Réunion technique du C.F.M.S. du 5 mai 2004

Dynamique, séisme, traitement des sols en zone sismique

Exemple du chantier de San Diego

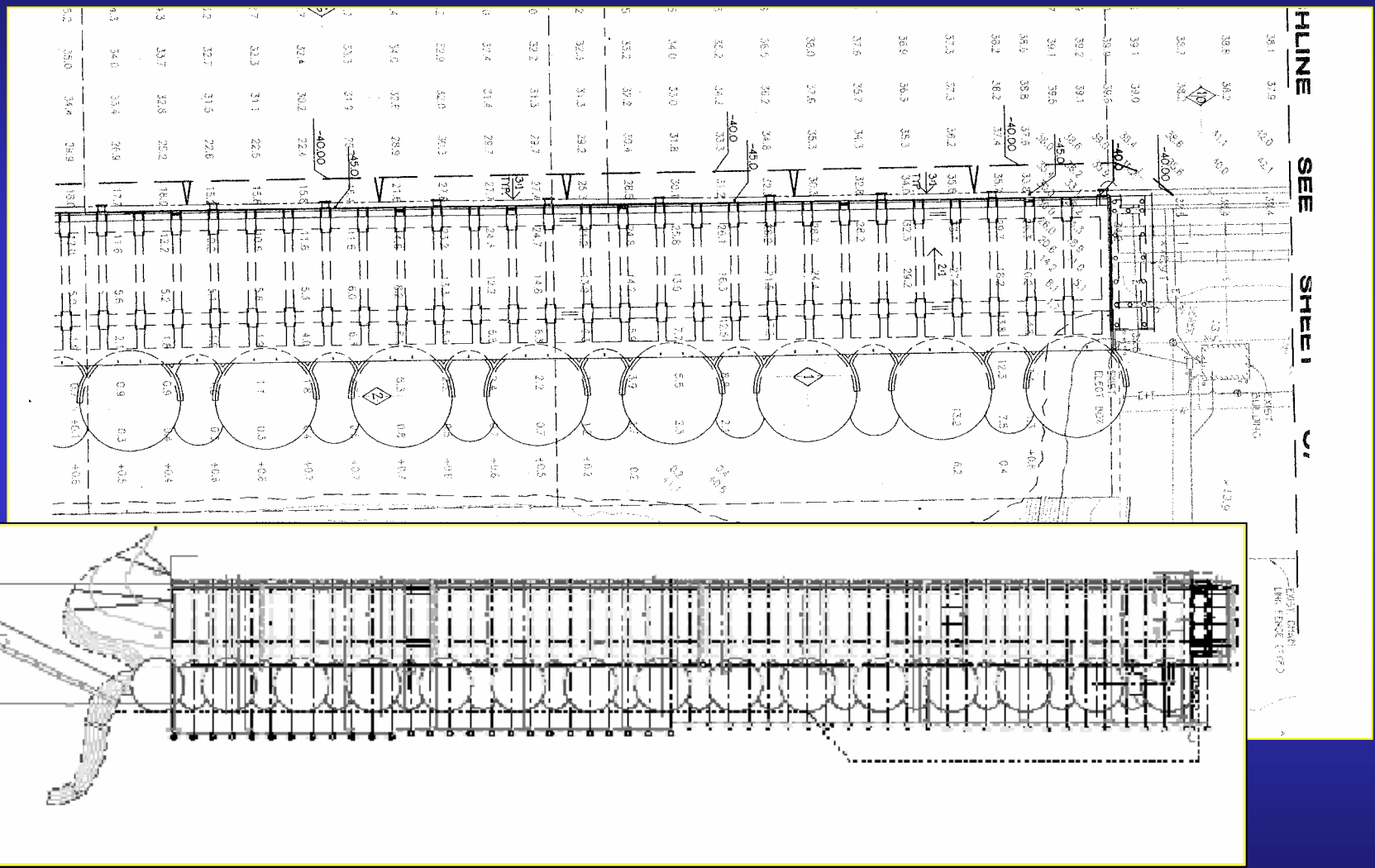
Philippe LIAUSU

MENARD SOLTRAITEMENT

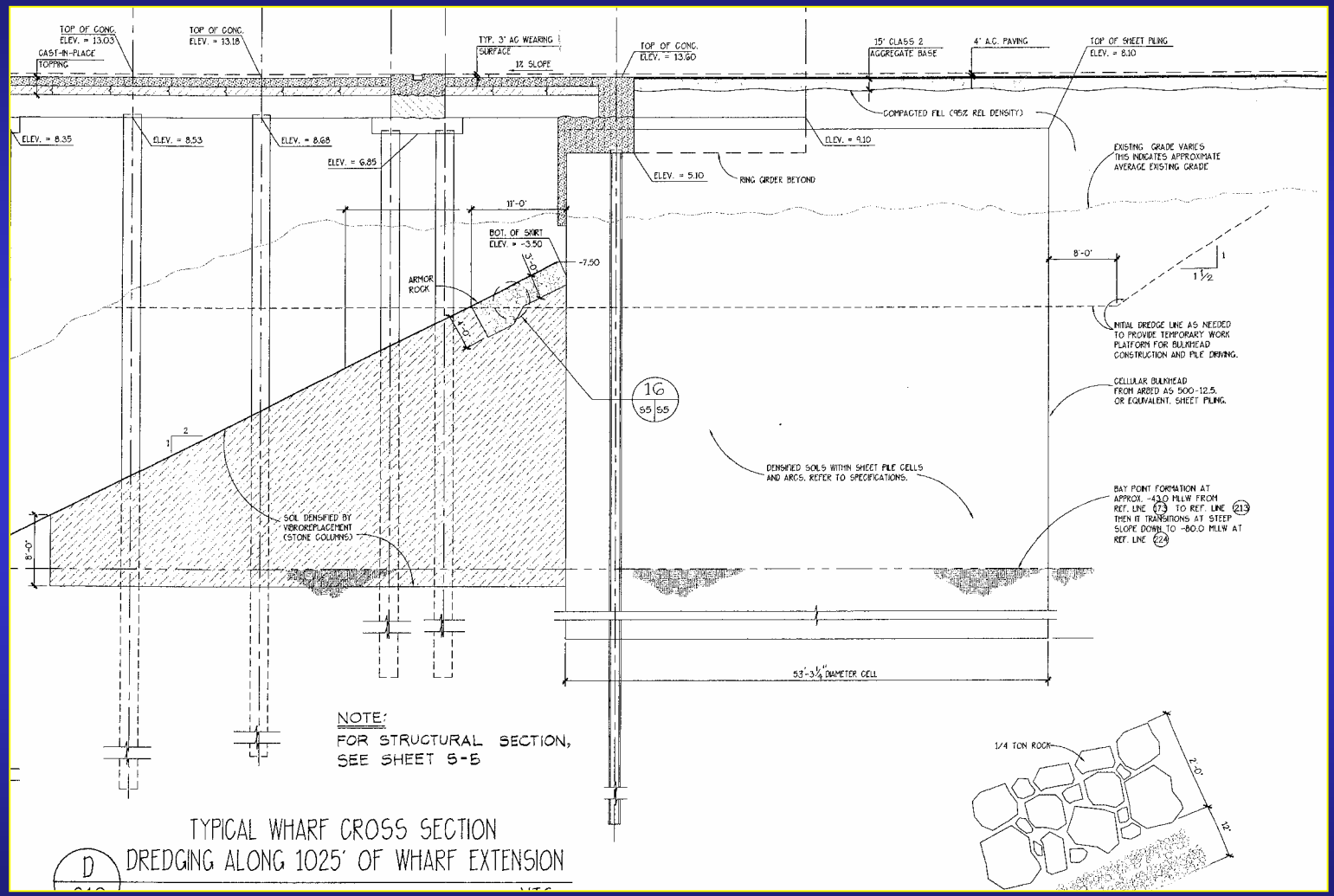
- ***Projet***: Extension du « National City Marine Terminal » dans le Port de San Diego en Californie
- ***Maître d'Ouvrage***: San Diego Unified Port District
- ***Architecte***: Atkinson, Johnson & Spurrier, Inc.
- ***Ingénieur***: URS Greiner
- ***Entreprise Générale***: General Constuction Co.
- ***Travaux:*** réalisés en 2002/2003

- Réalisation d'un quai de 340 m de longueur et 23 m de large
- Arrière-quai constitué de gabions en palplanches de 15 m de diamètre
- platelage du quai fondé sur pieux dans le talus situé devant les gabions
- sol en place constitué d'alternances de couches de sable et de limon
- zone sismique

Vue en plan de la zone du projet dans le port



Vue en plan du projet (générale et détail)



Coupe type du projet

Project: National City Marine Terminal
Project Location:
Project Number: 58-9551160H.00-SI003

Log of Boring B-27
Sheet 1 of 3

Date(s) Drilled	8/24/99	Logged By	A. Greene	Checked By	J. Metzinger
Drilling Method	Rotary wash	Drill Bit Size/Type	3.75" drag bit	Total Depth Drilled (feet)	84.5
Drill Rig Type	Mobile B-61	Drilling Contractor	F&C Drilling	Hammer Weight/ Drop (lbs/in.)	140/30
Groundwater Depth	NA	Sampler Type	SPT, Mod Cal	Approx. Surface Elev. (feet, MSL)	-6.3 MLLW
Location	See Site Plan			Borehole Backfill	Soil cuttings

Elevation, feet (MLLW)	Depth, feet	Sample Type	Sample Number	Sampling Resistance	Graphic Log	MATERIAL DESCRIPTION	Water Content, %	Dry Unit Weight, pcf	REMARKS/ LAB TESTS
	0		27-1	WR		BAY DEPOSITS Very loose, wet, dark gray, poorly graded fine to very fine SAND (SP), micaceous with shell fragments			
-10	5		27-2	6			29		
-15	10		27-3	12		Medium stiff to stiff, wet, dark gray, sandy SILT (ML)			WA(58)
-20	15								
-25	20		27-4	7			36	87	
						Loose to medium stiff, wet to moist, dark gray, interbedded silty fine SAND (SM) and sandy silty CLAY (CL-ML), micaceous			
			27-5	5			37		LL=30, PI=7
-30	25								
-35			27-6	12		Interbedded poorly graded, fine SAND with abundant shell fragments and sandy SILT (SP/ML)	36	86	WA(51)
	30					Very dense to dense, wet, gray, silty fine SAND (SM), micaceous, abundant shell fragments			
-40	35		27-7	50			25		SA(15)

URS

Figure A-10

7/18/01 1GL10P NCMT

Printed: 7/18/01

Project: National City Marine Terminal
Project Location:
Project Number: 58-9551160H.00-SI003

Log of Boring B-27
Sheet 2 of 3

Elevation, feet (MLLW)	Depth, feet	Sample Type	Sample Number	Sampling Resistance	Graphic Log	MATERIAL DESCRIPTION	Water Content, %	Dry Unit Weight, pcf	REMARKS/ LAB TESTS
	35					Increase in silt			
-45	40		27-8	21		Becomes medium dense, moist	29	97	
						Becomes finer			
-50	45		27-9	15		Very stiff, moist, dark gray, sandy SILT with shell fragments (ML)	29		WA(68)
						Becomes more clayey			
-55	50		27-10	17		Very stiff, moist to wet, dark gray, fat CLAY (CH)	60	65	WA(97), LL=85, PI=52, CORR
-60	55		27-11	18		Medium dense, moist to wet, dark gray, silty fine SAND (SM)	33		WA(48)
						Decreasing silt			
-65	60		27-12	44		Becomes dense	27	97	
-70						Stiff to very stiff, moist, dark gray, lean CLAY (CL), with sand and rootlets			
	65		27-13	15			32		WA(78), LL=48, PI=26
-75	70		27-14	16		Becomes olive gray	33	90	WA(98), DS, CONS
-80	75		27-15	23		Becomes olive brown	29		
						BAY POINT FORMATION			

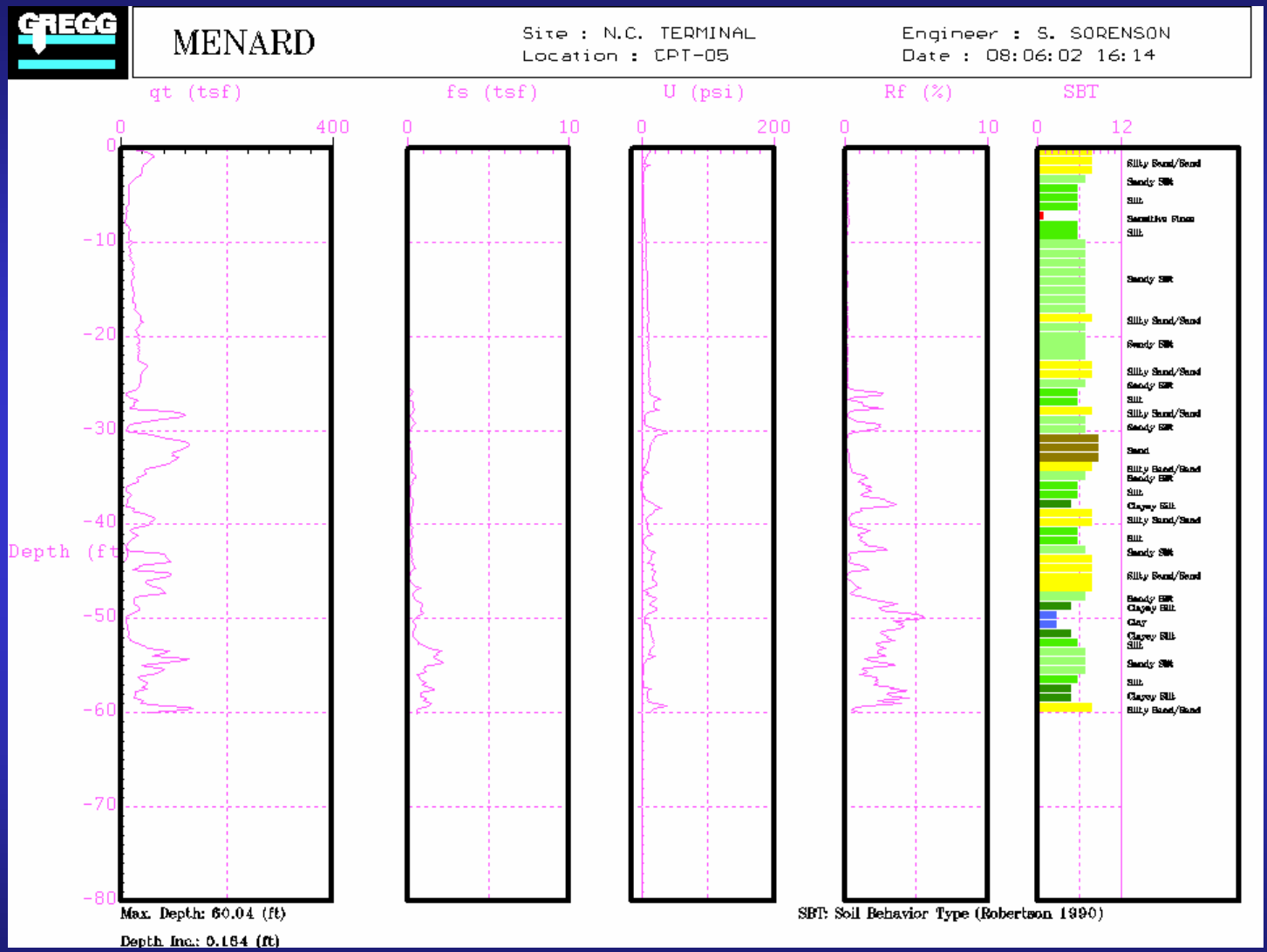
URS

Figure A-10 (cont'd)

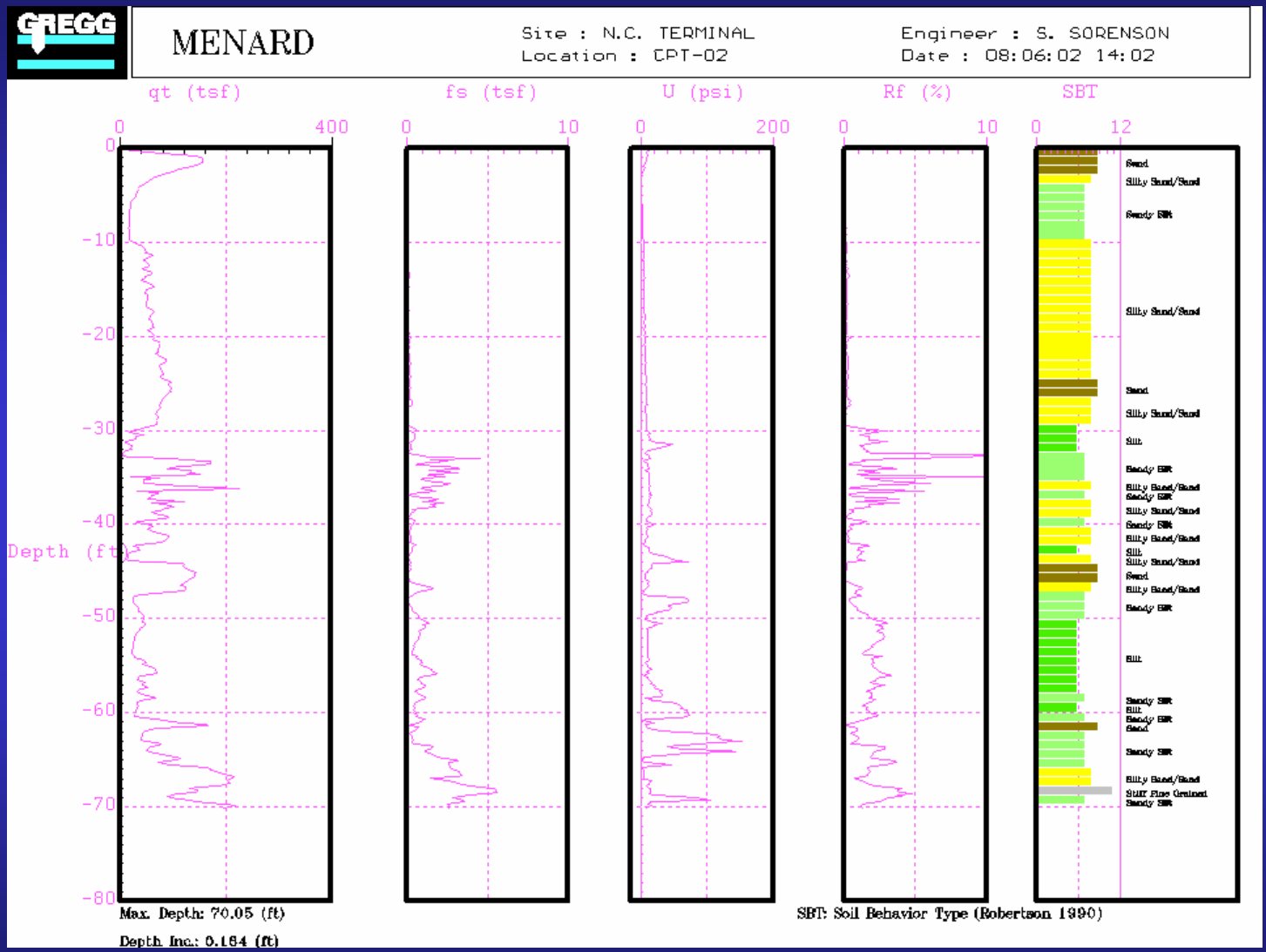
7/18/01 1GL10P NCMT

Printed: 7/18/01

Exemple de sondage de l'étude préliminaire

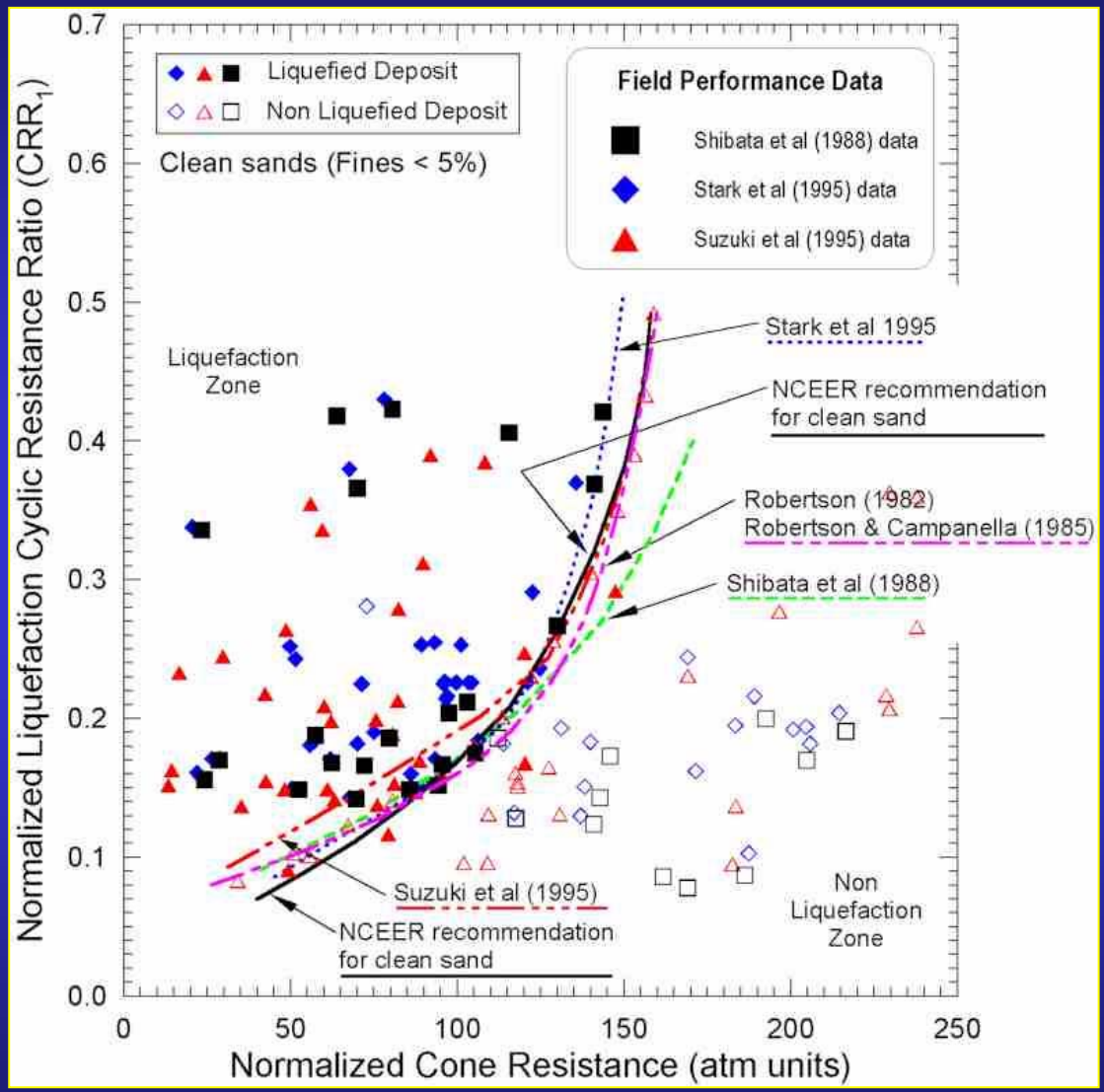


Exemple de CPT avant traitement (2)


GREGG
MENARD
Site : N.C. TERMINAL
Location : CPT-02
Engineer : S. SORENSON
Date : 08:06:02 14:02
qt (tsf)
fs (tsf)
U (psi)
Rf (%)
SBT
Depth (ft)
Max. Depth: 70.05 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)

Site	Sample Designation	% Gravel	% Sand	% Fines[a, b, c]	
				% Silt	% Clay
1	1-1T	6.4	72.3	16.2	5.1
1	1-2	8.5	49.8	24.0	17.8
1	1-3T	7.1	79.8	10.1	2.9
1	1-4T	0.1	92.5	3.7	3.7
1	1-4B	0.1	83.3	7.7	8.9
1	1-5	0.2	60.0	22.8	17.1
2	2-1	13.5	71.3	9.3	5.9
2	2-2T	4.3	85.0	6.3	4.4
2	2-2B	4.4	78.7	10.8	6.1
2	2-3	1.2	93.3	2.1	3.5
2	2-4T	3.7	85.1	8.1	3.0
2	2-4B	10.8	65.5	16.3	7.3
2	2-5T	3.3	78.8	15.2	2.7
2	2-5B	0.4	86.6	7.1	5.9
3	3-1T	6.7	75.7	11.4	6.2
3	3-1B	3.0	82.3	9.5	5.1
3	3-2	5.6	85.6	5.2	3.5
3	3-3	2.8	87.7	6.3	3.2
3	3-4T	2.2	73.5	19.9	4.3
3	3-4B	19.9	67.3	7.9	5.0
3	3-5T	1.5	64.1	24.4	10.0
3	3-5B	1.4	57.9	25.0	15.6
4	4-1	1.9	70.1	15.2	12.8
4	4-2T	1.2	78.9	13.3	6.6
4	4-2B	9.6	79.1	6.0	5.3
4	4-3	3.8	83.6	6.0	6.7
4	4-4T	2.5	73.9	16.7	6.8
4	4-4B	8.2	72.5	7.5	11.8
4	4-5T	0.6	74.8	16.4	8.2
4	4-5B	0.6	74.8	16.4	8.2
5	5 composite	3.4	62.5	21.0	13.1
6	6 composite	4.8	59.3	22.1	13.8

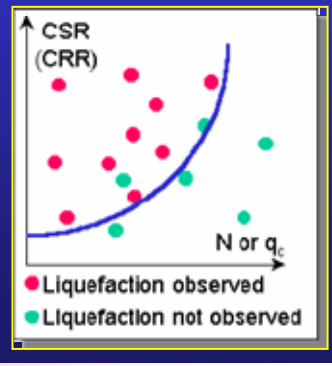
Granulométrie des échantillons de sol

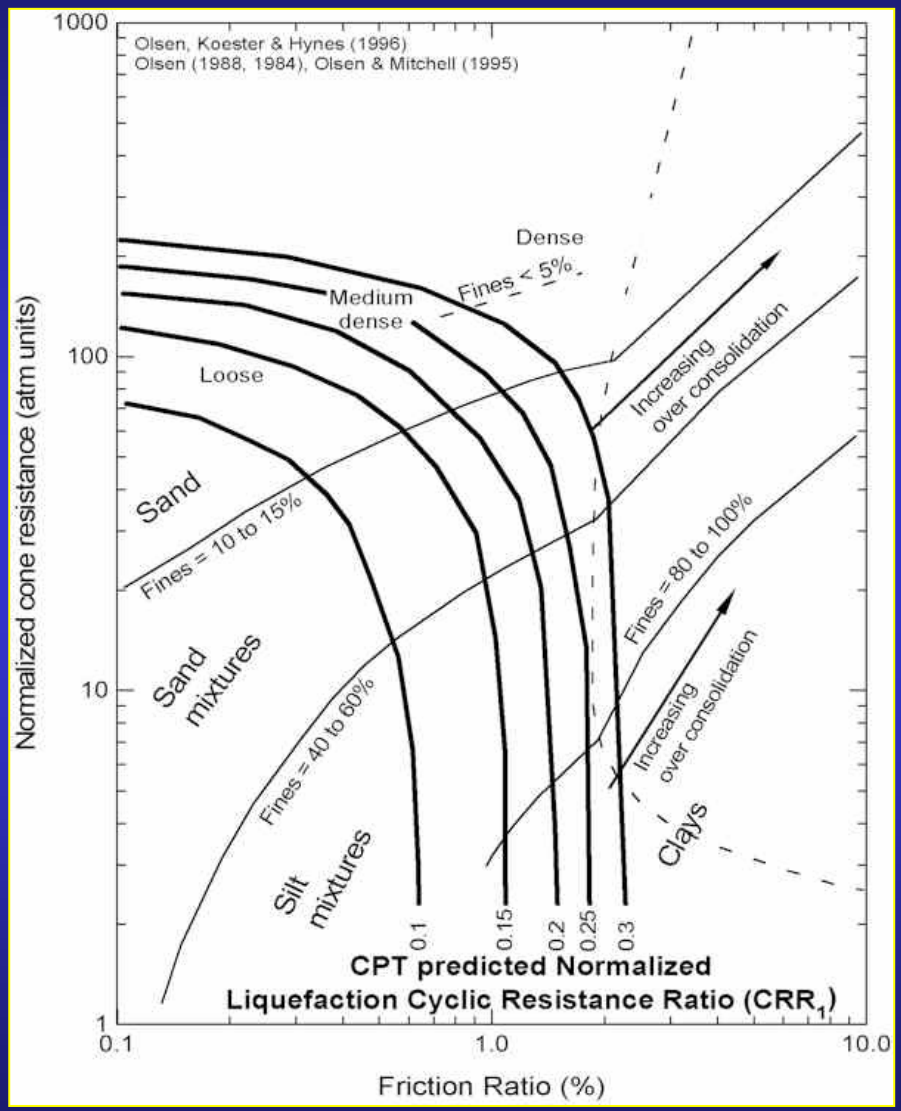


Pour les couches sableuses propres

Analyse du potentiel de liquéfaction

(selon méthode du National Center for Earthquake Engineering Research: NCEER)





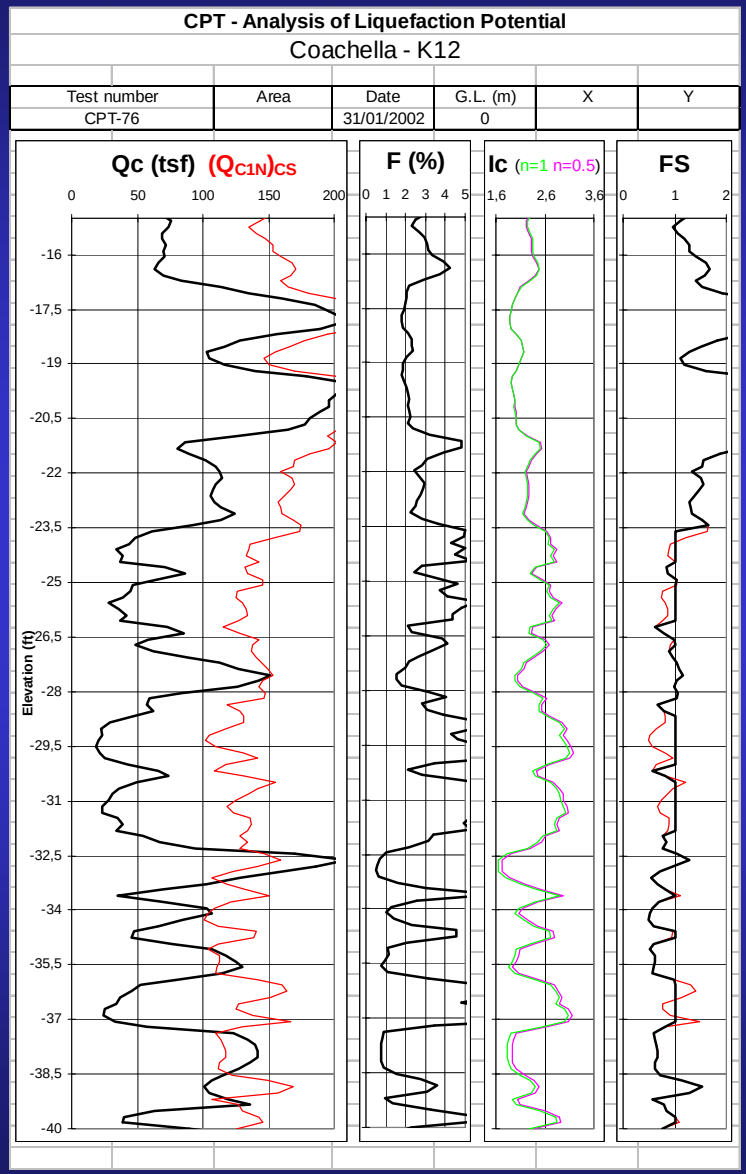
Analyse du potentiel de liquéfaction

(selon méthode du National Center for Earthquake Engineering Research: NCEER)

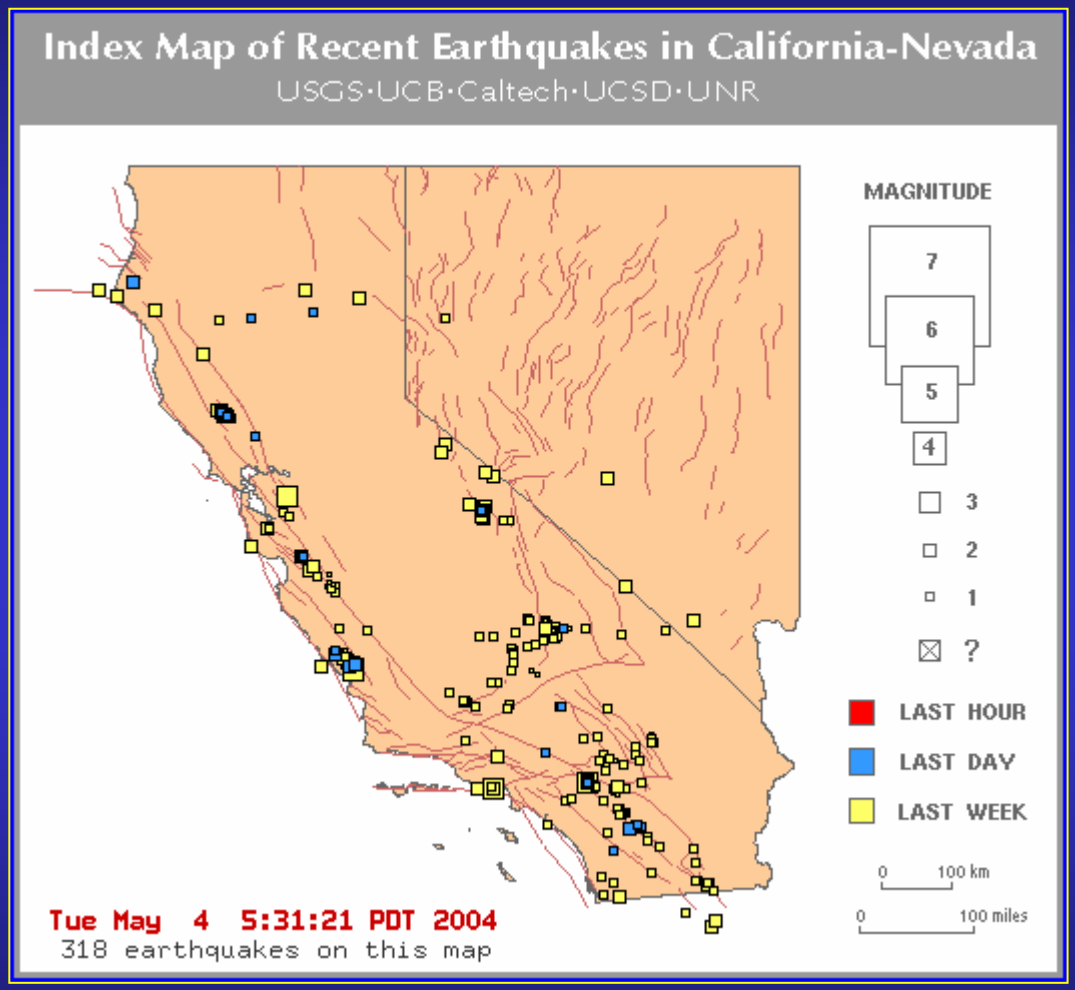
Pour les couches fines, vérification du critère de Wang:

Risque de liquéfaction si:

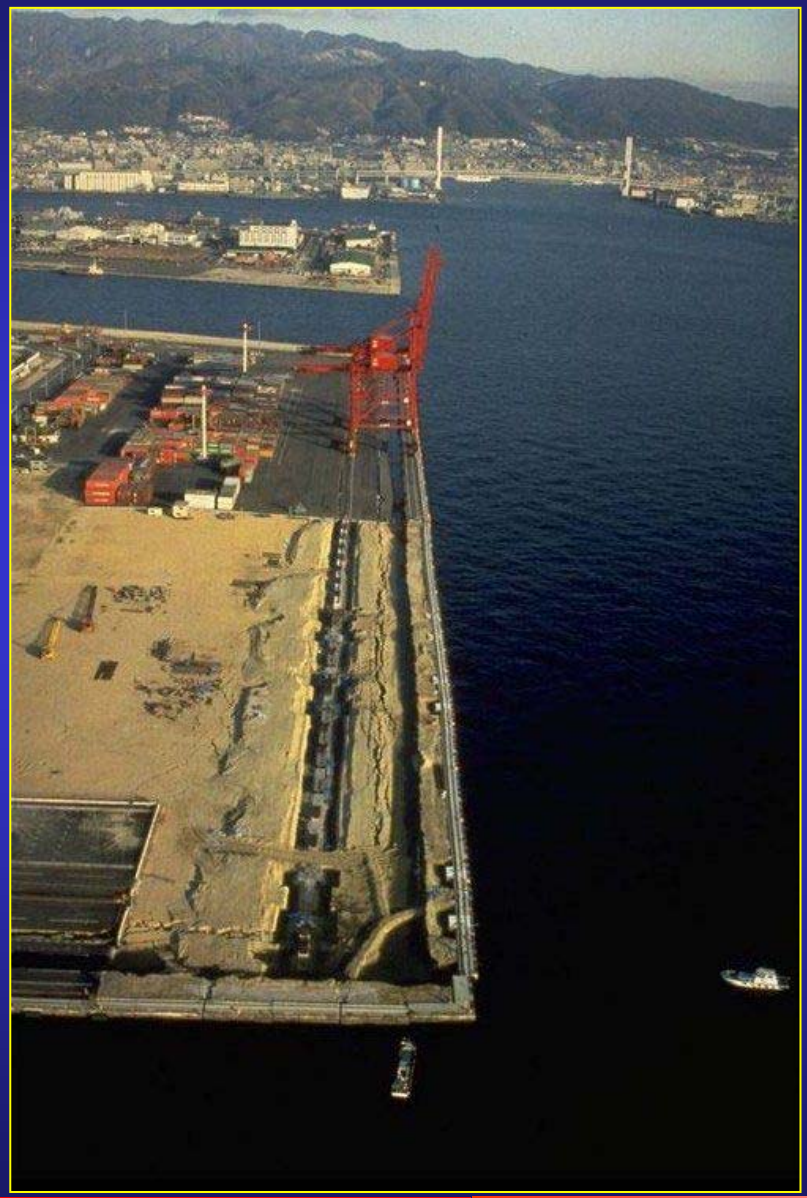
- **fraction fine 0,005 mm <15%**
- **limite de liquidité W_L <35%**
- **teneur en eau W > 0,9 x W_L**



Exemple d'analyse du risque de liquéfaction



La Californie est une zone sismique !



Nécessité d'un traitement de sol pour éviter les dommages potentiels consécutifs à une liquéfaction du sol en cas de séisme

(exemple de quai endommagé à Kobé)

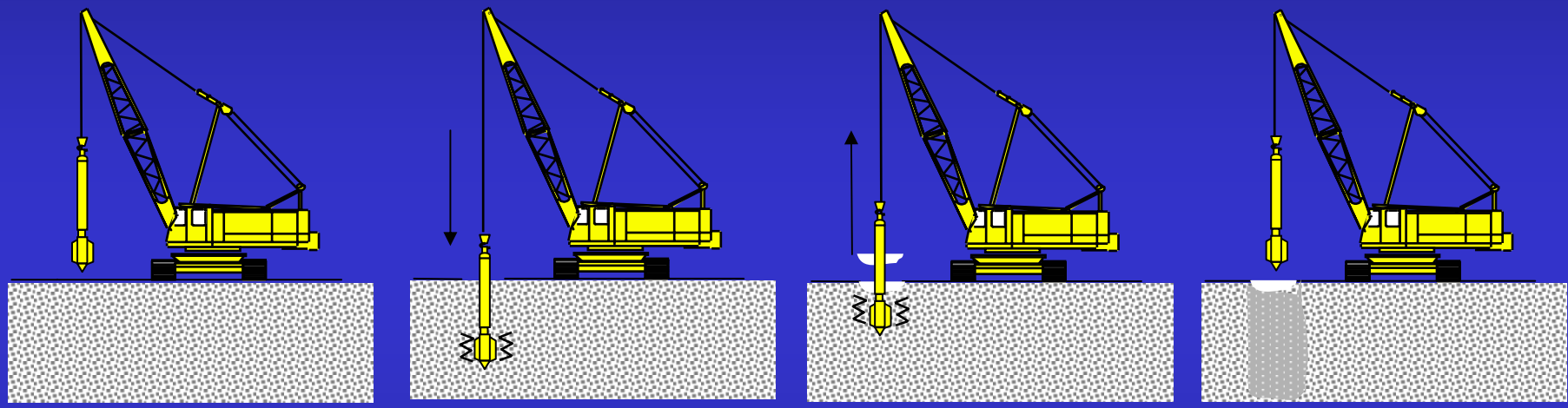
Spécifications du traitement de sol:

Fr = friction ratio

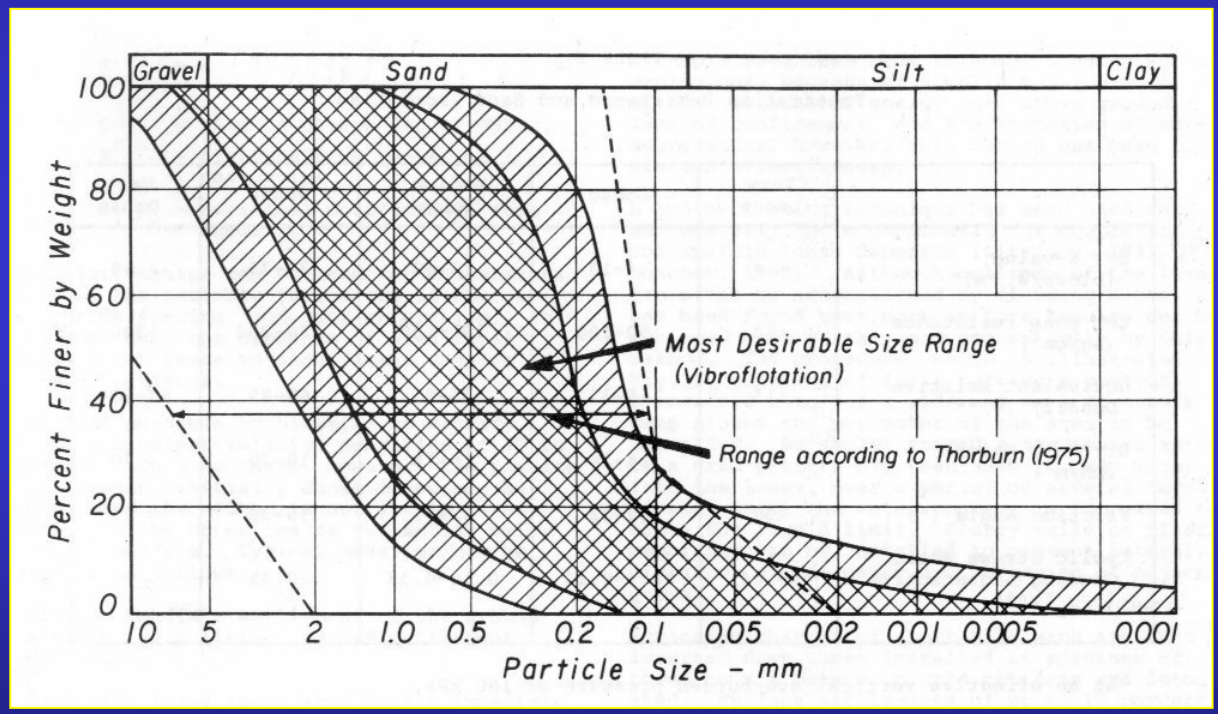
Qc = cone resistance

- **si Fr < 0,5% : Qc > 110 tsf**
- **si 0,5% < Fr < 1% Qc > 80 tsf**
- **si Fr > 1% Qc > 50 tsf**

(Séisme de référence: 0,38 g Magnitude 7)



Principe d’exécution de la vibroflotation



Fuseau granulométrique des sols traitables par vibroflotation

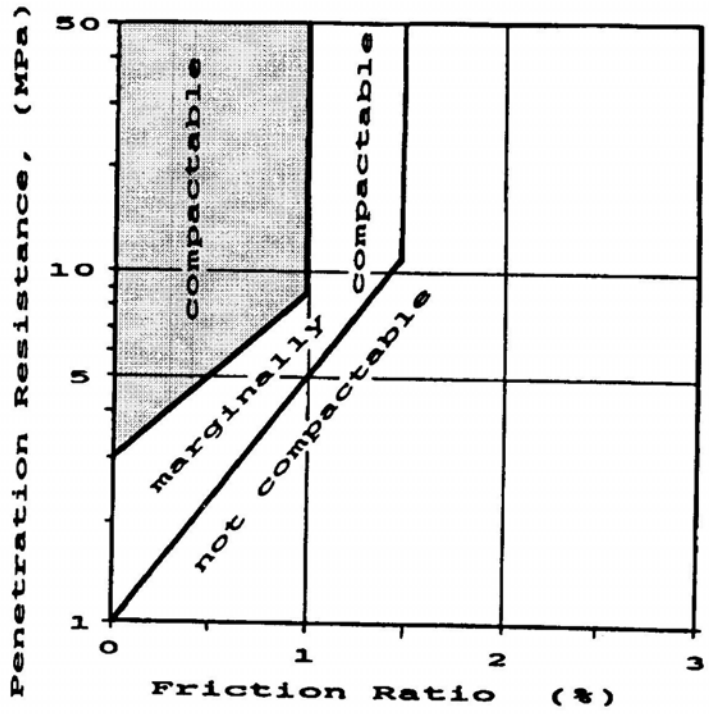
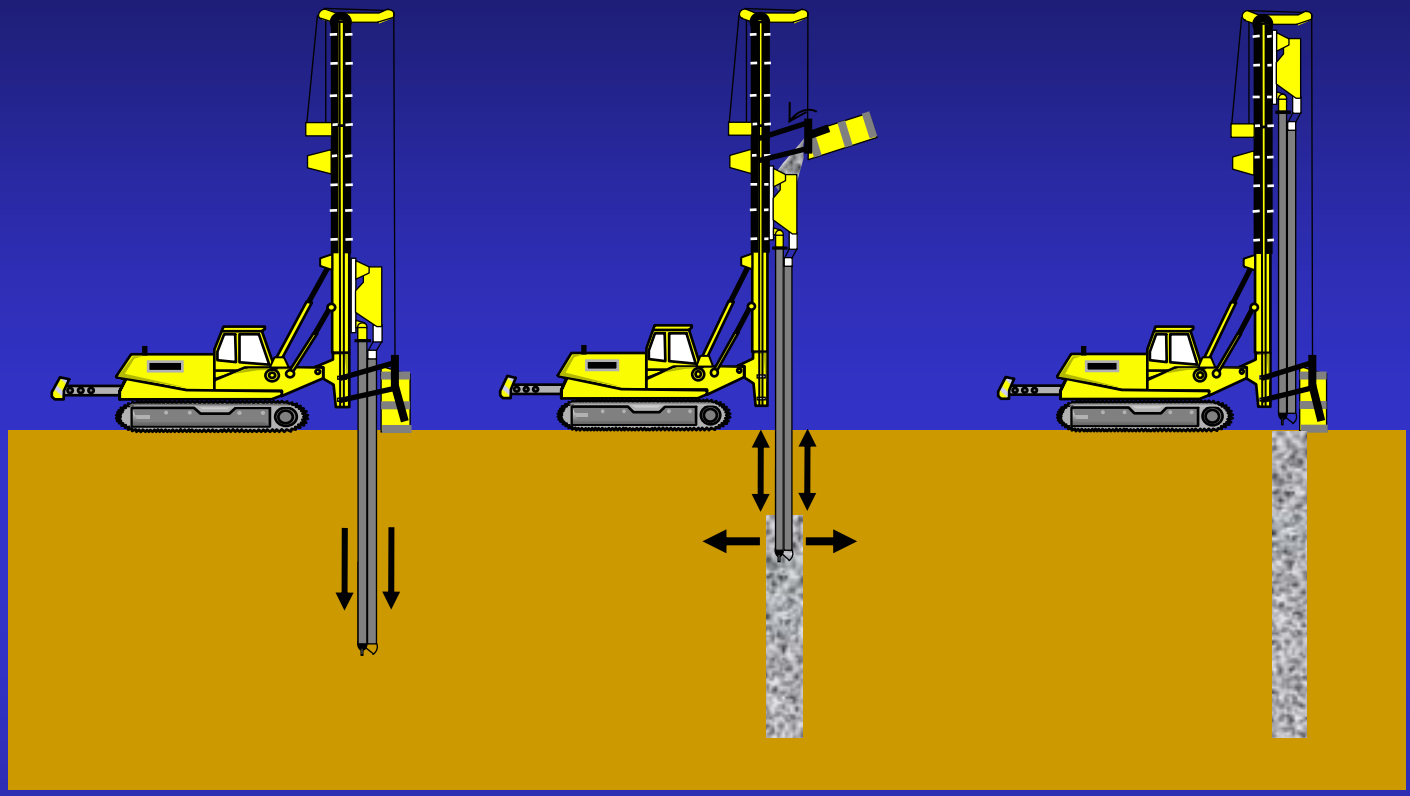


Figure 1 Suitability of Soils with Respect to Vibratory Compaction, Based on Electric Cone Penetration Tests with Friction Sleeve Measurements, Massarsch and Heppel (1991).

Utilisation du pénétromètre statique pour vérification de la possibilité de vibrocompactage des sols

Compactage en masse ***Renforcement de sol***

Sols à comportement granulaire **sols à comportement cohérent**

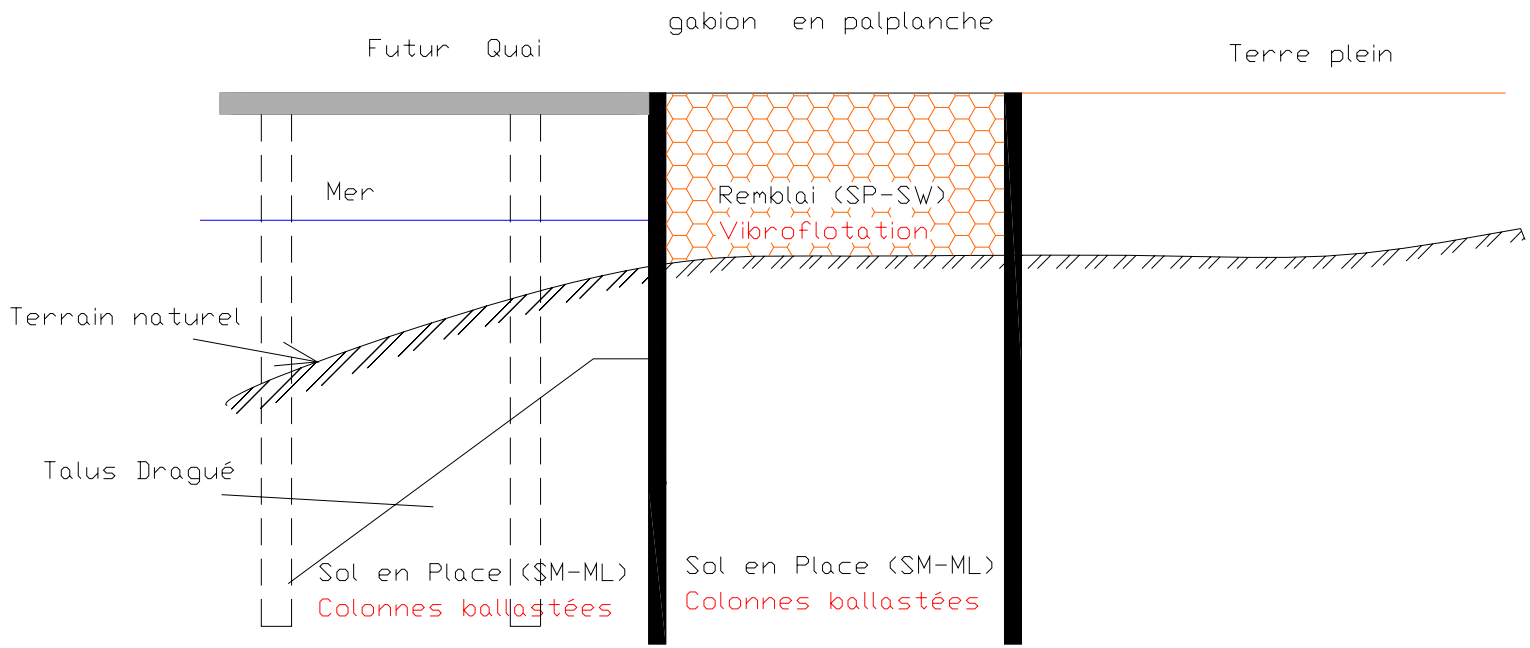


1 - Fonçage avec lançage (eau ou air)

2 - Incorporation de matériaux et compactage du ballast

3 - Colonne Terminée

Principe de réalisation des colonnes ballastées (« bottom feed »)



Principe du traitement de sol en coupe

Vue du vibreur Ménard BD 300

CARACTÉRISTIQUES TECHNIQUES			
SASà gravier préssurisé			
volume	1 m3	pression	< 7 bars
Skip automatique			
Volume	1 m3	vitesse	0.8 m/s
Groupe hydraulique			
CAT Engine		kW	245
Vibrofloat			
Type 300 BD HF		kW	140
Pression maximum		bars	300
Force centrifuge max		kg	14.500
Fréquence max		Hz	35
Amplitude max		mm	14
"bottom feed" tube		mm	170
Pompe de lançage (optionnelle)			
Landini	débit max	m3/h	120
	P max	bars	16
Compresseur			
	flow min.	litres/min	12.000
	P max.	bars	7

Spécifications du vibreur Ménard BD 300

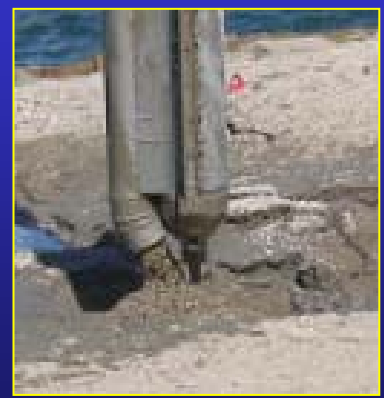
Les colonnes ballastées

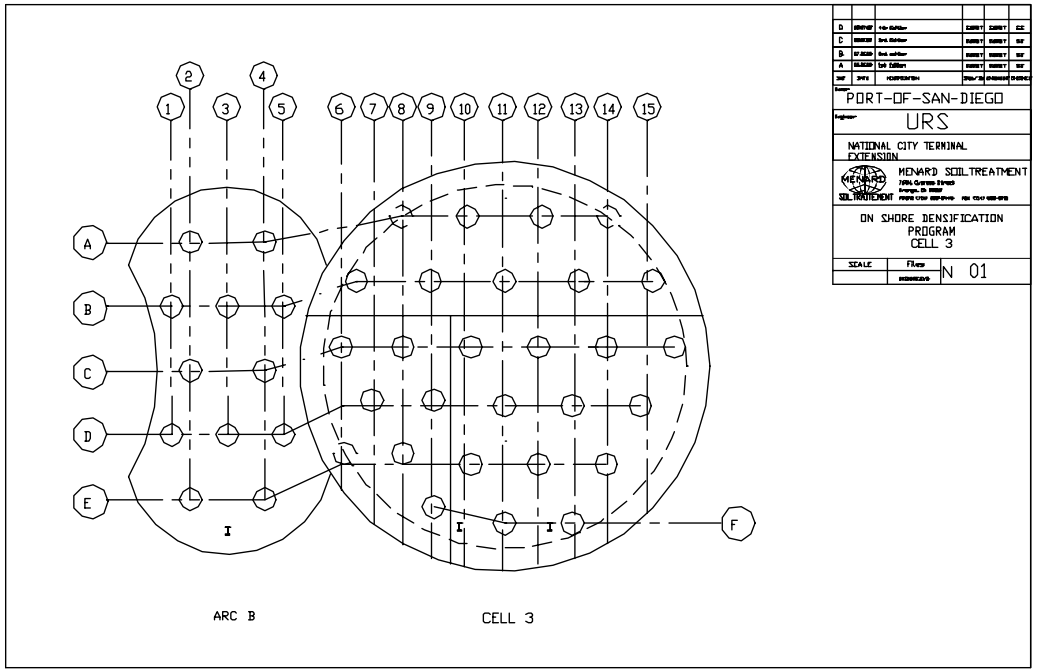
Vues de l’atelier

Vue du sas pressurisé

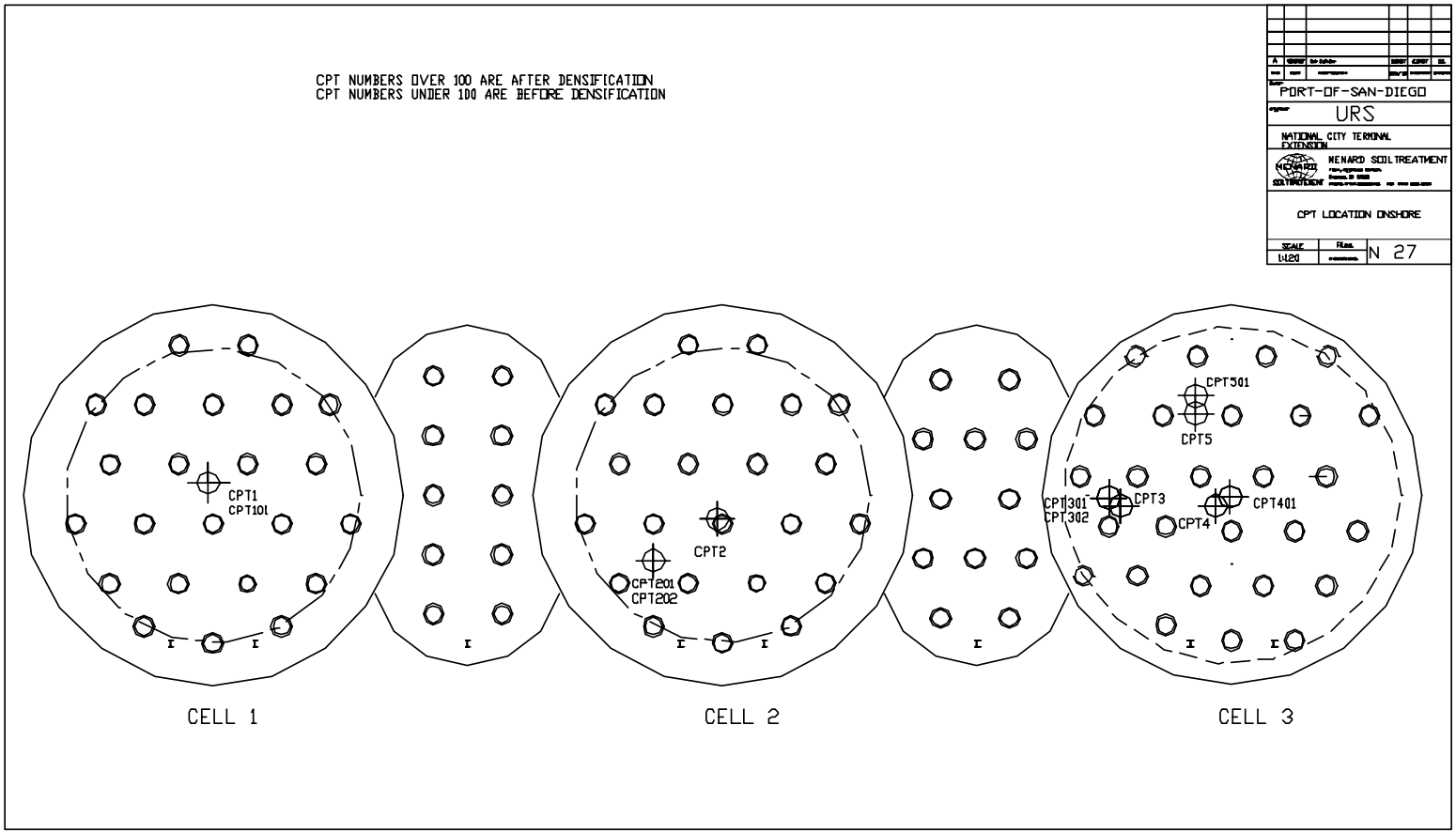
Traitement on-shore dans les caissons

Traitement on-shore





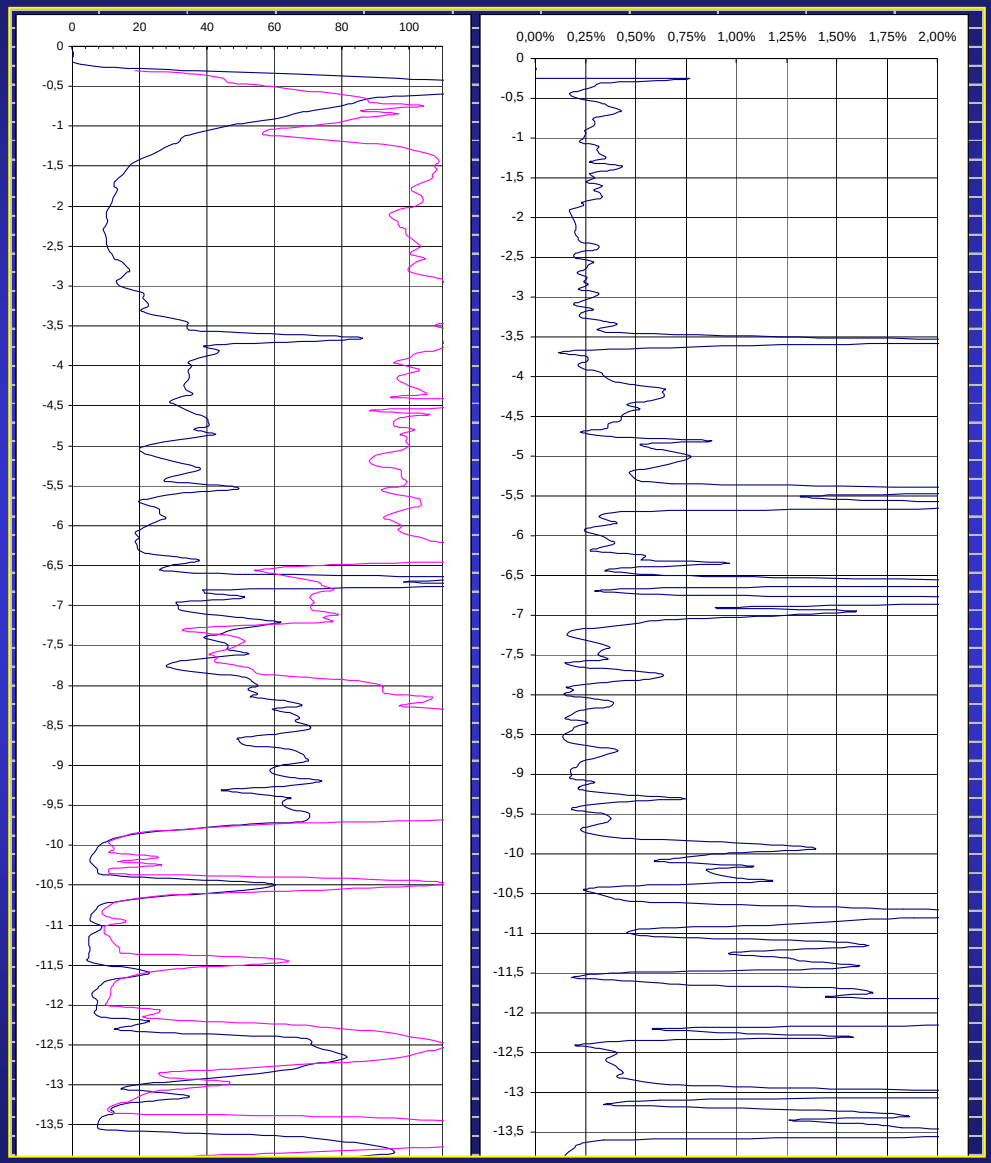
Traitement on-shore dans les gabions



Positionnement des sondages de contrôle on-shore

	feet	m
Plateforme elevation before compaction	9,9	3,01752
Plateforme elevation after compaction	7,9	2,40792
	sf	m²
Area of a cell	2289,06	212,7
	cf	m3
Settlement volume	4578,1	129,6
Stone quantity incorporated		94
Total incorporated		223,6
Area of a column (m²)	0,6	
Area of the grid (m²)	7,8	
Replacement ratio(%)	**8,2%**	

Analyse du taux d'incorporation (cellule 8)



Comparaison CPT

On-shore

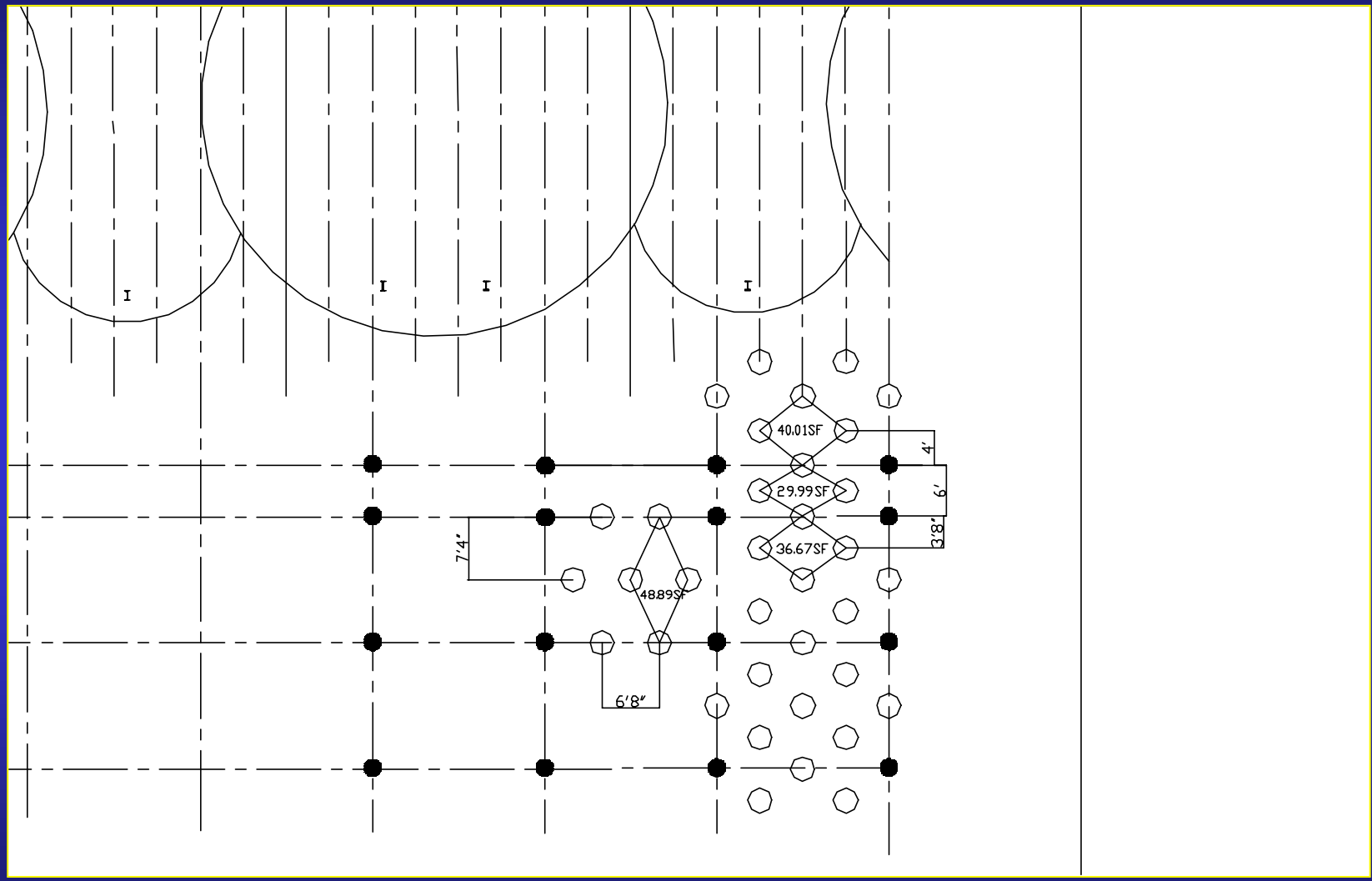
Avant traitement CPT 3

et

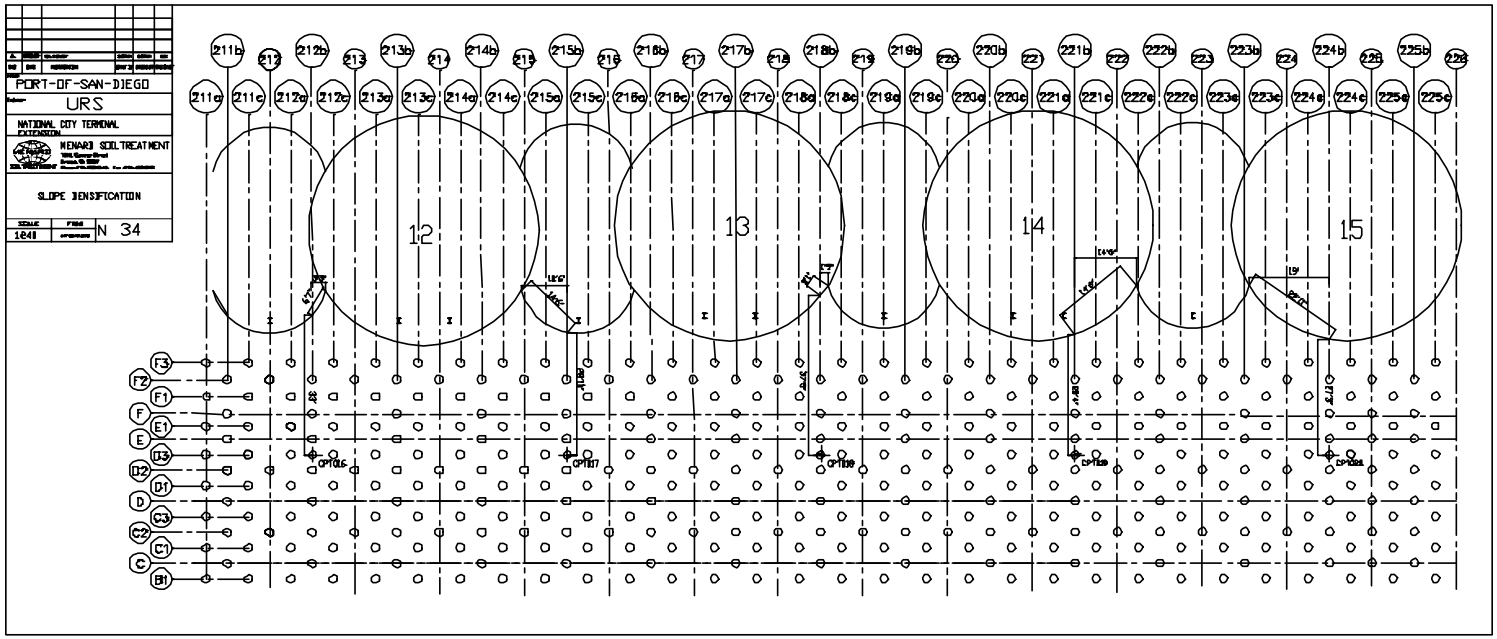
Après traitement CPT 301

Système de chargement du ballast pour les colonnes off-shore

Réalisation de colonnes off-shore



Zone d'essai off-shore



Traitement off-shore

Atelier de sondages de contrôle off-shore

Vue générale du chantier

Dragage du talus

San Diego Vibro SAS

Poste de pilotage

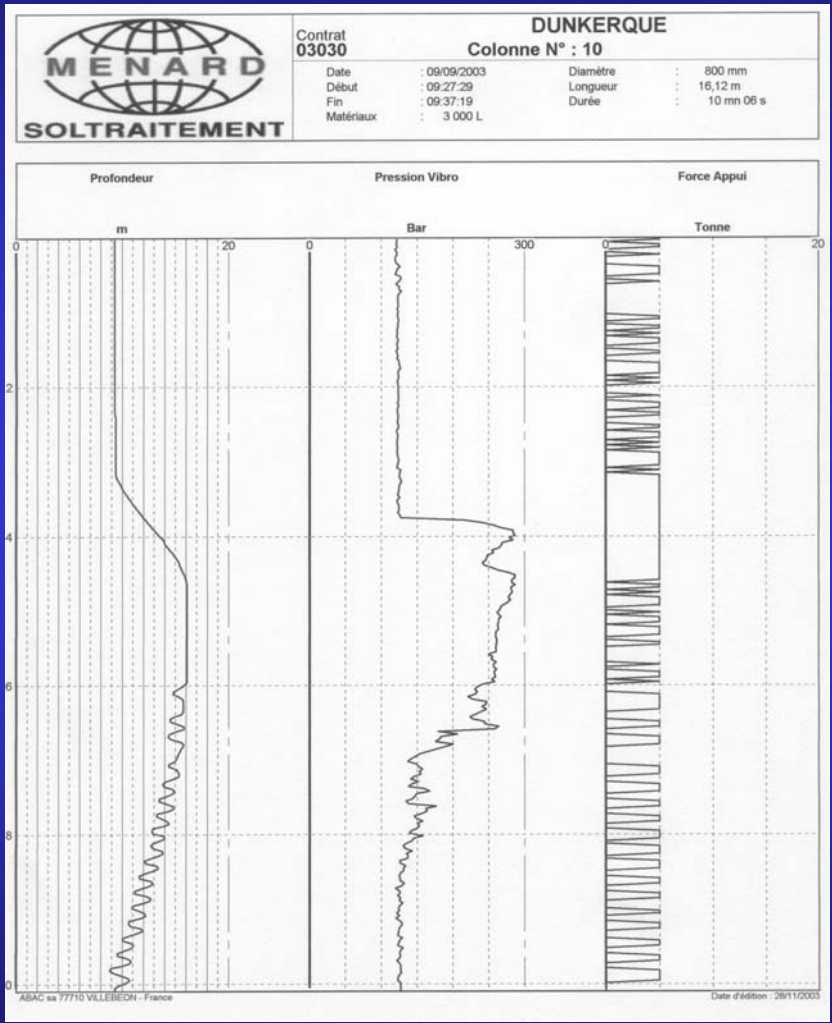
Gravel skip video monitoring

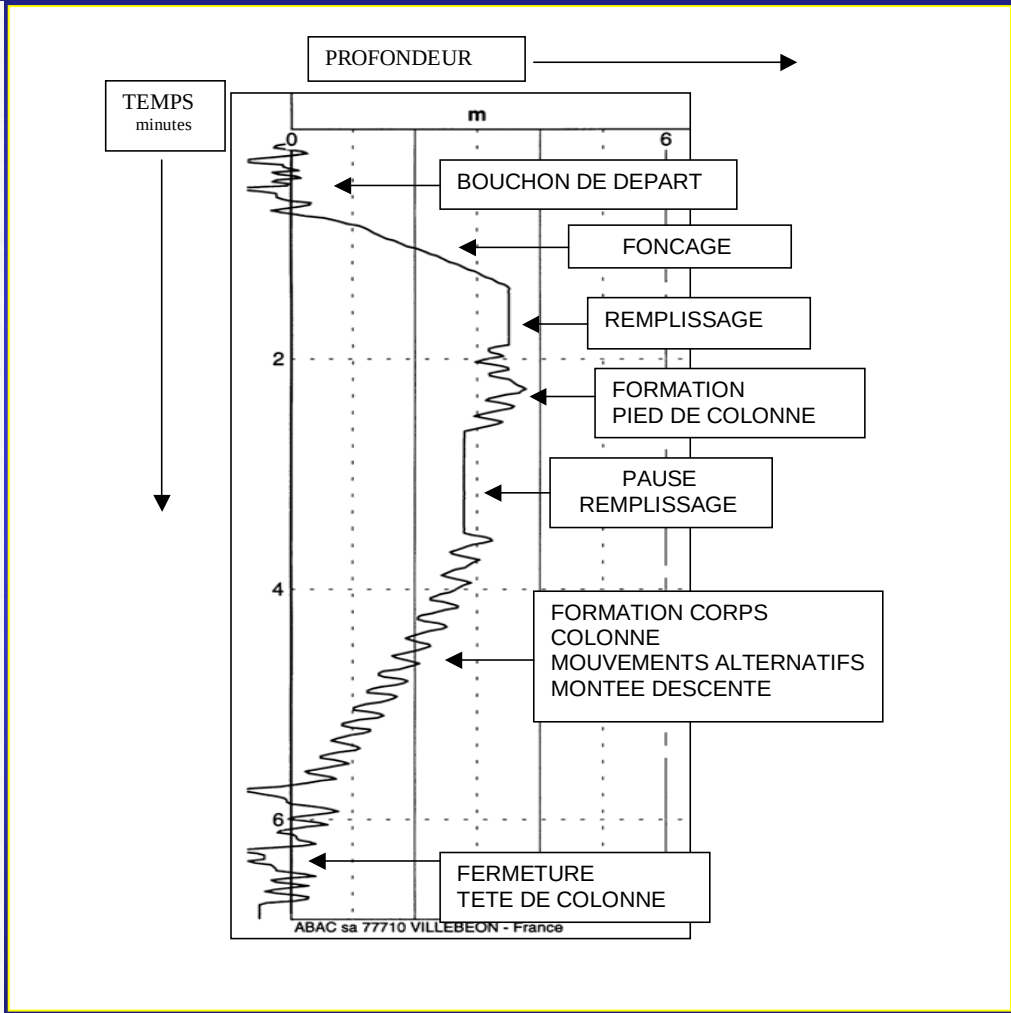
Crane load sensor

GPS screen For real time positioning

Menard Emparex data logger and process control system

Vibro SAS machine control panel





Exemple d’ enregistrement de paramètres

Liquefaction analysis - after compaction

Computation of Factor of Safety after treatment in each layer from 25 to 40 feet

layer [1]	level [2]	fines % [3]	D_{50}	Qc / Pa	N [4]	Cn [5]	α [6]	β [6]	Thin Soil Layers [7]		$N_{1,60CS}$	liquefaction potential
									H (ft)	ΔN		
-25/-26.5	-25	54	0,06	100	38	0,9	5,0	1,2	3,5	0	43	non liquefiable
-26.5/-28	-26,5	31	0,16	140	41	0,8	4,8	1,2	3,5	0	45	non liquefiable
-28/-29.5	-28	27	0,2	100	28	0,8	4,5	1,1	3,5	0	31	non liquefiable
-29.5/-31	-29,5	63	0,05	70	29	0,8	5,0	1,2	3,5	0	33	non liquefiable
-31/-32.5	-31	53	0,07	80	30	0,8	5,0	1,2	3,5	0	34	non liquefiable
-32.5/-34	-32,5	36	0,13	160	50	0,8	5,0	1,2	3,5	0	53	non liquefiable
-34/-35.5	-34	27	0,2	100	28	0,8	4,5	1,1	1,0	11	40	non liquefiable
-35.5/-37	-35,5	30	0,17	80	23	0,8	4,7	1,2	1,5	6	31	non liquefiable
-37/-38.5	-37	59	0,05	80	32	0,8	5,0	1,2	3,5	0	35	non liquefiable
-38.5/-40	-38,5	49	0,08	100	36	0,8	5,0	1,2	3,5	0	38	non liquefiable

Kh-1
3,05872E-05
3,05872E-05
3,05872E-05
3,05872E-05
3,05872E-05
3,05872E-05
3,05872E-05
0,401604864
0,258149888
3,05872E-05
3,05872E-05

[1] Layer depth based on CPT

[2] Layer depth based on BH

[3] Fines content based on the #200 sieve

[4] N computed using (Qc/Pa) = N 5.44 $D_{50}^{0.26}$

[5] Cn calculated based on document [2]

[6] $(N_1)_{60CS} = \alpha + \beta (N_1)_{60}$

for FC< 5% α=0 β=1

for 5%<FC<35% $\alpha=\exp[1.76 - (190/FC^2)]$ $\beta=[0.99 + (FC^{1.5}/1{,}000]$

for FC>35% α=5 β=1.2

[7] Thin Soil Layer correction using Kh = 0.25 $[(H/dc)/17-1.77]^2$ as recommended by NCEER

D50 - fines % constants

A	-53,8505
B	-62,2451

Quantités réalisées:

On-shore:

- 97 000 cu yd traités
- 525 points de traitement
- profondeur moyenne de traitement: 50 ft (61 ft maxi)

- Off-shore
  - 34 600 ft de colonnes ballastées
  - diamètre moyen: 2,5 ft

the end…

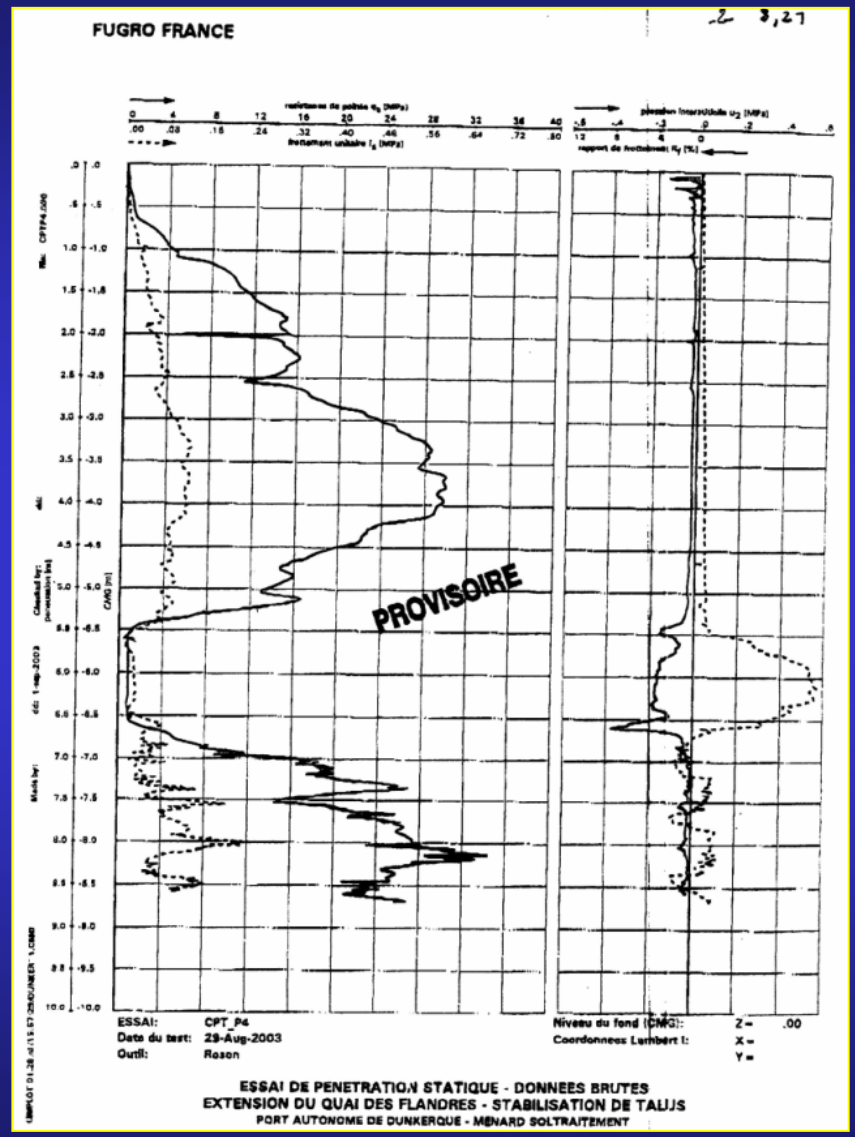
Port Autonome de Dunkerque

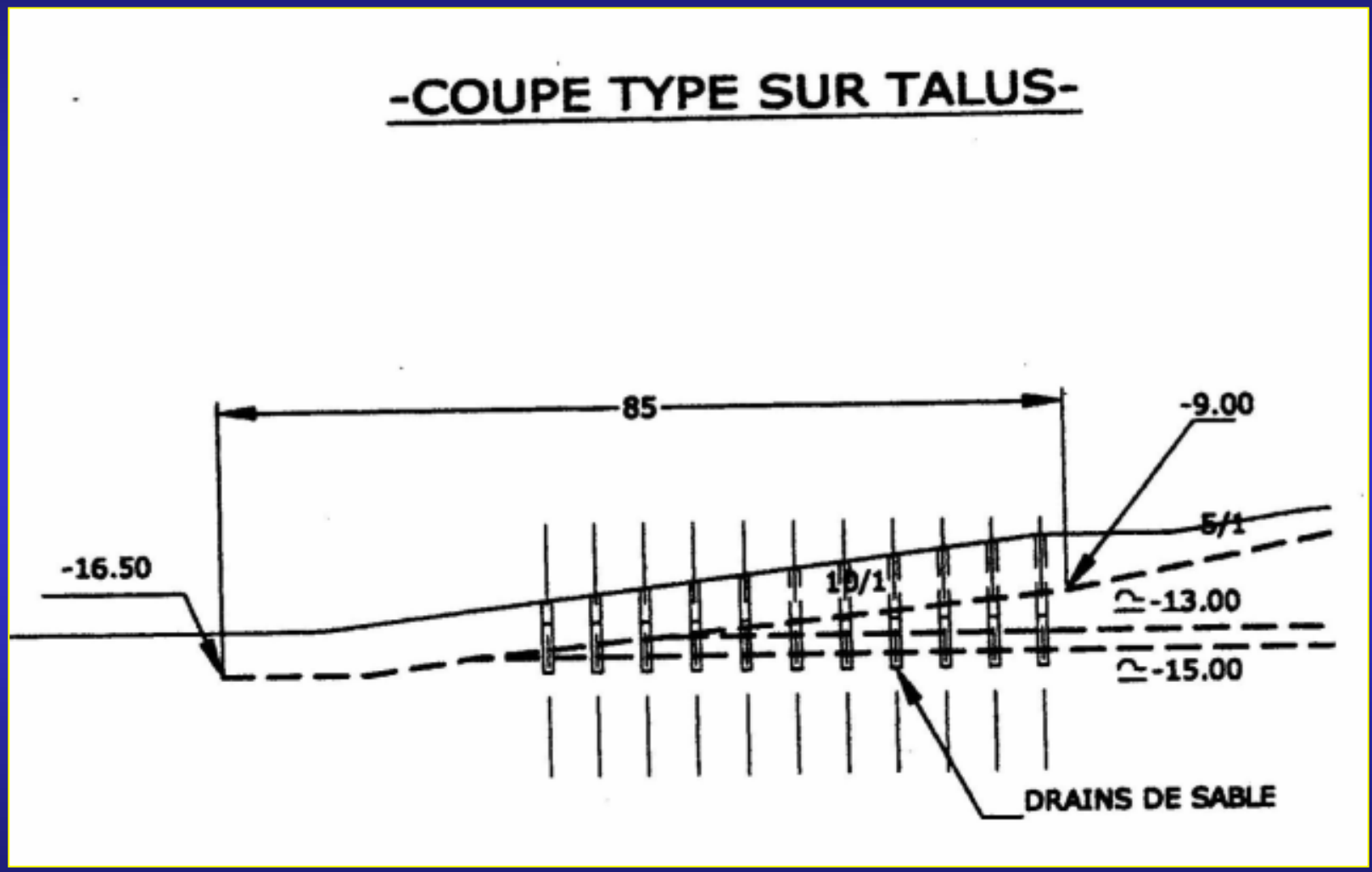
Extension du Quai de Flandres

Stabilisation de talus sous marin

Port de Dunkerque

Pénétromètre statique





Port de Dunkerque: renforcement de sol sous talus

Port de Dunkerque: vues des pontons de travaux

Port de Dunkerque: vue du vibreur