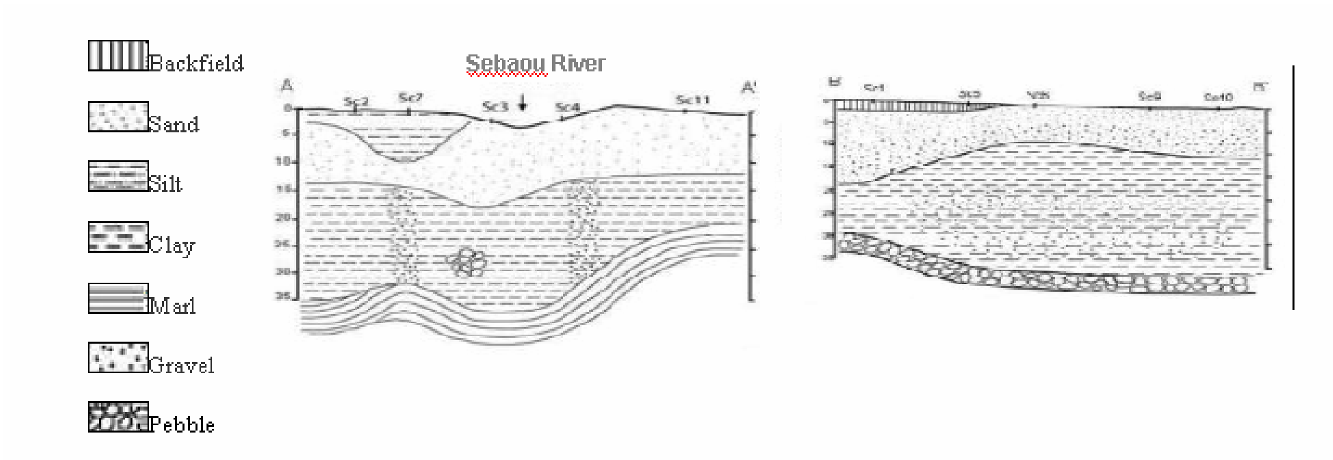

Figure 3 Geotechnical cross section

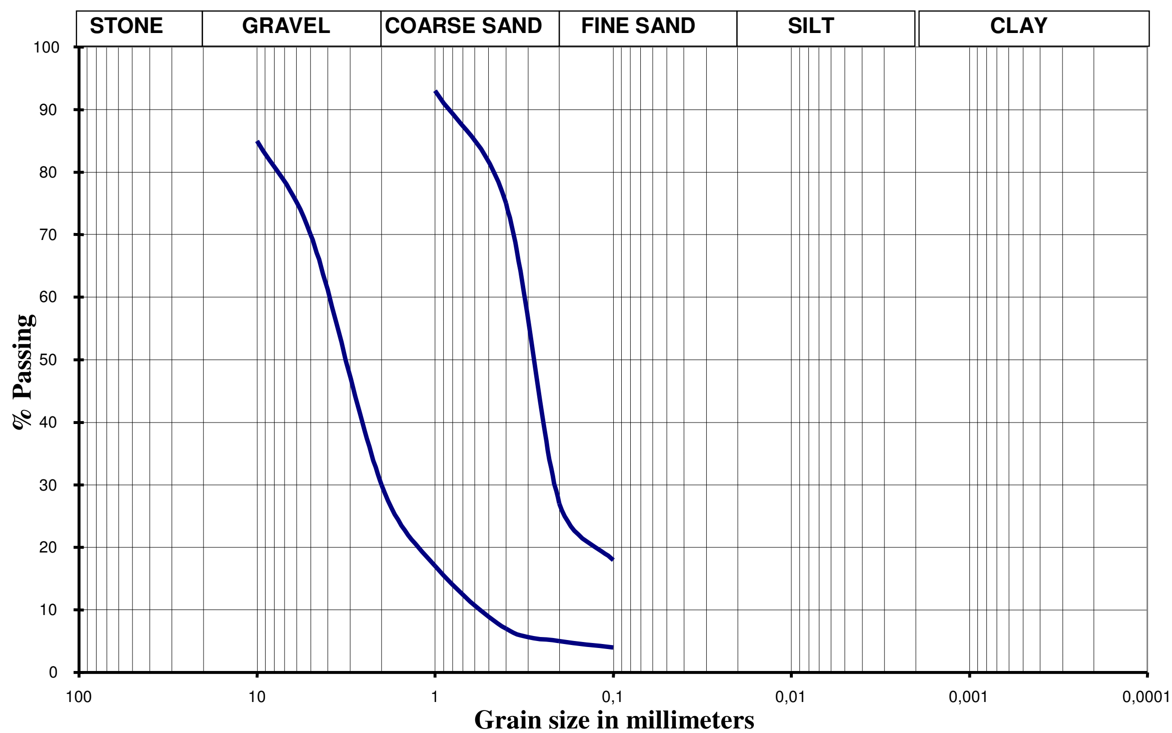

Figure 4 Envelopes of sand grading curves

Table 1 Geotechnical parameters of the soils

Lithology	ρ	*w*	*Sr*	*WL*	*Ip*	*D50*	*FC*	*C*	ϕ
Sand	2.1	15	85	/	/	0.3-3	5	0.46	34
clays	1.99	27	98	39	19	/	/	0.43	0.5

Table 2 SPT analysis results

	Lithology	Depth (m)	N' (blows / 30 cm)
Hole N°2	Fine sand	5.15 – 5.45	11
	Fine sand	7.70 – 8.00	13
	Fine sand	11.00 – 11.30	15
	Limon	14.15 – 14.45	20
	Limon	18.15 - 18.45	26
Hole N°7	Limon	3.00 – 3.30	20
	Clay	7.00 – 7.30	31
	Gravel	10.15 – 10.45	60
	Clay	15.00 – 15.30	21
Hole N°9	Coarse sand	2.30 – 2.60	8
	Coarse sand	4.00 – 4.30	10
	Coarse sand	6.00 – 6.30	8
	Coarse sand	7.70 – 8.00	8
	Clay	9.65 – 9.95	13
	Clay	11.65 – 11.95	18
	Clay	13.65 – 13.95	19
	Gravel	18.60 – 18.90	11
Hole N° 11	Gravel	4.45 – 4.75	55
	Fine sand	6.65 – 6.95	21
	Fine sand	10.15 – 10.45	17
	Fine sand	15.15 – 15.45	13
	Clay	25.15 – 25.45	30
	Marl	30.15 – 30.45	21

3. SITE RESPONSE ANALYSIS

The effect of soil conditions on the amplification of ground motion has long been recognized. Extensive studies of seismic site response have been performed over the last thirty years (Boore *et al*., 1980, Seed and Idriss 1982, Idriss, 1990).

Based on the geology of the site two different models of soil column are considered in this study. The first one represents the left side and the second one the right side of the river. The left side is essentially constituted from the bottom by a 10 m thickness of sandy layer followed by 14 m thickness of Limons. On the right side the soil column is constituted by 5m thickness of gravels, followed by 11m of coarse sand and 10 m of clays deposited on a marl basement. The dynamic characteristics of different layers are taken from CGS geotechnical data bank (Mezouer *et al*., 2007). N_{SPT} correlation versus V_s used is from Imai and Tanouchi, 1982 and shown on table 4. The amplification function between the basement and the free surface is assessed by the most widely used computer program (Idriss and Sun, 1992). The amplification functions of the two models representing the site are schematized in figure5.

Table 4 Dynamic characteristics of soil columns

Model	*Layers*	*Thickness(m)*	*ρ(Kg/m3)*	*V_s(m/s) (Imai correlation)*	*V_s (m/s) (CGS data)*	*V_s (m/s) (Average)*
1	Sand	10	2100	217	250	233
	Limon	14	2000	260	250	255
	Marl	/	2090	/	770	770
2	Gravel	5	2200	341	210	275
	Sand	11	2100	236	250	243
	Clay	10	2000	282	310	296
	Marl	/	2090	/	770	770

The used excitation for the amplification study corresponds to the accelerogramm recorded at Hussein Dey (Algiers) strong motion station during the 21 may 2003 earthquake, M_W=6.8 which is de-convoluted. Peak ground acceleration considered is calibrated to 0.30g. The amplified maximal accelerations for soil column models 1 and 2 at different layers are shown in table 5. An amplification ranging from 1.2 in intermediate layers to 1.5 in top layers is observed. These accelerations are used in liquefaction potential calculation.

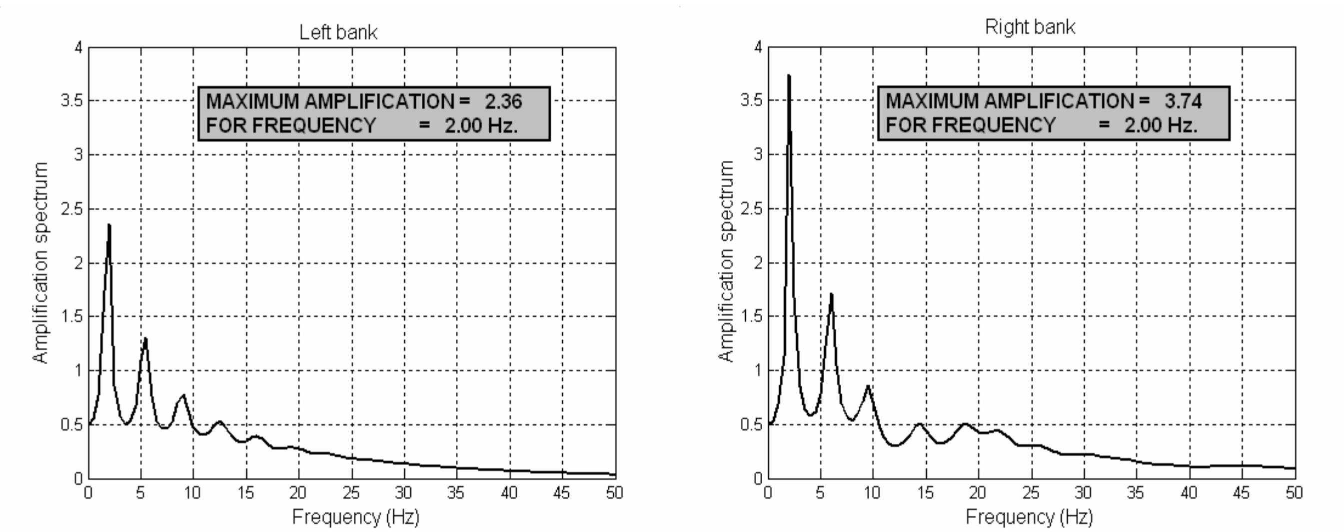

Figure 5 Amplification functions of the two soil column models

Table 5 Maximal accelerations at different layers

Model	*Layers*	*Maximal acceleration (g)*
1	Sand	**0.45**
	Limon	**0.36**
	Marl	**0.30**
2	Gravel	**0.43**
	Sand	**0.43**
	Clay	**0.37**
	Marl	**0.30**

4. LIQUEFACTION POTENTIAL ASSESSMENT

The saturated sandy alluvial deposits of the Sebaou site suggests that the soil is potentially liquefiable as observed during the May 21 2003 earthquake. Furthermore, the sand has fine content less than 35%, average grain size (D50) less than 10mm and the grain size of 10% passing is less than 1mm. It is obvious that the expected results will confirm such observations. Computation of safety factor F_L against liquefaction (Ratio of the cyclic shear resistance of the soil with the cyclic shear stresses caused by an earthquake) is performed following Youd and Idriss, 2001. The earthquake magnitude is 6.8 and the peak accelerations of different layers are indicated in table 5. The calculated safety factor is less than unity in all granular layers. In order to quantify the liquefaction effect the computation of liquefaction potential index P_L is made as follows:

$$P_L = \int_0^{20} F \cdot w(z)dz$$

Where $F = 1 - F_L$ and $w(z) = 10 - 0.5z$, P_L: Liquefaction potential index, F_L: Liquefaction resistance factor, w(z): weight function for depth, z: depth below the ground surface (m).
The results are interpreted according to Iwasaki *et al*. (1982) as follow: $P_L > 15$ (very high potential), $5 < P_L < 15$(Relatively high potential), $0 < P_L < 5$ (Relatively low potential), $P_L = 0$ (very low potential). The computation is made at the site of boreholes 2, 9 and 11 and results are shown in tables 6 and on figure 6. In all boreholes, the liquefaction potential index P_L is over 15; this indicates a high liquefaction potential.

Table 6 Computation of the security coefficient for liquefaction

	Z(m)	**γ(kN/m3)**	**N**	**FC %**	**N1(60)cs**	**a_{max}**	**CSR**	**CRR**	**F_L**
Hole N°2	5	21.0	11	5	12.7	0.47	0.413	0.138	**0.47**
	7	21.0	13	5	13.2	0.47	0.439	0,142	**0.42**
	11	21.0	15	5	12.6	0.47	0.442	0,137	**0.36**
	14	20.0	20	5	15.8	0.36	0.325	0,168	**0.58**
	18	20.0	26	5	18.4	0.36	0.281	0,196	**0.73**
Hole N°9	2	21.0	8	5	12.6	0.47	0.301	0.137	**0.77**
	4	21.0	10	5	12.5	0.47	0.390	0.136	**0.51**
	6	21.0	8	5	8.6	0.47	0.429	0.101	**0.32**
	7	21.0	8	5	8.4	0.47	0.451	0.100	**0.29**
Hole N°11	4	22.0	55	0	/	0.47	0.384	0.468	**/**
	6	21.0	21	5	22.64	0.47	0.428	0,251	**0.79**
	10	21.0	17	5	14.91	0.47	0.447	0,159	**0.42**
	15	21.0	13	5	9.56	0.36	0.396	0,109	**0.29**

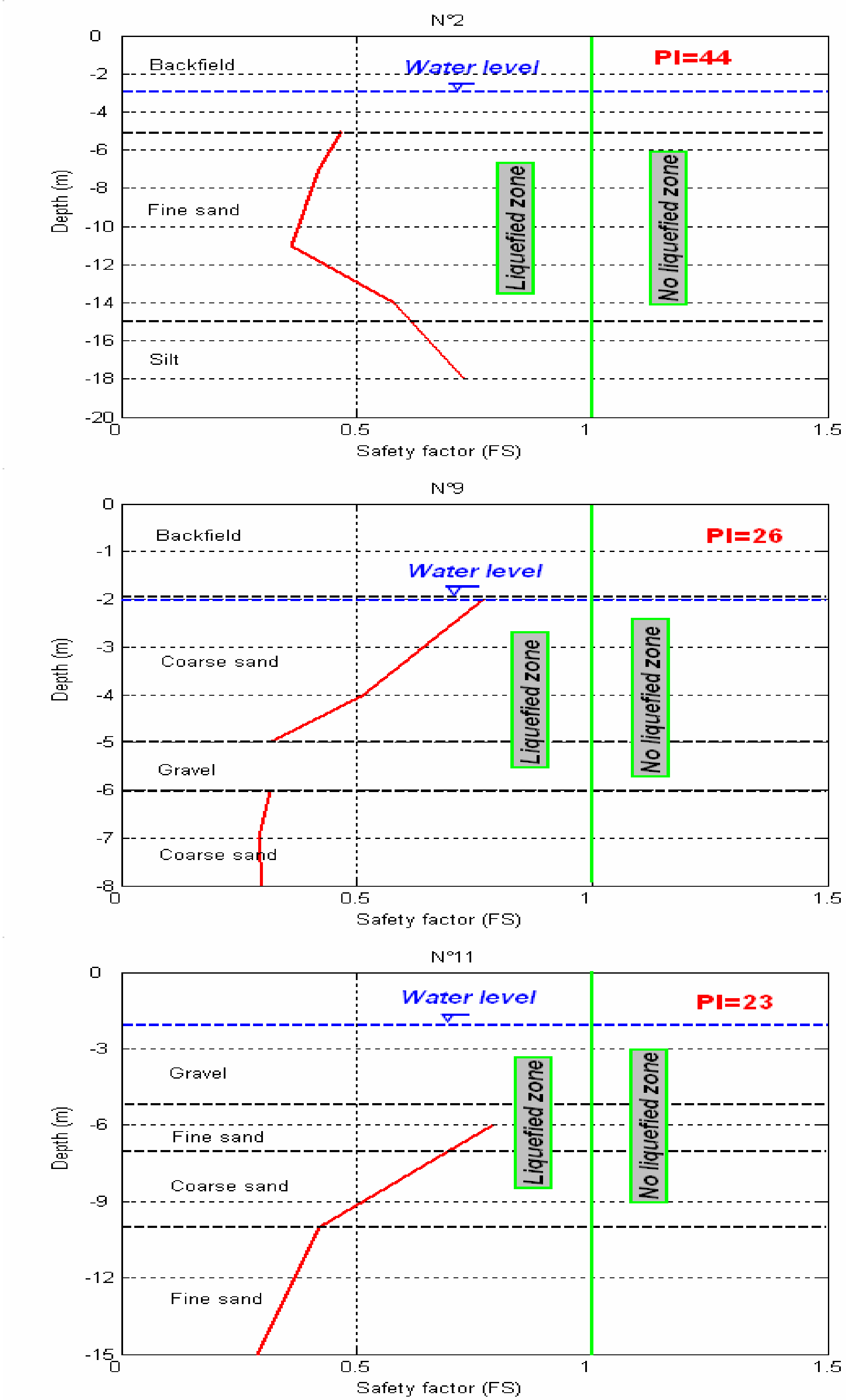

Figure 6 Variation of safety factor with depth at different boreholes

5. SURFACE SETTLEMENT EVALUATION

When liquefaction occurs, the increase in pore water pressure will dissipate. This dissipation is accompanied by a change of the soil deposits volume which appears at surface as settlement. A methodology to estimate the ground settlements resulting from liquefaction of sand deposits has been proposed by Ishihara and Yoshimine (1992). This methodology relates the factor of safety for liquefaction to the maximum shear strain developed in a deposit and a chart was developed to determine the volumetric strain as a function of the factor of safety as shown in figure 9.
The ground surface settlement may be estimated by multiplying the thickness of each layer by the strain. All the data needed for this estimation are taken from table 6, their average values are presented in table 7. The post liquefaction dynamic settlement estimated at boreholes sites seems important; it ranges from 25 to 72 cm following the thickness of the sand layer. Generally, the mean settlement is 40cm. This value should be taken into consideration in future constructions in the Sebaou site.
A geotechnical investigation (SPT) undertaken in 2004 at the Sebaou site, after the 2003 earthquake provide high values of the number of blows (Table 8). This is likely due to the compaction of the liquefied layers.

Table 8 SPT analysis results for the 2004 added borehole

Depth (m)	**N_1**	**N_2**	**N'**
9.00 – 9.45	32	36	68
11.00 – 11.45	22	42	64
13.00 – 13.45	25	33	58

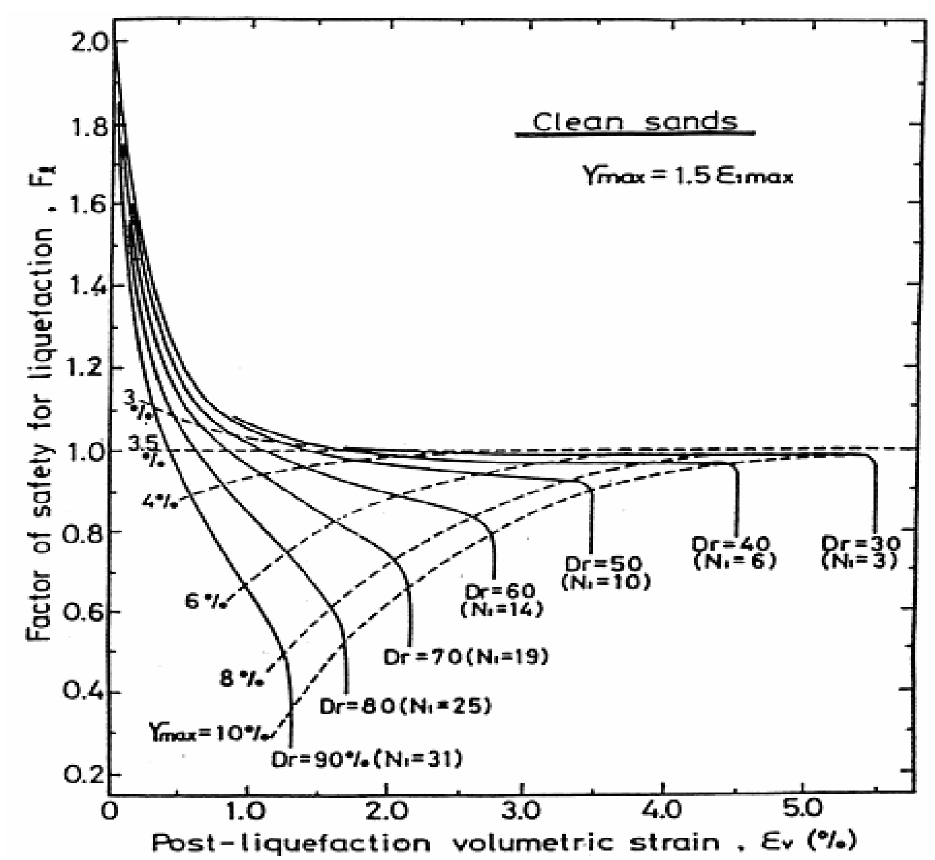

Figure 9 Estimation of the post liquefaction volumetric deformation

Table 7 Results of the settlement analysis

	H	**N**	**N1(60)cs**	**N1**	**FS**	ε_v	**ΔH**
Hole N° 2	10	13	12.8	10.65	0.48	3.4	0.34
	14	23	17.1	14.19	0.68	2.7	0.38
	Total						**0.72**
Hole N° 9	4	8	12.6	10.46	0.60	3.5	0.14
	3	10	12.5	10.37	0.30	3.5	0.11
	Total						**0.25**
Hole N° 11	2	21	22.64	18.79	0.90	1.3	0.03
	3	19	18.32	15.20	0.56	2.6	0.08
	6	15	12.23	10.15	0.42	3.5	0.21
	Total						**0.32**

6. LATERAL SPREADING EVALUATION

Lateral spreading is the horizontally motion of superficial soil following liquefaction. It occurs, usually, on very gentle slope. Several methods have been developed to estimate the lateral ground displacement at liquefaction sites. These methods include analytical models (Prevost *et al*., 1986Finn), physical models based upon sliding block analyses (Byrne *et al*., 1992), and empirical models. Among the empirical models that one been proposed by Bartlett and Youd (1992); They consider two statistically independent models, one for areas near steep banks with a free face, the other for ground slope areas with gently sloping topography. The second model is used in this study. The horizontal ground displacement is estimated by using the following formula:

$$\log DH = -15.7870 + 1.1782M - 0.9275\log R - 0.0133R + 0.4293\log S$$

$$+ 03483\log T_{15} + 4.5270\log(100 - F_{15}) - 0.9224D50_{15}$$

Where, DH lateral soil displacement (m.), $D50_{15}$ The mean size of particles in T_{15}, (mm), F_{15} mean amount of fines particles in T_{15}, (%), R the horizontal distance from the seismic energy source (km), S the slope angle (%.), T_{15} is total saturated granular thickness layers with *N1(60)cs* less or equal to 15 (m). The taken value of this latter is 10m. The mean particle size is 0.28mm. The mean fines particles, is 5%. The site is located 30km far from the epicenter. The site is characterized by a slight slop of 1%. The earthquake magnitude is 6.8.

$$\log DH = -0.5011$$

$$\mathrm{DH} = 0.32\,\mathrm{m}.$$

Generally, the lateral displacement could range from 1.5 to 2 times the estimated value. Therefore, the value of DH is about **16 cm to 64 cm**.

7. CONCLUSION AND DSICUSSION

A strong earthquake M_w=6.8 hits the Algiers-Boumerdes region on May 21st 2003. This earthquake triggered extensive liquefaction along the Sebaou valley. Based on the geology of the site and geotechnical data gathered from 10 boreholes performed at the time of Sebaou bridge construction during the seventeenth, a site response analysis is performed. The peak acceleration calibrated to 0.30g at the bedrock is amplified after propagation through the soil column model. An amplification ranging from 1.2 in intermediate layers to 1.5 in top layers is obtained. These accelerations are used for liquefaction potential calculation through the safety factor calculation according to Youd and Idriss method. In all granular layers, the safety factor is less than one. In order to quantify the liquefaction effect the computation of liquefaction potential index P_L is made according to Iwasaki and *al*. In all boreholes, the liquefaction potential index P_L is over 15, which means that the liquefaction potential is high. The ground surface settlement induced by liquefaction is estimated and appears important; it ranges from 25 to 72 cm with an average settlement of 40cm. A geotechnical investigation (SPT) undertaken in 2004 at the Sebaou site, after the 2003 earthquake, provide high values of the number of blows, this is due to the compaction of the liquefied layers.

A statistically independent model proposed by Bartlett and Youd for ground slope areas with gently sloping topography is used in this study to estimate the horizontal ground displacement. The obtained results are about 16 cm to 64 cm.

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