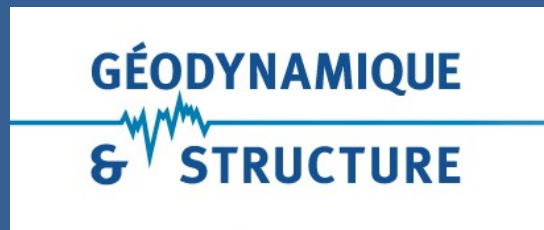


LIQUEFACTION

Le phénomène et sa prise en compte dans la réglementation

Alain PECKER



PRESENTATION

- Pionniers
- Dates importantes
- Evolution de l'évaluation de la liquéfaction
- Prise en compte dans la réglementation future

VALDEZ 1964

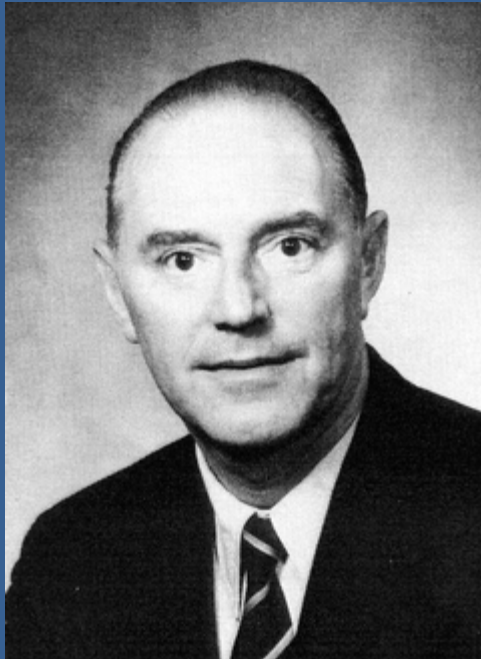


NIIGATA 1964





Harry SEED



Journal of the
SOIL MECHANICS AND FOUNDATIONS DIVISION
Proceedings of the American Society of Civil Engineers

**SIMPLIFIED PROCEDURE FOR EVALUATING SOIL
LIQUEFACTION POTENTIAL**

By H. Bolton Seed,¹ M. ASCE and Izzat M. Idriss,² A. M. ASCE

Catastrophic failures in recent earthquakes have provided a sobering reminder that liquefaction of sandy soils as a result of earthquake ground shaking poses a major threat to the safety of civil engineering structures. Major landslides (25), lateral movements of bridge supports (6,24), settling and tilting of buildings (19,26), and failure of waterfront retaining structures (1,8,30) have all been observed in recent years as a result of this phenomenon and efforts have been increasingly directed to the development of methods of evaluating the liquefaction potential of soil deposits. It is the purpose of the present paper to describe a simplified procedure for evaluating liquefaction potential and to compare the results obtained by the method with a number of cases in which liquefaction is known either to have occurred, or not occurred in the field.

It should be noted at the outset that the term liquefaction as used herein describes a phenomenon in which a cohesionless soil loses strength during an earthquake and acquires a degree of mobility sufficient to permit movements ranging from several feet to several thousand feet. When the term was originally introduced it was intended to describe a phenomenon in which a soil could undergo large movements, as in flow slides, with little or no resistance to movements. However failures due to limited movements of several feet in recent earthquakes have been attributed to liquefaction. While the term cyclic mobility might be more appropriate to describe this type of soil behavior, the broader use of the term liquefaction is adopted in the following pages.

In addition, considerations of liquefaction are limited to cases of relatively level ground where the response of the soil to stresses induced by an earth-

Note.—Discussion open until February 1, 1972. To extend the closing date one month, a written request must be filed with the Executive Director, ASCE. This paper is part of the copyrighted Journal of the Soil Mechanics and Foundations Division, Proceedings of the American Society of Civil Engineers, Vol. 97, No. SM9, September, 1971. Manuscript was submitted for review for possible publication on January 8, 1971.

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Arthur CASAGRANDE

HARVARD SOIL MECHANICS SERIES



No. 88

LIQUEFACTION AND CYCLIC DEFORMATION OF SANDS
A CRITICAL REVIEW

by

ARTHUR CASAGRANDE

Presented at
Fifth Panamerican Conference
on Soil Mechanics and Foundation Engineering
Buenos Aires, Argentina, November 1975

Janvier 1976

Pierce Hall
Cambridge, Massachusetts
January 1976
Reprinted (with corrections) January 1979

I. INTRODUCTION

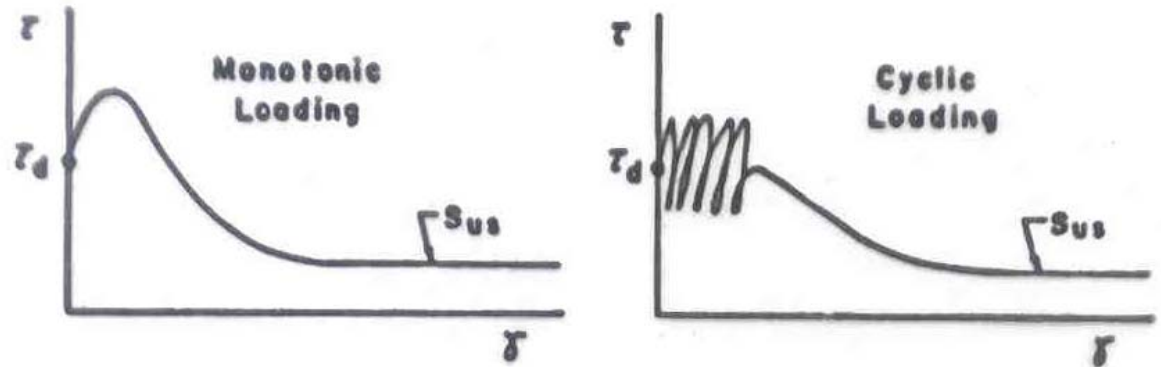
I express my sincere gratitude to the Organizing Committee of the 5th Panamerican Conference for honoring me by their invitation to present this keynote lecture. It is indeed a great privilege to address my colleagues from the American countries stretching from Canada to Argentina, our host country, and also colleagues from other continents.

Soon it will be 50 years since the day when I started assisting Karl Terzaghi. The principal task which he assigned to me from the first day was the improvement and development of soil testing apparatus and techniques of testing. Already then, and many times since, I have observed that the introduction of soil mechanics theories into design practice was handicapped by the limitations of subsurface exploration, sampling and testing. The need of practicing engineers for specifications, their desire to use standards and similar demands by governmental regulatory agencies, were often responsible for premature adoption of informal or formal standards that lingered on in engineering practice for a long time after they were proven to be unsatisfactory. I have also learned during these decades that whenever I found myself in disagreement with a highly experienced and respected colleague, it was for one or more of the following reasons: (1) we looked at different aspects of the same problem; (2) we generalized too much on the basis of different sets of empirical data; and (3) we used the same terminology for different phenomena. I could describe instructive examples of such differences that had arisen also between Terzaghi and myself; examples that would demonstrate how well such differences have served to set the stage for further necessary investigations and developments. An example from recent years I will describe in this lecture, namely the differences between my views on liquefaction and those by Professor H. B. Seed and his collaborators which they developed in connection with certain aspects of their pioneer work on the design of foundations and dams for earthquakes. I hope that a frank discussion of these differing views will help to clarify the issues and to promote development of reliable methods for determining the in situ response of sand strata to seismic loading.

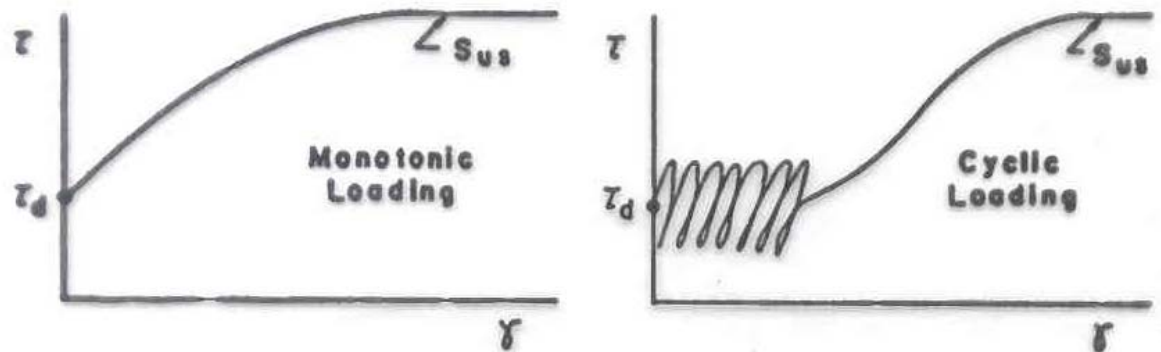
The purpose of my talk is a critical review of two basically different phenomena which in literature are both referred to as "liquefaction". To distinguish between them, one related to the behavior of loose sands and the other to the response of dense sands under cyclic loading in triaxial tests, I found it necessary to introduce in this paper differentiating adjectives, as discussed under the next heading.

Sable lâche

Liquéfaction



INSTABILITY and FLOW



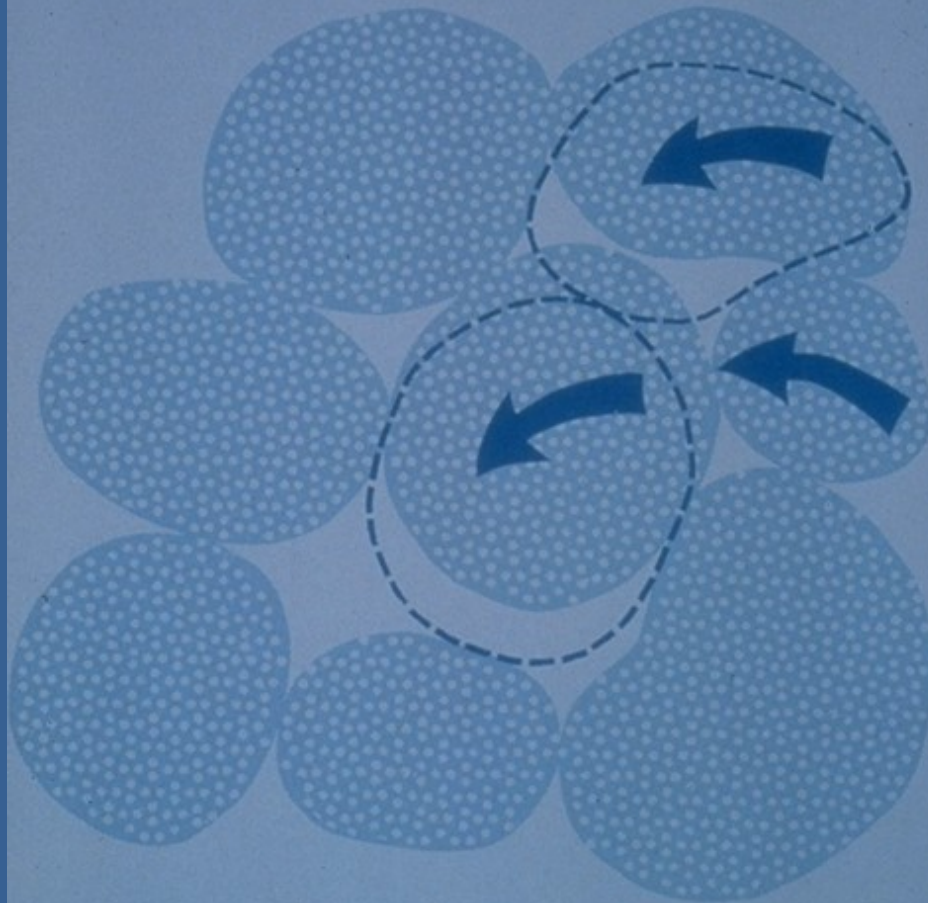
DEFORMATIONS of STABLE SOIL

Legend: τ = Shear Stress
 τ_d = Static (Driving) Shear Stress
 γ = Shear Strain
 S_{us} = Undrained Steady State Strength

Sable dense

Mobilité cyclique

SHEAR DEFORMATION

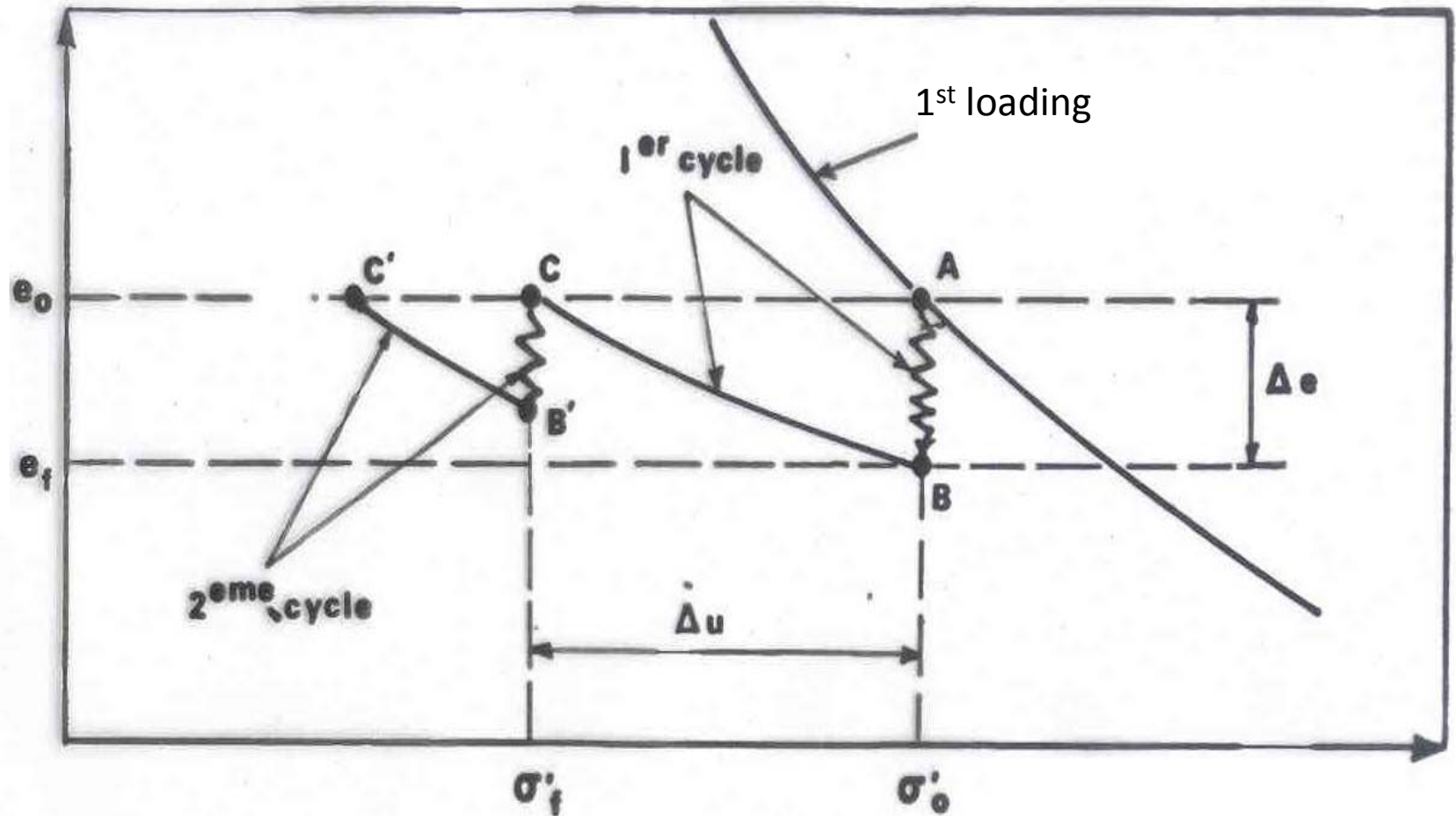


EAR DEFORMATION

MECANISME FONDAMENTAL

Martin, Finn, Seed, 1975)

Indice des vides

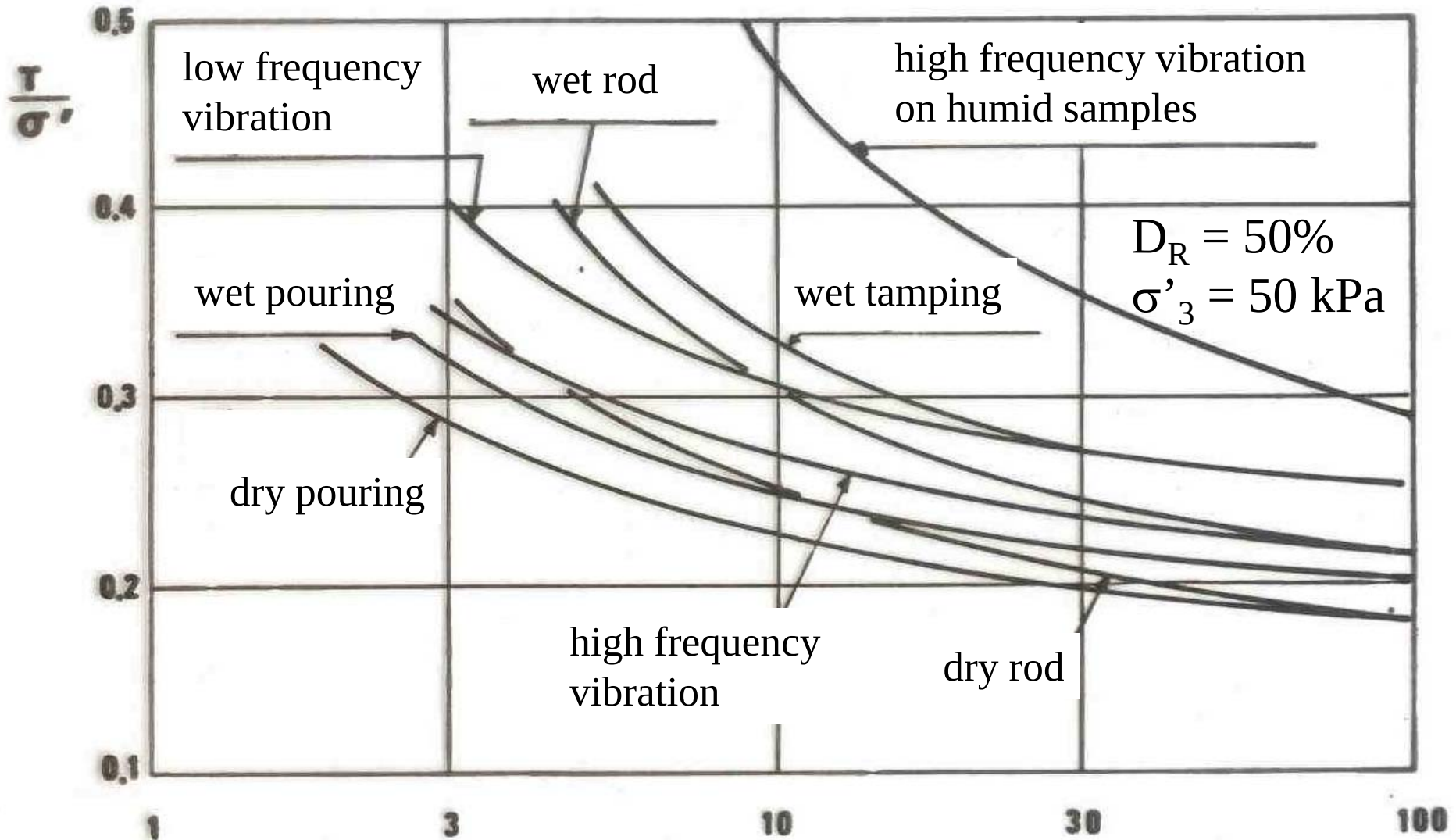


Contrainte effective de consolidation

METHODES ETUDE

- Jusque dans les années 1980 l'analyse du risque de liquéfaction est essentiellement fondée sur la réalisation d'essais de laboratoire
- Après 1980, changement total : les essais de laboratoire sont délaissés au profit des corrélations expérimentales établies à partir d'essais en place (SPT)
- Essais de laboratoire réservés à des projets importants et assortis de méthodes de prélèvement sophistiquées et coûteuses

METHODE DE PREPARATION



Nombre de cycles

PRELEVEMENT EN GROS DIAMETRE



NAS 1985



Liquefaction of Soils During Earthquakes



National Academy Press

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EC8 – Partie 5

- Fondations
 - Ouvrages de soutènement
 - Aspects géotechniques
- ✓ Texte principal : 24 pages, 6 annexes

ACTION SISMIQUE

PROPRIETES DES SOLS

1. Généralités

1. Domaine d'application
2. Hypothèses
3. Principes & règles d'application

2. Action sismique

1. Définition
2. Représentation temporelle

3. Propriétés du sol

1. Caractéristiques de résistance
2. Caractéristiques de rigidité et d'amortissement

SOL DE FONDATION

4. Prescriptions relatives au choix du site et aux sols de fondation

1. Choix du site

- ✓ Proximité des failles sismiquement actives
- ✓ Stabilité des pentes
- ✓ Sols potentiellement liquéfiables
- ✓ Tassements sous charges cycliques

2. Reconnaissances et études de sol

SYSTEMES DE FONDATION

5. Système de fondation

1. Prescriptions générales
2. Règles de conception et de dimensionnement
3. Effets des actions de calcul
4. Vérification et critères de dimensionnement
 - ✓ Fondations superficielles ou enterrées
 - ✓ Pieux et puits

6. Interaction sol structure

OUVRAGES DE SOUTÈNEMENT

7. Ouvrages de soutènement

1. Prescriptions générales
2. Choix et considérations générales de conception
3. Méthodes d'analyse
4. Vérifications de la stabilité et de la résistance

8. Annexes

1. Coefficient d'amplification topographique (I)
2. Liquéfaction (N)
3. Rigidité statique en tête des pieux (I)
4. Interaction sol structure (I)
5. Ouvrages de soutènement (N)
6. Capacité portante sismique des fondations superficielles (I)

PARAMETRES DETERMINES AU NIVEAU NATIONAL

Annexe Nationale

- Statut des annexes informatives
 - ✓ A, C, D, F
- Coefficients partiels sur les caractéristiques des matériaux
 - ✓ C_u , $\tau_{cy,u}$, $tg(\phi')$
- Coefficient de sécurité vis à vis de la liquéfaction
- Réduction de l'accélération maximale avec la profondeur

DEFINITION DE L'ACTION SISMIQUE

$$S_a(T, \xi) = a_{gR} \gamma_I R(T, \xi, S)$$

$S_a(T, \xi)$: Pseudo accélération

a_{gR} : pga sur sol de référence (rocher)

γ_I : Coefficient d'importance $a_g = \gamma_I a_{gR}$

$R(T, \xi, S)$: Forme spectrale normalisée

Zonage administratif proposé

1 : 0

2 : 0.7 m/s²

3 : 1.1 m/s²

4 : 1.6 m/s²

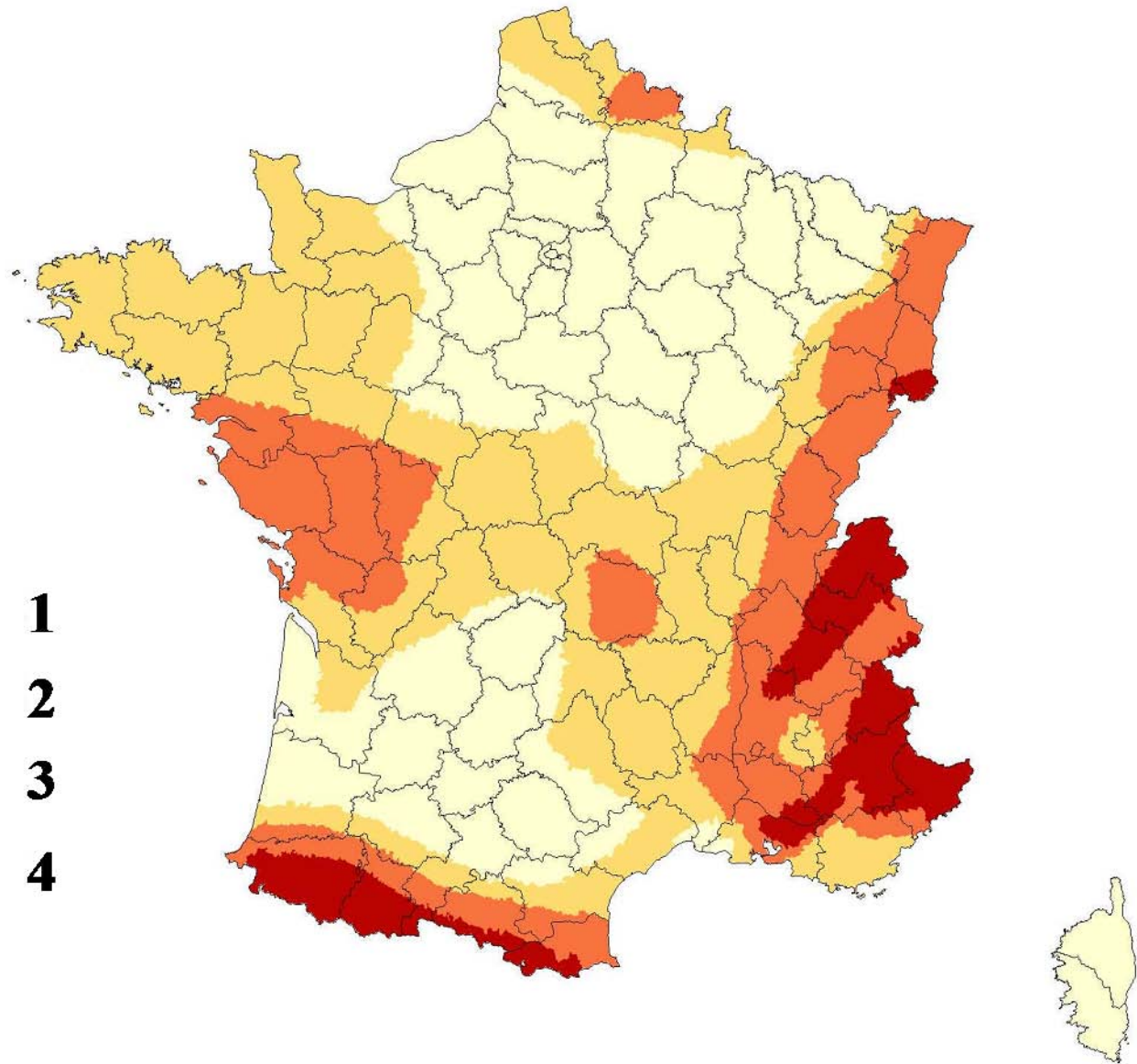
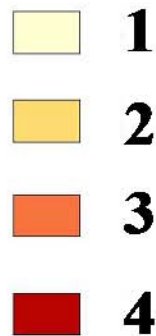
5 : 3.0 m/s²

$\text{pga} < 0.7 \text{ m/s}^2$

$0.7 < \text{pga} < 1.1 \text{ m/s}^2$

$1.1 < \text{pga} < 1.6 \text{ m/s}^2$

$1.6 < \text{pga} < 2.3 \text{ m/s}^2$



CATEGORIES D'IMPORTANCE POUR LES BATIMENTS

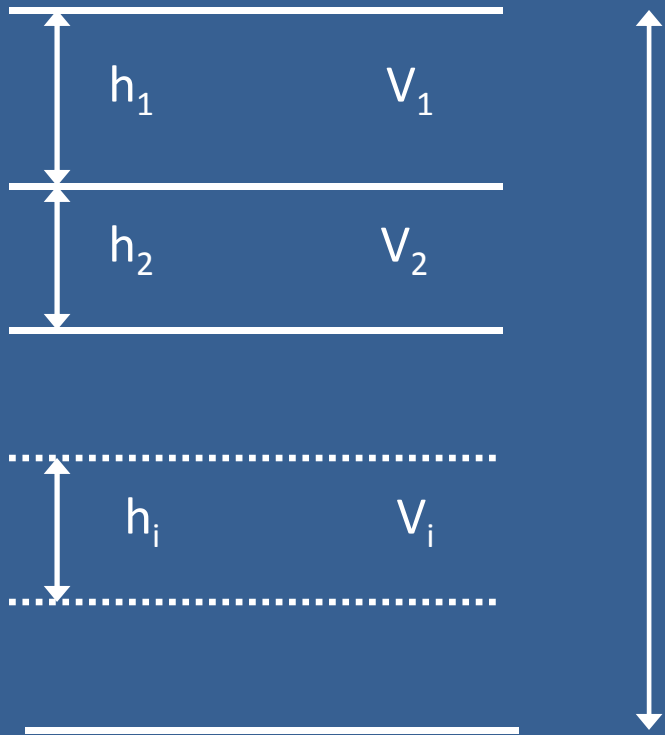
Catégorie Importance	Bâtiment
I	Bâtiments d'importance mineure pour la sécurité des personnes, par exemple, bâtiments agricoles, etc.
II	Bâtiments courants n'appartenant pas aux autres catégories
III	Bâtiments dont la résistance aux séismes est importante compte tenu des conséquences d'un effondrement, par exemple : écoles, salles de réunion, institutions culturelles, etc.
IV	Bâtiments dont l'intégrité en cas de séisme est d'importance vitale pour la protection civile, par exemple : hôpitaux, casernes de pompiers, centrales électriques, etc.

COEFFICIENT D'IMPORTANCE

Catégorie Importance	Coefficient Importance
I	0.8
II	1.0
III	1.2
IV	1.4

Classe	Description	Paramètres		
		$V_{S,30}$ (m/s)	N (SPT)	C_u (kPa)
A	Rocher – Au plus 5m d'alluvions	> 800	-	-
B	Sable très dense, gravier, argile raide; h>10m	360 - 800	> 50	> 250
C	Sable dense, moyennent dense; argile raide; h=10 – 100 m	180 - 360	15 - 50	70 - 250
D	Sable lâche, moyennent dense; argile ferme à molle	< 180	< 15	< 70
E	Alluvions C ou D, h=5 – 20m Surmontant rocher (A)			
S_1	Couches contenant strates h>10m Argile molle (IP > 40), w élevée	< 100 (indicatif)	-	10 - 20
S_2	Sites liquéfiables; tout autre type de site non référencé ci dessus			

DEFINITION DE $V_{S,30}$

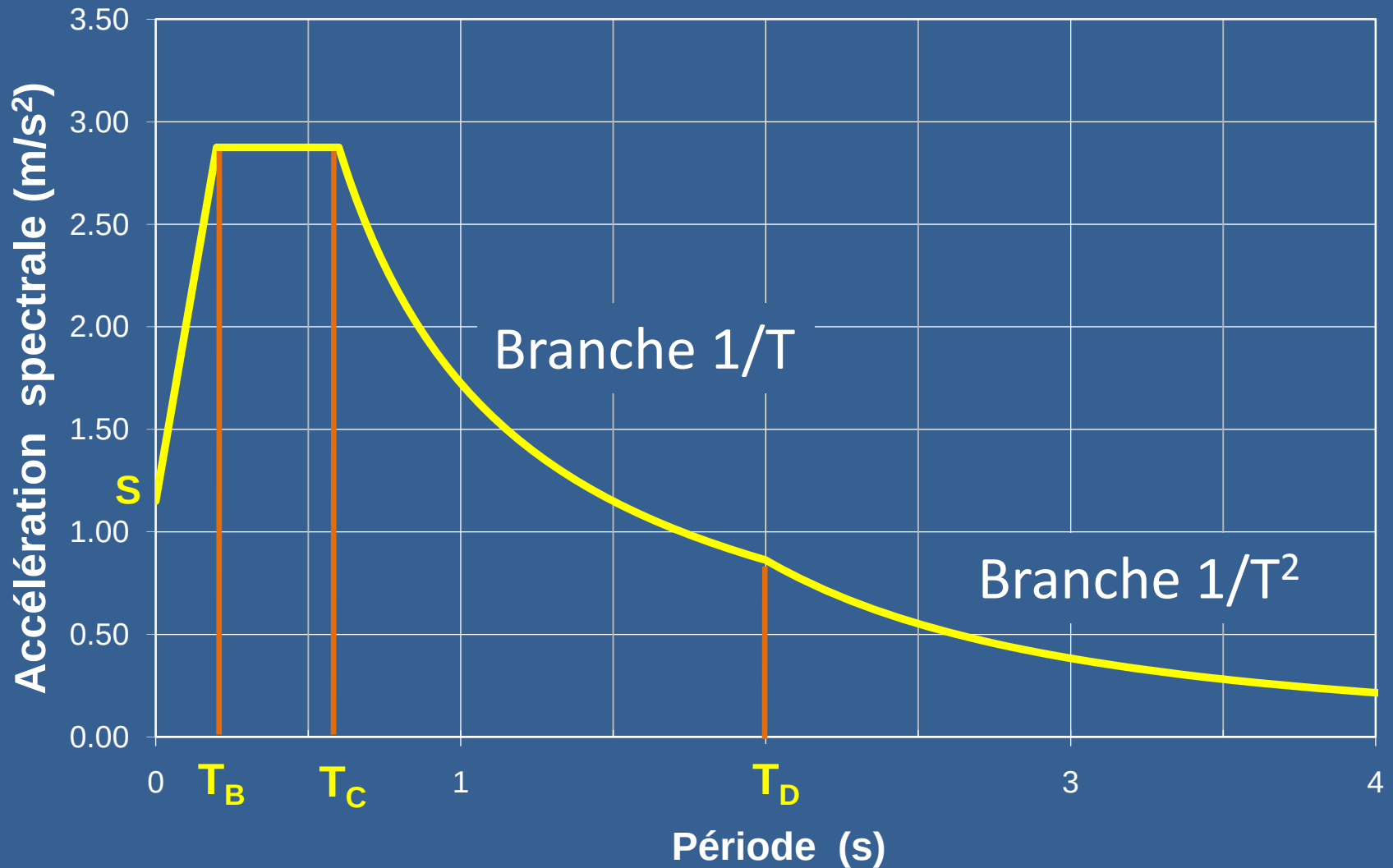


$$H = \sum_{i=1}^N h_i = 30 \text{ m}$$

$$t = \sum_{i=1}^N t_i = \sum_{i=1}^N \frac{h_i}{V_i} = \frac{H}{V}$$

$$V_{S,30} = \frac{H}{\sum_{i=1}^N \frac{h_i}{V_i}}$$

FORME SPECTRALE NORMALISEE



ILES CARRAIBES: TYPE I

	S	T_B	T_C	T_D
A	1.0	0.15	0.40	2.0
B	1.20	0.15	0.50	2.0
C	1.15	0.20	0.60	2.0
D	1.35	0.20	0.80	2.0
E	1.40	0.15	0.50	2.0

TERRITOIRE METROPOLITAIN

	S	T_B	T_C	T_D
A	1.0	0.03	0.20	2.5
B	1.35	0.05	0.25	2.5
C	1.50	0.06	0.40	2.0
D	1.60	0.10	0.60	1.5
E	1.80	0.08	0.45	1.25

METHODE DE VERIFICATION

- Vérification en **champ libre**, conditions prévalant pendant durée de vie ouvrage (nappe)

- Méthode de **Seed – Idriss** pour évaluation de **demande sismique**

$$\tau_e = 0.65 \sigma_v \frac{a_g S}{g}$$

- Evaluation de la **résistance** à partir d'essais **SPT** (annexe normative), **CPT** ou **V_s** ;

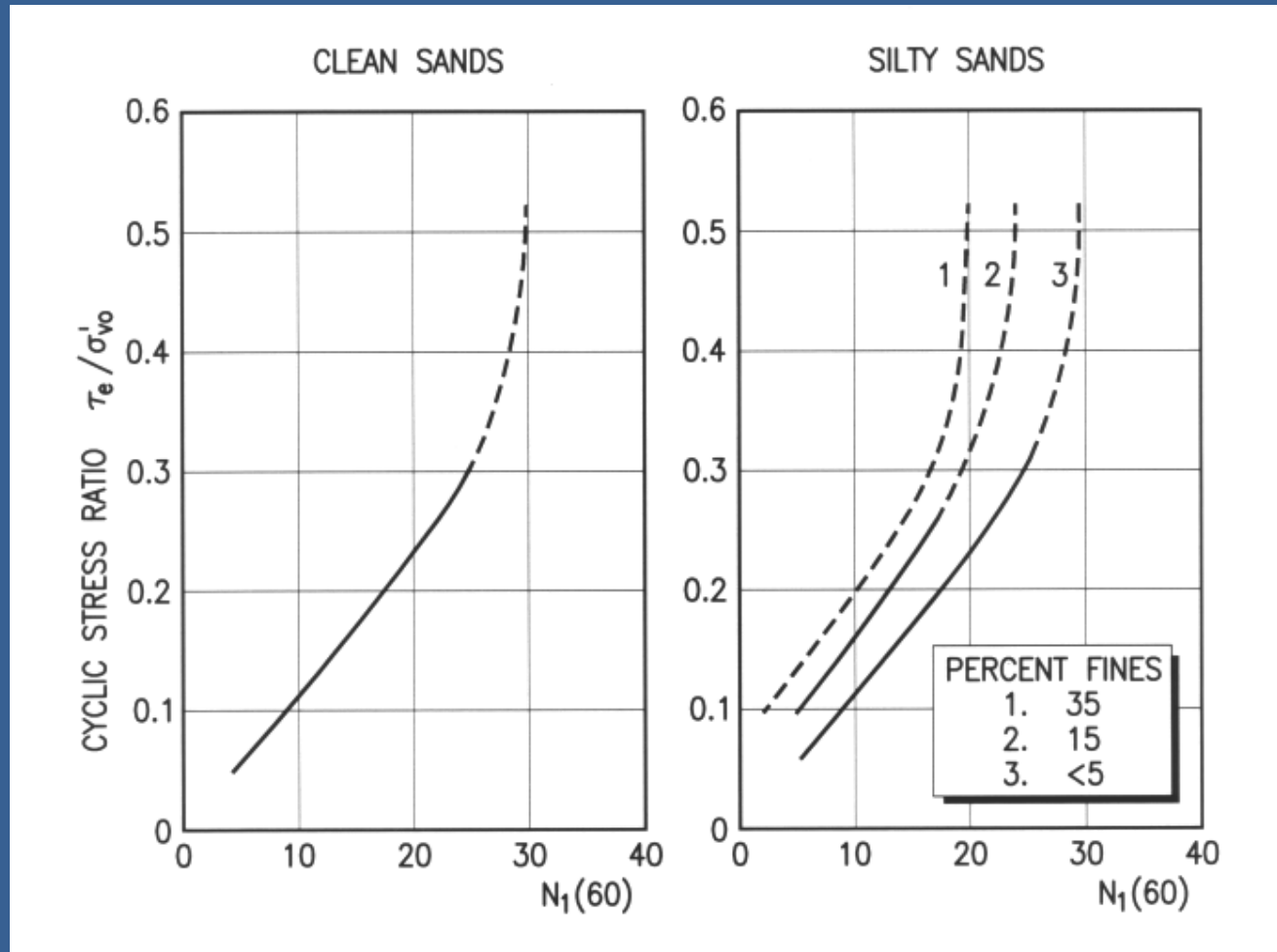
✓ *corrections précisées (σ'_v , E_R)*

$$(N_1)_{60} = \frac{E_R}{60} \left(\frac{p_a}{\sigma'_v} \right)^{0.5} N$$

- Nécessité d'**analyses granulométriques**

ABAQUES LIQUEFACTION

Annexe B



Rapports de contrainte produisant la liquéfaction en fonction des valeurs $N_{1(60)}$ pour des sables propres et silteux et des séismes de magnitude $M_s = 7.5$

CORRECTION DE MAGNITUDE

Zone de sismicité	Magnitude	C_M
1	Analyse non requise	
2		
3	5.5	2.86
4	6.0	2.20
5	7.5	1.0

COEFFICIENT DE SECURITE

- FS : 1.25
- Pas de nécessité de vérification : $(a_g / g)S < 0.15$ et soit
 - ✓ % argile > 20% et IP > 10%
 - ✓ % silt > 35% et $N_1 > 20$
 - ✓ Sable propre et $N_1 > 30$
- Vérification peut être omise pour fondations superficielles et sols sableux saturés situés à $h > 15\text{m}$

CONSEQUENCES LIQUEFACTION

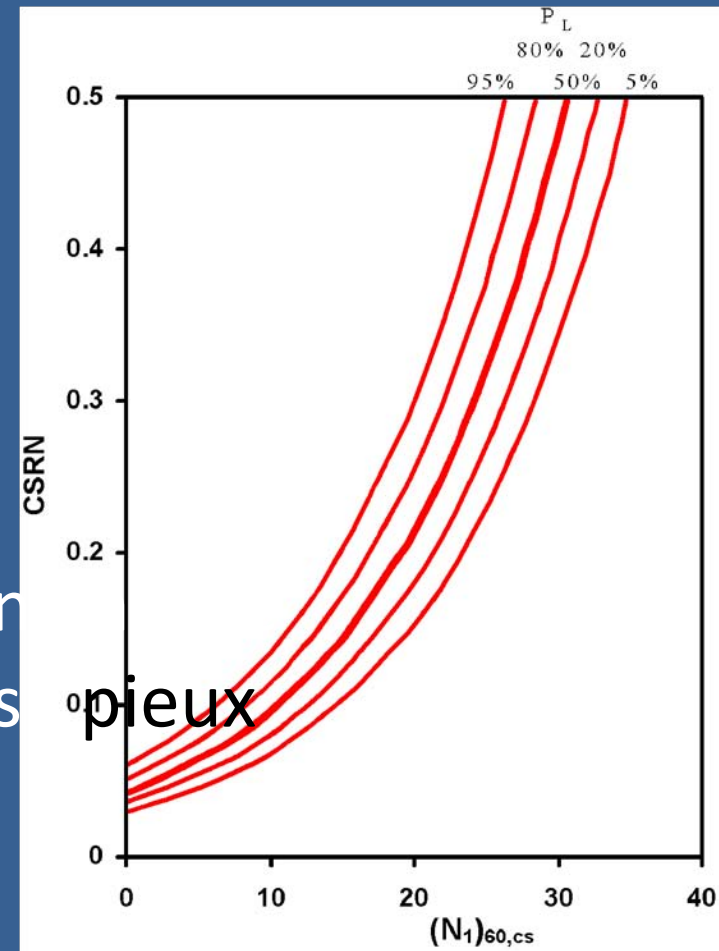
- Si des **sols** sont identifiés comme **liquéfiables** et si les effets qui en découlent sont jugés **capables d'affecter la capacité portante ou la stabilité des fondations**, la stabilité des fondations doit être assurée par exemple par une **amélioration du sol** et des **fondations sur pieux**.
- Il convient d'envisager avec **prudence la seule utilisation de fondations sur pieux**, en raison des **forces importantes** induites dans les pieux par la perte de résistance du sol dans la ou les couches liquéfiables, et en raison des **incertitudes** inévitables liées à la détermination de l'emplacement et de l'épaisseur de cette ou ces couches.

EVOLUTIONS FUTURES

- Evaluation probabiliste de la résistance à la liquéfaction

$$P_L(N_{1,60}, FC, CSR, M, \sigma'_v)$$

- Prise en compte de la liquéfaction dimensionnement des fondations



PROBABILITE D'OCCURRENCE DE LA LIQUEFACTION

