Regional Workshop on Volcanic, Seismic and Tsunami Hazard Assesment Related to NPP siting Activities and Requirements

13-17 June 2011

Jakarta – Indonesia

“*Geotechnical Aspects of Site Evaluation and Foundations in NPP*”

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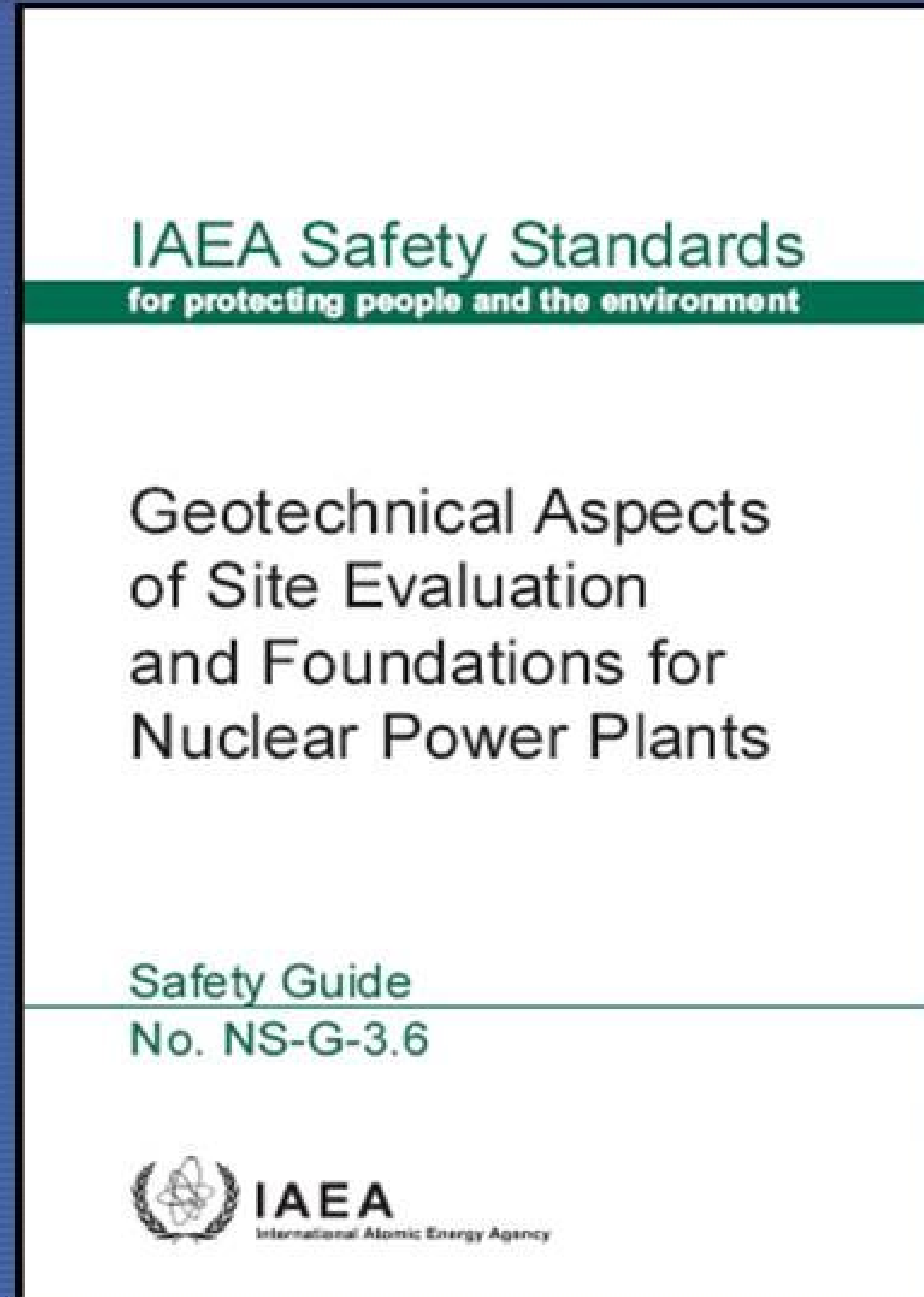
International Atomic Energy Agency

Introduction

- The purpose of this Safety Guide is to provide guidance on dealing with geotechnical engineering consideration that are important for safety of nuclear power plants,
- This Guide provides interpretation of the Safety Requirements for site evaluation ,
- This Guide provide guidance on the methods and procedures for analyses that support the assessment of the geotechnical aspects of the safety of NPPs .



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Scope

- This Guide discusses the geotechnical engineering aspects of the subsurface conditions and not the geological aspects ,
- It discusses the programme of investigations that should be carried out in order to obtain an appropriate understanding of the subsurface conditions ,
- It also provides a description of the geotechnical profiles and the parameters suitable for performing the geotechnical analyses required for the design ,
- It discusses also the monitoring of the geotechnical parameters of the site ,

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Contents

- Introduction
- Site investigation
- Site considerations
- Considerations for the foundations
- Earth structures
- Buried structures
- Monitoring of geotechnical parameters

Siting process

- **Regional analysis**

  High level review of an area where there is an interest to build a nuclear power plant to identify some potential sites. This is largely based on excluding areas that do not meet some high level criteria such as adequate water supplies or seismic stability.

  Potential sites (*sites within the area of interest not ruled out by the regional analysis*)

  This analysis shall be conducted as much as possible on the basis of existing data without engaging important survey means (mainly for confidentiality reasons).

- **Screening analysis / Site selection**

  Reduce the number of potential sites to a few (less than 10) candidate sites that can then be analyzed in detail. This involves either further exclusion criteria or very simple assessment to identify those sites that are most likely to provide a suitable site. The sites from this step are called candidate sites.

  Candidate sites (*a list of less than 10 sites that appear suitable and can be ranked*).

- **Ranking analysis /Site selection**

  final step of the process

  Preferred candidate sites (*sites suitable and choose to implement a nuclear power programme*).

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Site Investigation

- Investigation Programme

1. Site selection stage
   Screening and ranking analysis
2. Assessment stage
   - Verification
   Suitabilty of the site
   - Confirmation
   Suitabilty of site for THE NPP
3. Pre-operational and operational Stage

- **Sources of data**
  - Historical and current documents
  - In situ exploration
  - Laboratory tests

- **Investigations for complex subsurface conditions**
  - Prediction of complex subsurface conditions
  - Detection of subsurface cavities
  - Evaluation and treatment of complex subsurface conditions

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Selection Stage

The investigation at the site selection stage is to determine the suitability of candidate sites. On the basis of the above mentioned information on subsurface conditions, the potential or candidate sites can be ranked according to the suitability of the foundation.

- Unacceptable subsurface conditions.
- Groundwater regime.
- Classification of sites.
- Foundation conditions.

The type of soil, depth to bedrock and the properties of the deposit may be inferred. This allows a preliminary selection of acceptable foundation types to be made.

Verification Stage

In this stage, the investigation programme should cover the site as a whole as well as a smaller scale appropriate for layout considerations

- Geological hazards, geological and subsurface conditions
- Liquefaction potential
- Feasible foundation types (preliminary bearing capacity and foundation stability, preliminary settlement ranges
- Groundwater levels and regime
- Site preparation requirements (earthworks, excavations…)
- Site investigation techniques used at this stage
  - Seismic refraction and reflection survey
  - Rotary borehole drilling
  - In situ mechanical testing
  - Laboratory testing

Confirmation stage

- In this stage, preliminary plant characteristics such as the loads, the physical dimensions of the buildings, preliminary structural engineering criteria and the preferred plant layout are know
- In this stage, sufficient in situ and laboratory testing should be conducted to allow the estimation of the bearing capacity, determination of settlements of structure and the site amplification of seismic waves, establishment of soil– structure interaction parameters (dynamic and static), evaluation of the liquefaction potential and evaluation of a site specific design response spectrum, if required.
- As a minimum, the following indicators of potential cavities and susceptibility to ground collapse should be considered:
  - Sinks, sink ponds, caves and caverns, sinking streams, historical ground subsidence, mines, surface depressions, Rock types such as limestone, dolomite, gypsum, anhydrite, halite,

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Before operation of NPP

- Pre-operational stage :

complete and refine the assessment of site characteristics by incorporating geotechnical data newly obtained during foundation excavation and construction.

- Operational Stage :
  - settlement of structures should be measured and used to confirm its safety and integrity by comparing with prediction analyses ,
  - level of the water table, should be measured and compared with predictions to enable an updated safety assessment to be made

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Geotechnical design process

Geotechnical design process involves 6 stages :

- Ground investigations
- Selection of parameter values
- Design calculations
- Checking ground conditions during construction
- Monitoring performance of structure during and after construction
- Specifying requirements for maintenance of completed structure

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ETC-C part2

	Objectives	**Means**
PHASE 1	Geological and geotechnical conditions and raising of uncertainties for critical features : Settlement, Liquefaction, Stability des foundations, Underground seepage, Site seismic level.	Geophysics. Borehole sampling and destructive drilling with recording of parameters. On-site soil and/or rock mechanics tests, water tests. Hydrogeological study. Lab tests.
PHASE 2	Confirmation of conditions: Geological, Geotechnical, Hydrogeological, Seismic. Parameters needed for dimensioning the structures. Adaptation of structures to site conditions. Use of backfill materials Safety report documents.	Investigations on the various structures, comprising : On-site tests for determining: Strength and load-bearing capacity, Deformability, static and dynamic, shear properties, permeability. Lab tests : Identification Deformability : static and dynamic shear, creep, compaction.

Sources of Data

- **Historical and current documents**
  - maps (topographic, geological, geophysical,soil…)
  - geotechnical reports and other geotechnical literature
  - earth satellite imagery
  - aerial photographs water well reports and water supply reports
  - oil and gas well records
  - hydrogeologic maps, hydrologic and tidal data, flood, climate and rainfall records
  - mining history, old mine plans and subsidence records
  - seismic data and historical earthquake records
  - newspaper accounts of events of significance
  - records of performance of structures in the vicinity.
- **In situ investigation tests**
- **Laboratory tests**

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Geotechnical investigations

- It should be considered that knowledge of the ground conditions depends on the extent and quality of the geotechnical investigations.
- Such knowledge and the control of workmanship are usually more significant than is precision in the calculation models or the partial factors
- Geotechnical investigations shall provide **sufficient data** concerning the ground and the ground-water conditions at and around the construction site for a proper description of the essential ground properties and a **reliable assessment of the characteristic values** of the ground parameters to be used in design calculations

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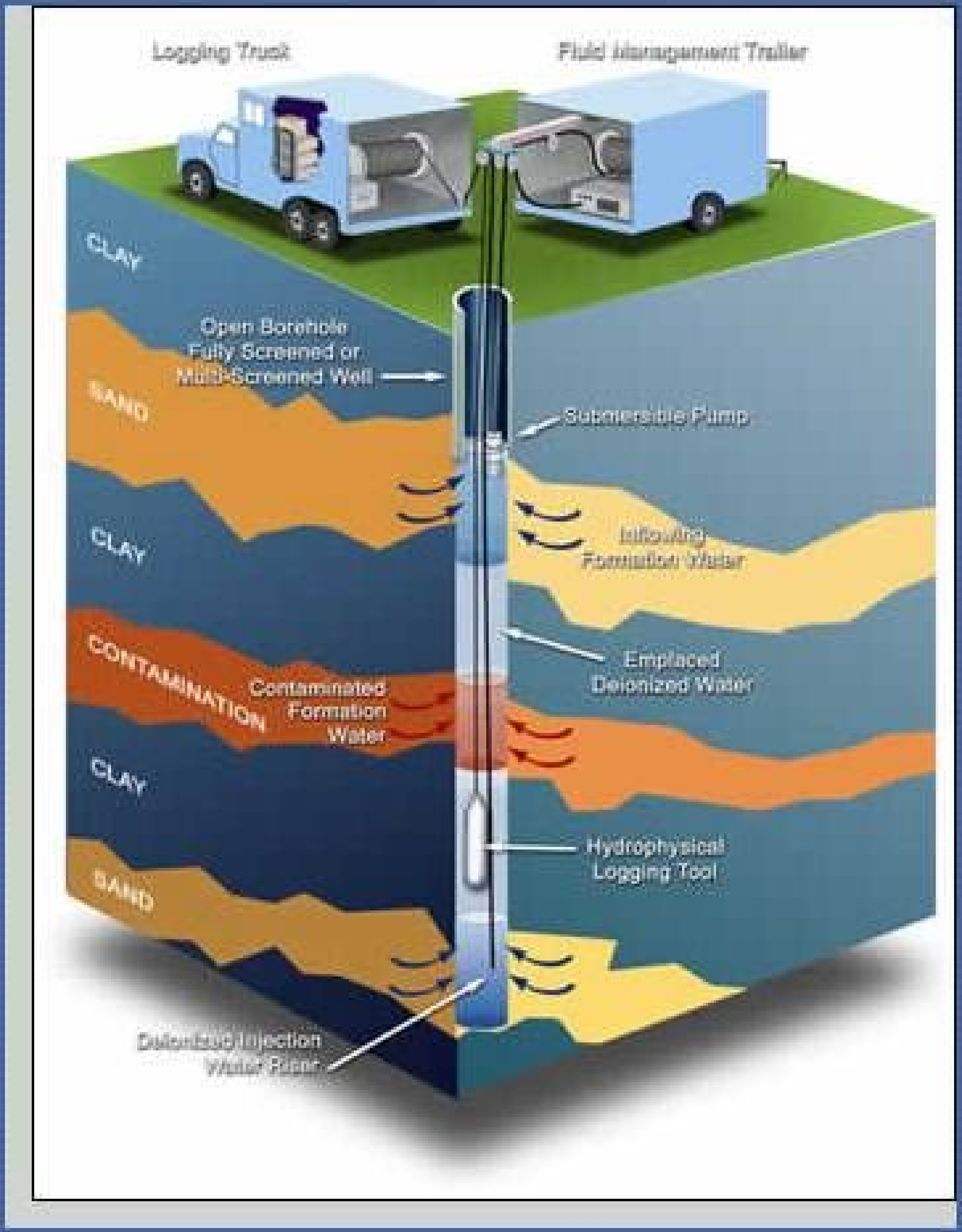
Geophysical in situ tests

	Nature of materials	Parameters measured	Types of problems	Commentaries
Cross hole seismic test	Gravel to cohesive	Shear wave velocity	Site categorization, SSI	
Uphole/downhole seismic test	Gravel to cohesive	Shear wave velocity	Site categorization, SSI	1 hole instead of 2 holes
Electrical resisitivity	Gravel to cohesive	Porosity and water content	Internal erosion	Using of logging
Nuclear logging	Gravel to cohesive	Water content		
Surface seismic investigation	All types	Surface wave velocity	Site categorization	
Microgravimetry	All types	Acceleration due to gravity	Sinkholes, heterogeneities	Subsurface complex
Ground Penetrating Radar	All types	Speed of propagation	Cavities	Subsurface complex
Acoustic	All types	Speed of propagation	Damaged zones	Dikes and dams maintenance
Magnetic technics	All types	Magnetic field intensity	Areas of humidity	Dikes and dams maintenance

What is geophysics ?



- Seismology - Study of natural [from earthquakes] and man-induced seismic waves
- Gravity - Study of variations in earth's gravitational field
- Electrical Methods - Use of electrical conductivity / resistance of earth
- Electromagnetics - Study of induced electromagnetic fields
- Magnetics - Analysis of variations in earth's magnetic field
- Radioactivity - Study of natural and induced response to radioactivity

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Seismic In Situ Methods

- Invasive methods
  - Crosshole
  - Downhole/SCPT
  - P-S suspension logger
- Invasive methods for non linear soil properties
- Vertical arrays

- Non invasive methods
  - Refarction
  - High-resolution seismùic reflection
  - Surface wave methods
- Empirical correlations with SPT and CPT

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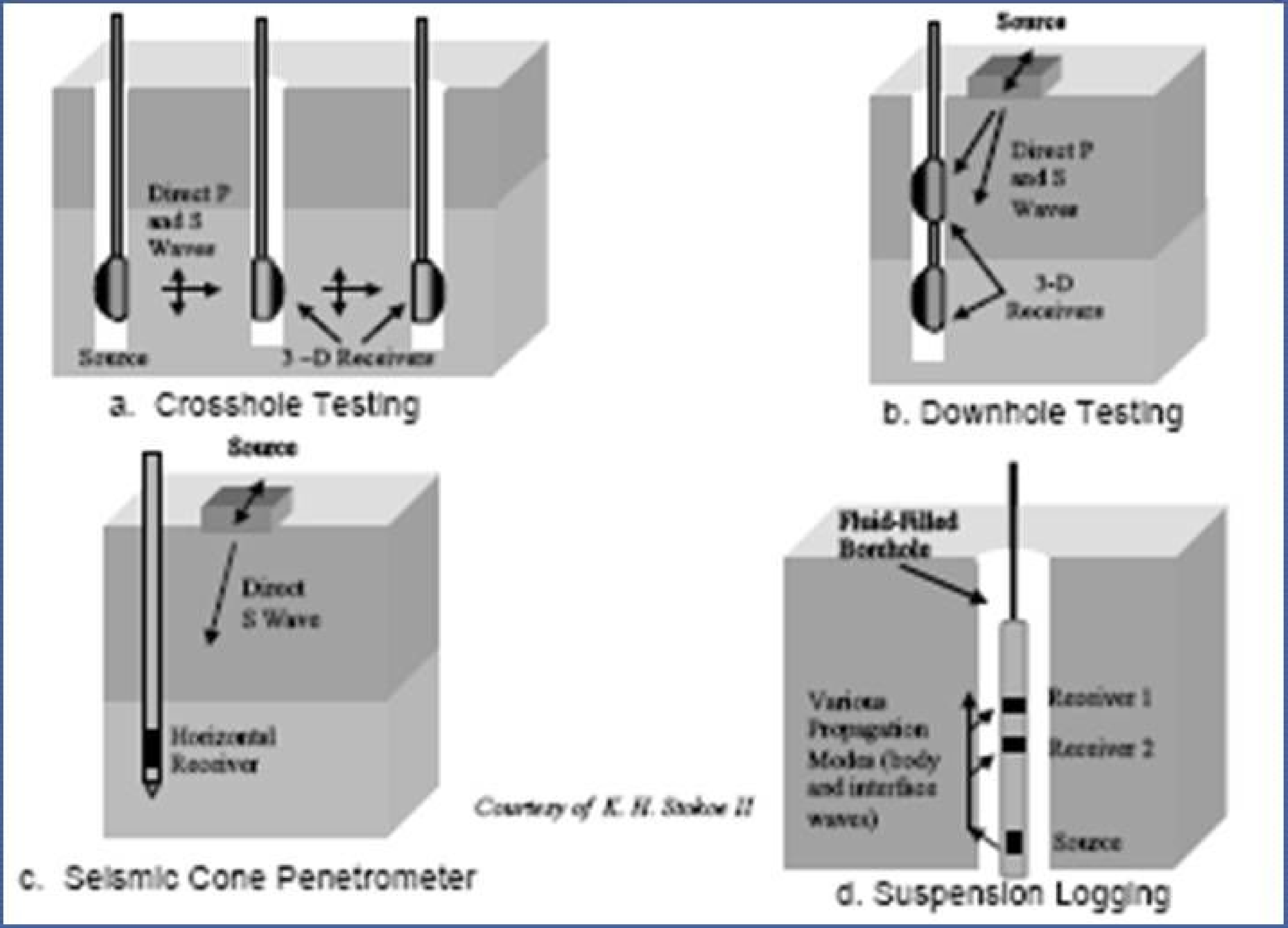
Field Tests to Measure Seismic Wave Velocities



Geotechnical in situ tests

	Nature of materials	Parameters measured	Type of problem	Commentaries
Flat jack test	Rock	In situ normal stress	Convergence	
Hydraulic fracturing test	Rock	In situ stress state	Convergence	
Direct shear stress test	Rock	Shear strength	Stability problems	
Plate bearing tests	Clay, sand, gravel	Reaction modulus	Compaction control Settlement	Used for excavations and embankments
Pressure meter test	Clay, sand, gravel	Elasticity modulus Compressibility	Settlement Bearing capacity	Needs a preliminary hole
Static penetrometer test	Clay, sand, gravel	Cone resistance	Bearing capacity Shear strength	Called also cone penetrometer test
Dynamic penetrometer test	Clay, sand, gravel	Cone resistance Relative density	Liquefaction	Called also Standard Penetration Test
Vane shear test	Cohesive soil	Shear strength	Bearing capacity, slope stability	
Pumping test	Clay, sand, gravel	Field permeability	Transmissivity of soil	Needs piezometers
Overcoring tests	Cohesive soils and rocks	In situ stress state	Consolidation studies	Needs laboratory tests

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Drilling Program

- Invasive methods
- The purpose of the Drilling Program is to determine the:
  - Thickness,
  - Lateral Extent, and
  - Physical Properties of Each Layer of Soil
  - Presence, Depth and Pressure of Water in the Soil
- To take soil's samples (undisturbed samples) in order to perform laboratory tests
- Coupled with the Topographic Survey, it provides a 3D view of the site and the soil underneath.
- If the Upper Soils are Weak, a deep Foundation system must be developed.

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Borehole Drilling

- Drilling Rig
- Continuous Hollow Stem Augers With Removable Drill Rod And Center Head

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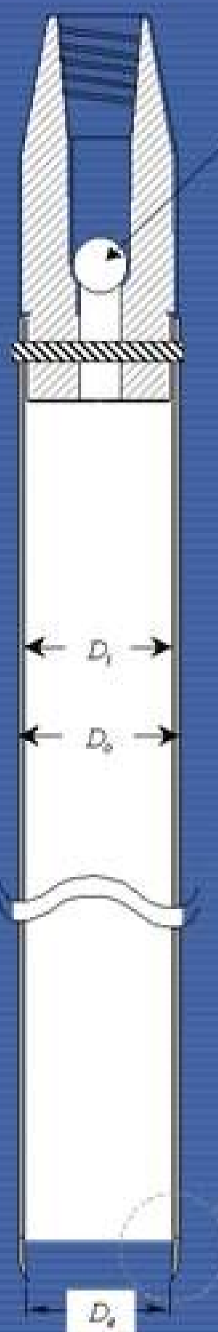
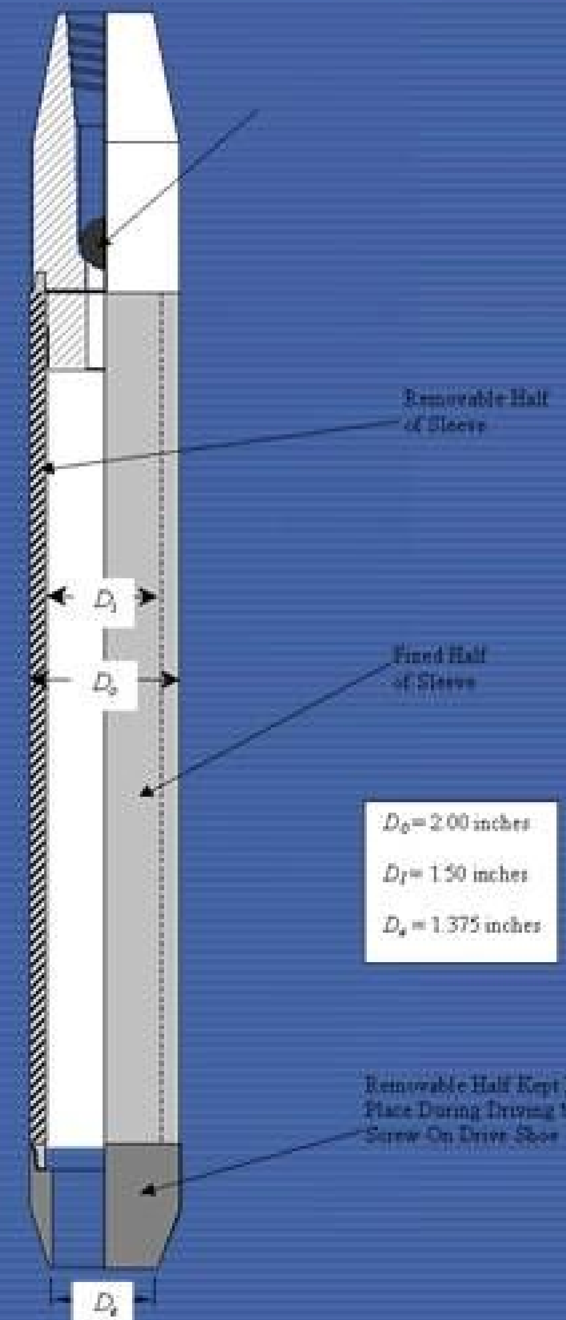
www.cmeco.com

Samplers



Shelby Tube
– Undisturbed Samples



Split Spoon Sampler
– Disturbed Samples

Borehole Logs

REPORT OF FOUNDATION AND BORROW INVESTIGATION — Date: 5 Aug 1986

Site	Type of Exploration	Boring Number	Location	Ground Elevation
Airfield Jamaica	Hasty	1	Sta 0+00	236'

Purpose of Exploration: Determine Soil Profile along Runway Centerline

Depth Below Surface	Elevation	Sample Number	Graphic Log	Group Symbol	Description, Test Data, and Remarks
1" = 2' / 1'	235'	No 1 at ½'		OH	Dark Brown and very plastic. Typical Top Soil of the Area
3'	233'	No 2 at 2½'		SM	Soil with low adhesion, some sand with large percentage of silt.
5'	231'			SC	Coarse Sandy Soil with a plastic binder material. Light red color
7'	229'	No 3 at 7'		CH	Brown Silty clay, very high plastic qualities. Fingernail cut w ½ inches with little trouble. Rolled into a thread very readily

Depth to Water Table: 3 feet — Submitted By: SFC McGurk

ATC — 11121 Canal Road, Cincinnati, Ohio 45241, (513) 771-2112, (513) 782-6908

TEST BORING LOG

CLIENT	Arnold Estates Development LLC	BORING #	B-04 Sta. 121+88 37' Lt. (approx)
PROJECT NAME	Pierce Estates Retaining Wall	JOB #	72.29817.0004
PROJECT LOCATION	Pierce Township, Clermont County, Cincinnati, Ohio	DRAWN BY	LL
		APPROVED BY	LL

DRILLING and SAMPLING INFORMATION

Date Started	7/11/06	Hammer Wt.	140 lbs.
Date Completed	7/11/06	Hammer Drop	30 in.
Drill Foreman	BW	Spoon Sampler OD	2 in.
Inspector		Rock Core Dia.	in.
Boring Method	HSA	Shelby Tube OD	in.

SOIL CLASSIFICATION — SURFACE ELEVATION 562.0

Soil Classification	Stratum Depth
FILL: Dark brown to Light Brown SILTY CLAY with a trace of Sand and organics. Moist and stiff	3.0
Brown SILTY CLAY (very weathered shale). Slightly moist and very stiff to hard.	12.0
Brown VERY WEATHERED SHALE and LIMESTONE layers. Dry and hard	18.0
Gray weathered SHALE and LIMESTONE layers. Dry and soft shale with hard limestone.	23.9
Boring discontinued at a depth of 23.9 feet due to sampler refusal.	

TEST DATA

Sample No.	Sample Type	Standard Penetration Test, blows per foot	Qu/Qp Unconfined Compressive Strength	PP/tsf Pocket Penetrometer	Moisture Content %	Liquid Limit (LL)	Plasticity Index (PI)	Remarks
1	SS	16		2.50	26			dozer cut 1'
2	SS	25		3.50	19			
3	SS	45		4.00	11			
4	SS	72		4.00	14			
5	SS	100		4.50	13			
6	SS	50/.5		4.50	13			
7	SS	50/.4		4.50	0			
8	SS	50/.1			0			
9	SS	50/.5			3			
10	SS	50/.3			6			

Top of Rock

Sample Type
SS - Driven Split Spoon
ST - Pressed Shelby Tube
CA - Continuous Flight Auger
RC - Rock Core
CU - Cuttings
CT - Continuous Tube

Depth to Groundwater
Noted on Drilling Tools: None ft.
At Completion (in augers): ft.
At Completion (open hole): None ft.
After ___ days ___ ft.
After ___ days ___ ft.
Cave Depth: 18.0 ft.

Boring Method
HSA - Hollow Stem Augers
CFA - Continuous Flight Augers
DC - Driving Casing
MD - Mud Drilling

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Rough Spacing and Deep Guidelines for bore holes testings

Soil Type	Structure Footprint Area / Boring (min)	Depth (min)
	m^2	m
Poor Quality	100 - 300	$6\,(S)^{0.7}+D$
Average	200 - 400	$5\,(S)^{0.7}+D$
High Quality	300 - 1000	$3\,(S)^{0.7}+D$

Source: Coduto, 1999

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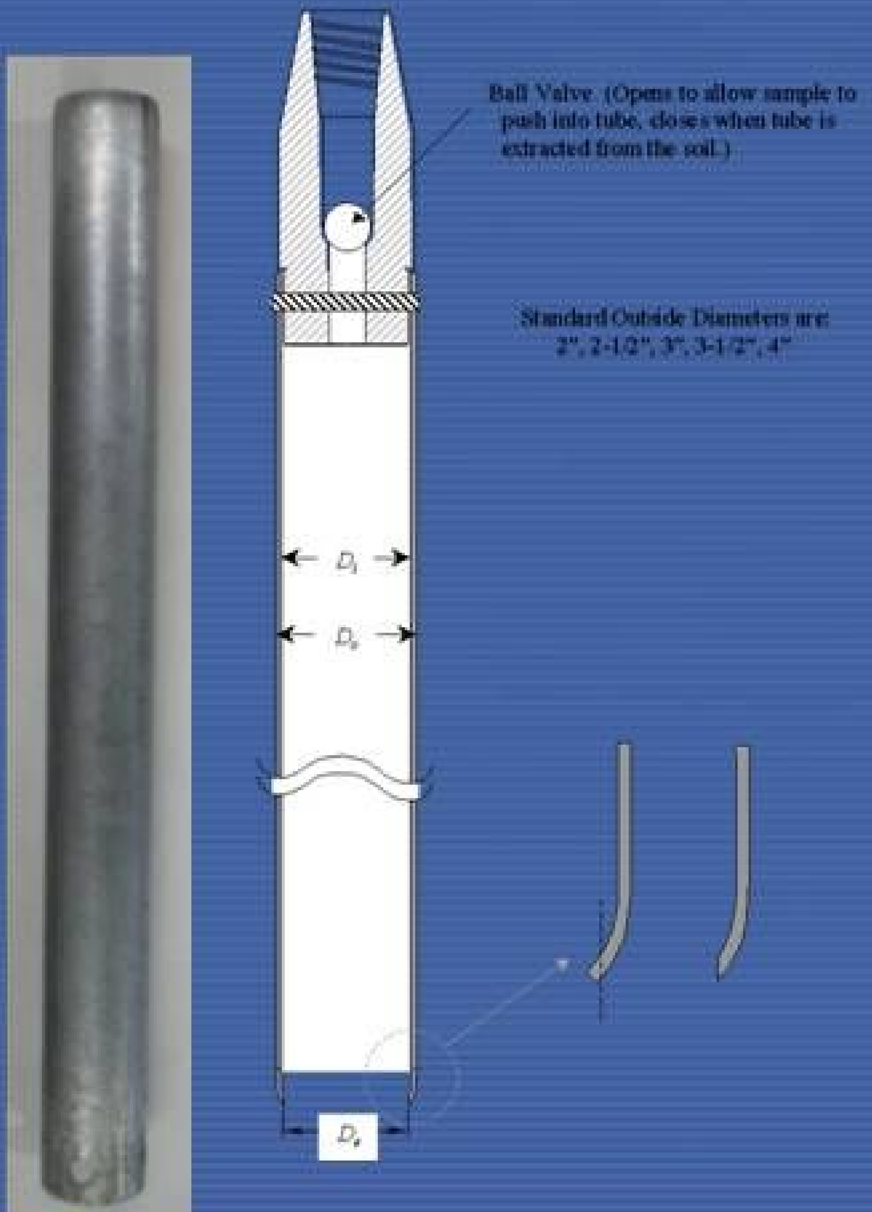
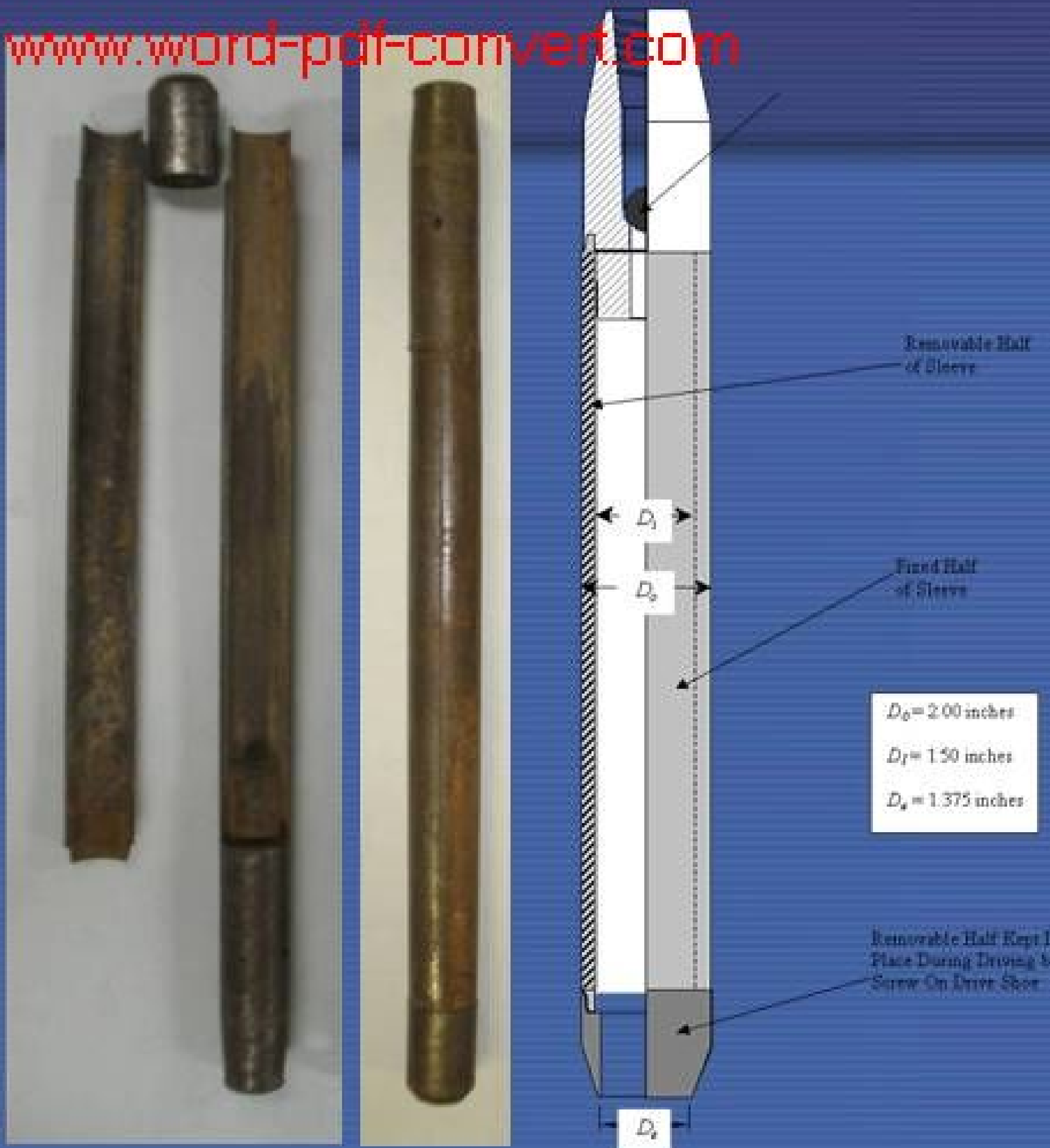
Borehole Drilling

- Drilling Rig
- Continuous Hollow Stem Augers With Removable Drill Rod And Center Head

Samplers





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Brown SILTY CLAY (very weathered shale). Slightly moist and very stiff to hard.		5	2	SS	25	3.50	19			
			3	SS	45	4.00	11			
		10	4	SS	72	4.00	14			
	12.0		5	SS	100	4.50	13			
Brown VERY WEATHERED SHALE and LIMESTONE layers. Dry and hard		15	6	SS	50/.5	4.50	13			
	18.0		7	SS	50/.4	4.50	0			
Gray weathered SHALE and LIMESTONE layers. Dry and soft shale with hard limestone.		20	8	SS	50/.1		0			
			9	SS	50/.5		3			
	23.9		10	SS	50/.3		6			
Boring discontinued at a depth of 23.9 feet due to sampler refusal.										

Top of Rock

Sample Type
- SS - Driven Split Spoon
- ST - Pressed Shelby Tube
- CA - Continuous Flight Auger
- RC - Rock Core
- CU - Cuttings
- CT - Continuous Tube

Depth to Groundwater
- Noted on Drilling Tools: None ft.
- At Completion (in augers) ____ ft.
- At Completion (open hole) None ft.
- After ____ days ____ ft.
- After ____ days ____ ft.
- Cave Depth 18.0 ft.

Boring Method
- HSA - Hollow Stem Augers
- CFA - Continuous Flight Augers
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Standard Penetration (SPT)

Penetration Number, N

Raising 70 lb Weight
Conventionally 140 lb Weight is Used)

Proper Technique of Releasing the Weight to Reduce Pulley Friction

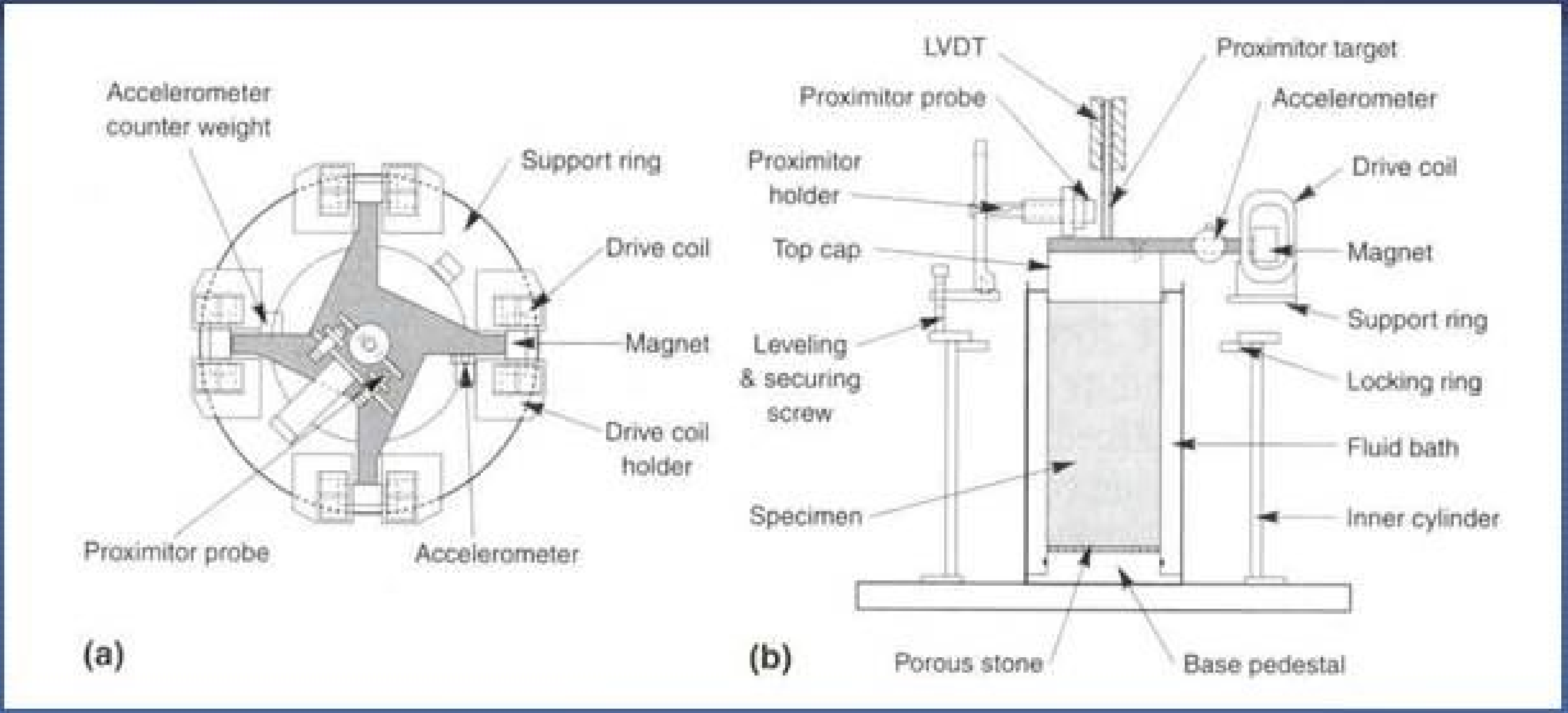
Geotechnical Laboratory tests

	Type of soils	Type of test	Parameter measured	Purpose
Soil index and classification	clayey soil	Atterberg limits	I_p, w_L, w_P,	Compressibility and plasticity
Physical and chemical properties of soils	All types	Dietrich- Fruhling apparatus	Carbonates and sulphates	Soil classification
Physical and chemical properties of groundwater	All types		Salt content	Influence on permeability
Soil moisture- density relationships	All types	Proctor test, gammametry, ASTM test (relative density)	γ_h, γ_d, w, S_r, D_r	Settlement, consolidation, bearing capacity, consolidation
Consolidation and permeability characteristics	All types	Oedometer	C_v, E_{oed}	Settlement, consolidation
Shear strength and deformation capability of soil	All types	Shear test box triaxial compression tests	E, ν,c, ϕ,drained and undrained,	Settlement, bearing capacity,
Engineering properties of rock	Rock	Shear test, biaxial or triaxial compression tests	E, ν,	Stability, strenthening
Dynamic characteristics of the soil.	All types	Cyclic triaxial tests, resonant column	E_{dyn}, ν, internal damping, pore pressure	Site categorization, SSI, liquefaction

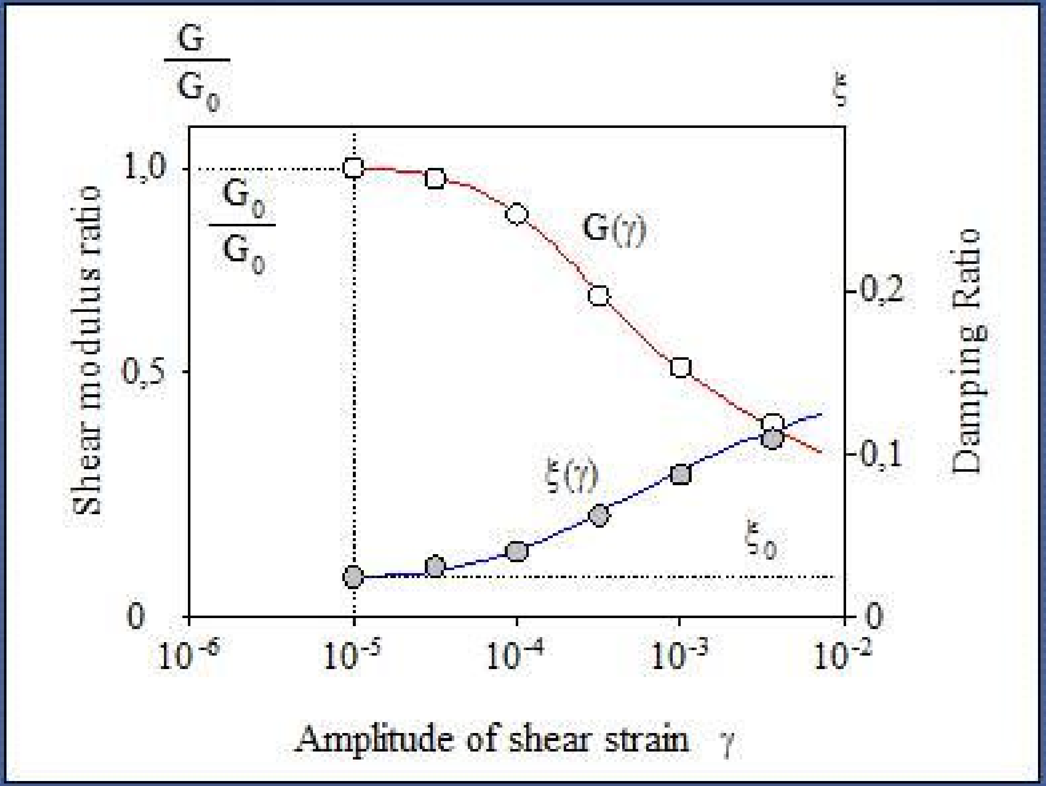
Triaxial test apparatus

Resonant Column Test

The resonant column test is the most commonly used laboratory test for measuring the low-strain properties of soils (Vs and damping)



It subjects solid or hollow cylindrical specimens to torsional or axial loading by an electromagnetic loading system. Usually harmonic loads for which frequency and amplitude can be controlled



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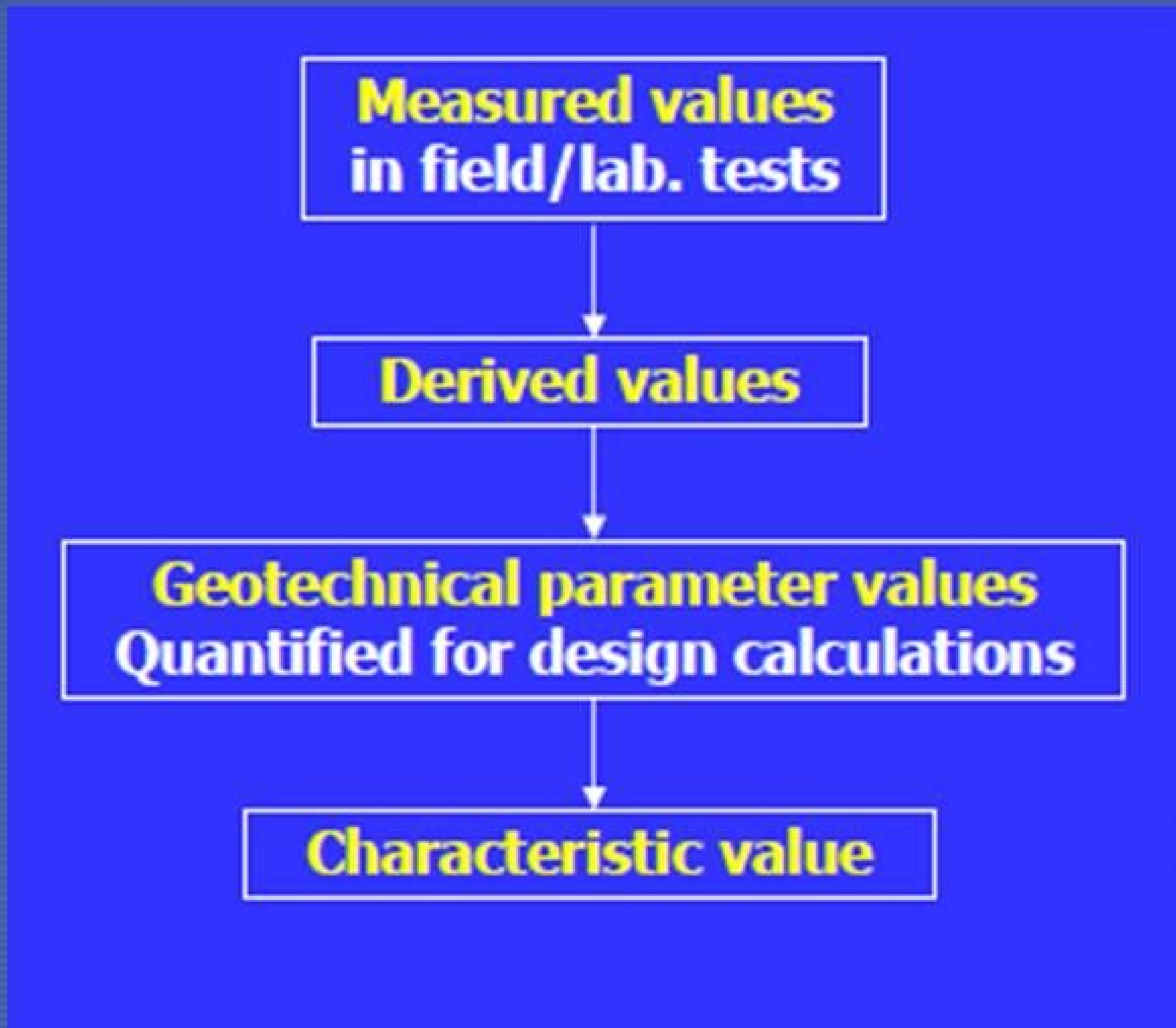
How to get characteristic values ?



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Derived Value

Definition

Value of a geotechnical parameter obtained from test results by theory, correlation or empiricism (EN 1997-2: Clause 1.5.3.1)

Examples

- The Annexes for the sections of Eurocode 7, Part 2 for different types of field and laboratory tests provide theories, correlation equations and graphs, to obtain derived parameter values from test results
- An example is the following equation given in Clause D2(2) of Annex D of Part 2 to obtain f'' from the results of a CPT test :

$$\phi' = 13.5 \times \log q_c + 23$$

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Characteristic Parameter Value

Principle

- The characteristic value shall be selected as a cautious estimate of the value affecting the occurrence of the limit state (*EN 1997-1: Clause 2.4.5.2(2)P*)

Application Rule

- The zone of ground governing the behavior of a geotechnical structure at a limit state is usually much larger than a test sample or the zone of ground affected in an in situ test. Consequently the value of the governing parameter is often the mean of a range of values covering a large surface or volume of the ground. The characteristic value should be a cautious estimate of this mean value (*EN 1997-1: Clause 2.4.5.2(7)*)

Innovative Feature

- Guidance on how to select this value is an innovative feature in Eurocode 7

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Difference between Derived and Governing Geotechnical Parameter Values

Reasons for difference between derived geotechnical parameter values and values governing behaviour of geotechnical structure (Clause 2.4.3(3))

- Many geotechnical parameters are not constants but depend on stress level
- and mode of deformation
- Soil and rock structure (e.g. cracks, laminations, or large particles) that may
- play a different role in the test and in the geotechnical structure
- Time effects
- Softening effect of percolating water on soil or rock strength
- Softening effect of dynamic actions
- Brittleness or ductility of the soil and rock tested
- Method of installation of the geotechnical structure
- Influence of workmanship on artificially placed or improved ground
- Effect of construction activities on the ground properties

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Characteristic values and Statistics

- If statistical methods are used, the characteristic value should be derived such that the calculated probability of a worse value governing the occurrence of the limit state under consideration is not greater than 5% (*EN 1997-1: Clause 2.5.4.2(11)*)
- Note :
  - In this respect, a cautious estimate of the mean value is a selection of the mean value of the limited set of geotechnical parameter values, with a confidence level of 95%; where local failure is concerned, a cautious estimate of the low value is a 5% fractile
- At present it is not anticipated that statistical methods will routinely be used to select characteristic values

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Process to Obtain Characteristic Value

Stage 1

Covered by:
EN 1997-1, *Clauses 2.4.3 (Ground properties, 3.3 (Evaluation of geotechnical parameters)* and EN 1997-2

Values at particular points in the ground or locations on site where tests carried out or values from particular lab. specimens

Measured values in field/lab. tests

↓

Test results

↓

Derived values

↓

Geotechnical parameter values
Quantified for design calculations

Factors involved and to be considered at each stage are given; e.g.

- Assessment of test and design conditions on parameter values
- Relevant published data and local and general experience

Stage 2

Covered by
EN 1997-1, Clause 2.4.5.2 *(Characteristic values of geotechnical parameters)* and 2.4.6.2 *(Design values of geotechnical parameters)*

Overall parameter value for volume of soil affecting the occurrence of the limit state

↓

Characteristic value

↓

Application of partial factor, γ_M

↓

Design value
For use in design calculations

Cautious estimate taking account of :

- Number of test results
- Variability of ground
- Scatter of test results
- Particular limit state and volume of ground involved
- Nature of structure

Investigations for complex subsurface conditions

- Prediction of complex subsurface conditions
  - The greatest risk is mainly from the existence of filled or open cavities
- Detection of subsurface cavities
  - The conventional methods of site exploration are applicable
  - Some geophysical methods are useful in a reconnaissance mode for the detection of subsurface cavities (electrical resistivity profiling, microgravimetry, seismic refraction surveys, seismic fan shooting and ground probing radar).
  - The compressibility and erosion potential of the natural filling material should be evaluated in order to determine their impact on bearing capacity, settlement and future erosion
  - The stability of natural cavities below the foundation level should be considered and estimated.

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Subsidence and karstic phenomena

- The site will be investigated for subsidence of ground due to occurrence of geological feature called 'karst', mining activity or oil extraction.
- Karst is a special type of landscape that is formed by the dissolution of soluble rocks. During rainfall, water seeps into the soil. The water becomes weakly acidic when it reacts chemically with carbon dioxide in the atmosphere and the soil to form carbonic acid. This acidic water, when passes through the bedrock, dissolves the rock material which eventually forms into cave passages and caverns, which is termed as karst.
- In case of potential such geological hazards exist and no practical engineering solutions are available to mitigate their effects, the site will be rejected.

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- Site considerations
- Foundation Considerations
- Earth structures
- Buried structures
- Monitoring of geotechnical parameters
- Quality insurance

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Site considerations

- Site categorisation

  For the purpose of seismic response analyses, the following site categorization is introduced:

  - Type 1 sites: Vs > 1100 m/s
  - Type 2 sites: 300 m/s < Vs < 1100m/s
  - Type 3 sites: Vs < 300m/s

- Parameters of the profiles

  - Geometrical , mechanical description, best estimates and ranges of variation of the subsurface materials determined and described in a way directly applicable to the subsequent analysis.

- These values are supposed to be estimated in free field conditions
- and in absence of earthquake ;

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Remarks

- This Classification of the sites is important for the ranking of the different sites at the stage of candidate sites.
- This demand (type of soil and shear wave velocity) is well adapted to the capabilities of geophysical surveys.
- Knowing this site classification allows to evaluate the risk and to have an idea of the type of foundations . Shallow foundation or piles foundation ? Ground improvement or not ? Seismic high accelerations or not? Large displacements or not ?

Remarks on sites classification

- We know that a NPP designer prefers hard soil conditions than soft soil conditions for many reasons.
- The classification of the sites in 1,2 and 3 categories is not sufficient if it's not associated with the seismic level of DBE. This is particularly important for the category 1 site.
- If the seismic level is important, a site category 1 can become unacceptable because it generates too huge and expensive works in terms of design justifications (beyond standard methodologies).
- In addition, this classification is also dependent of the type of reactor one intends to install. As an example, a site with a DBE scaled to a PGA of 0.3g can be acceptable for one type of reactor and not for an other due to his foundation type.

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Chart of seismic studies

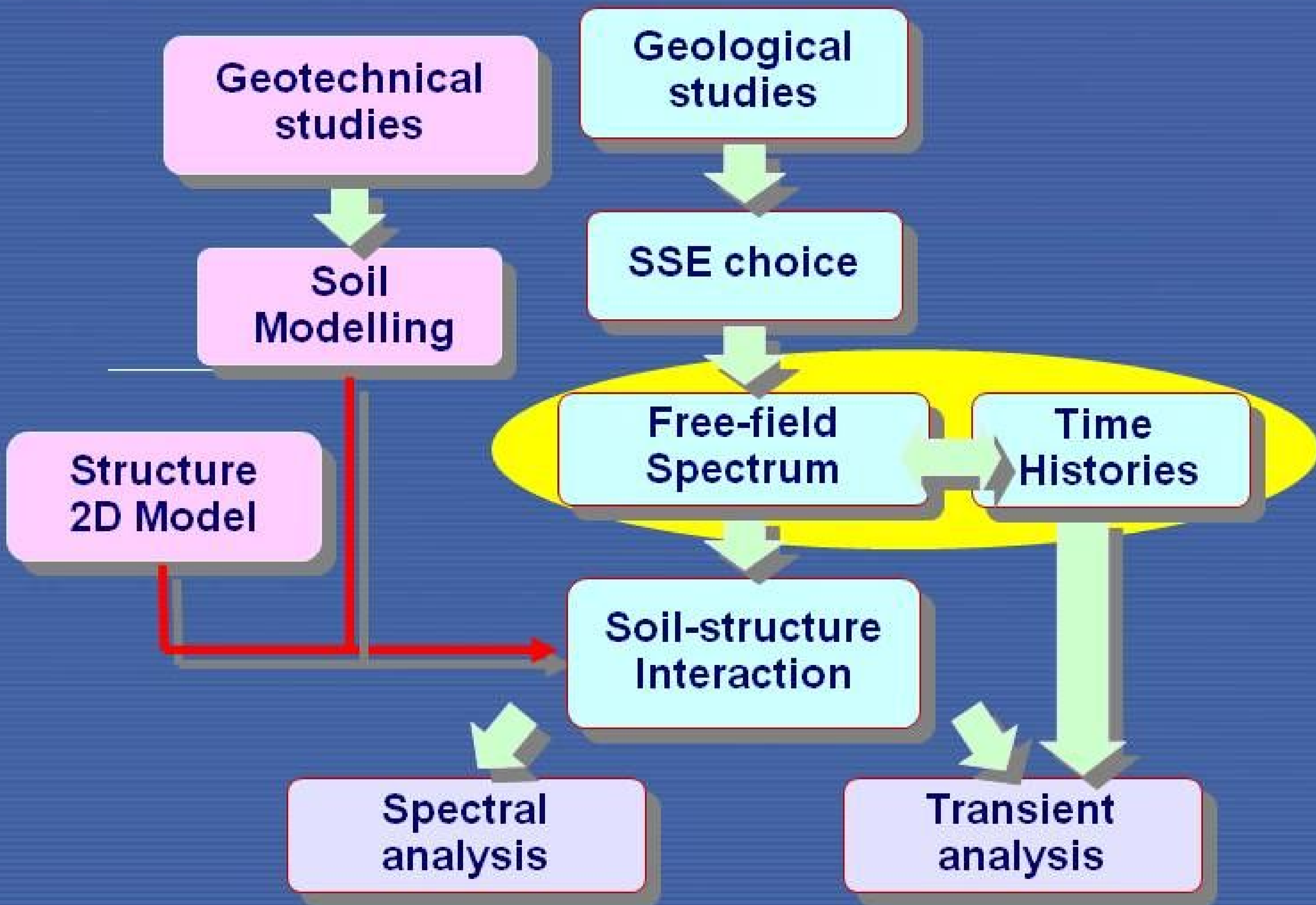
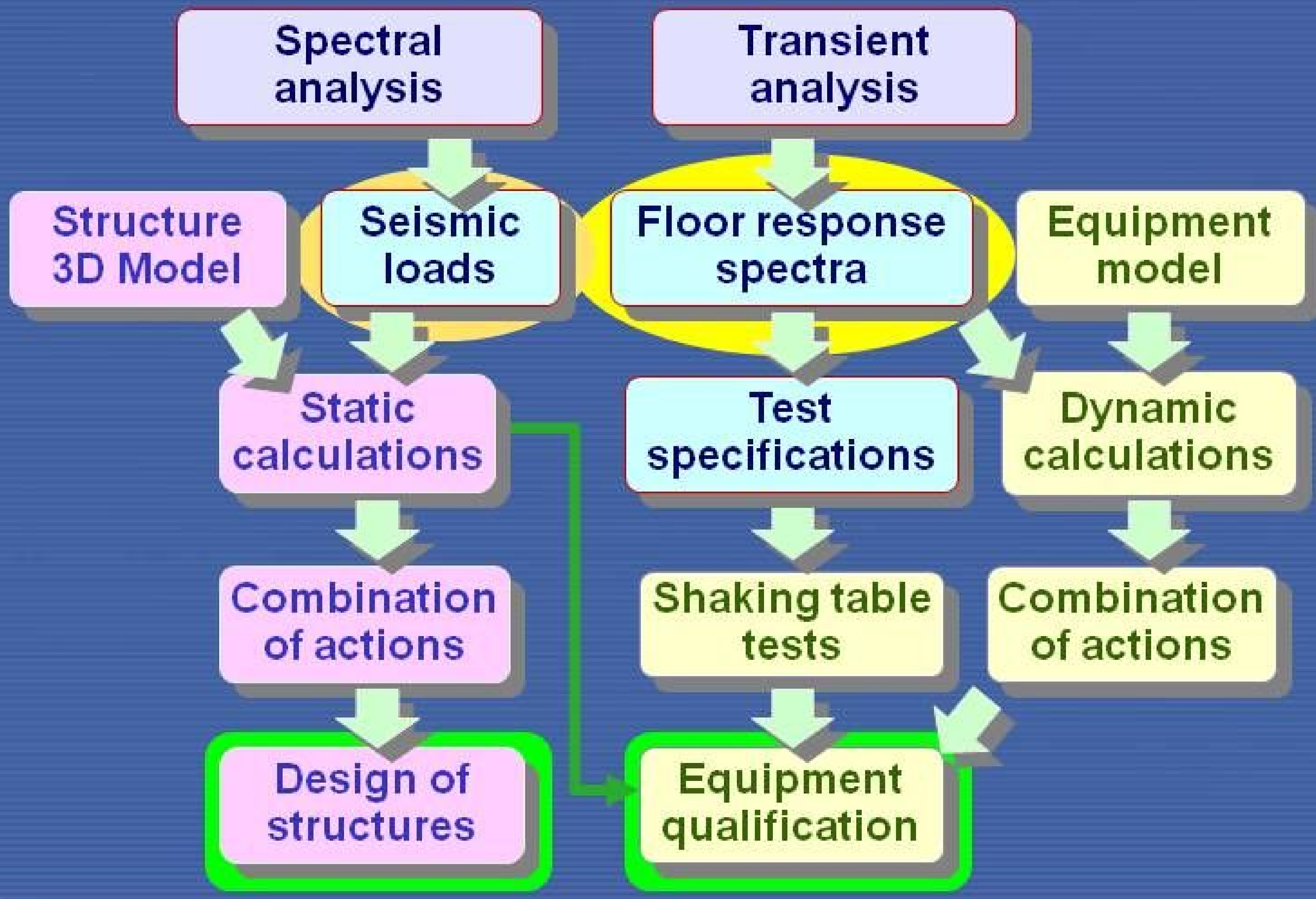


Chart of seismic studies (ctd)



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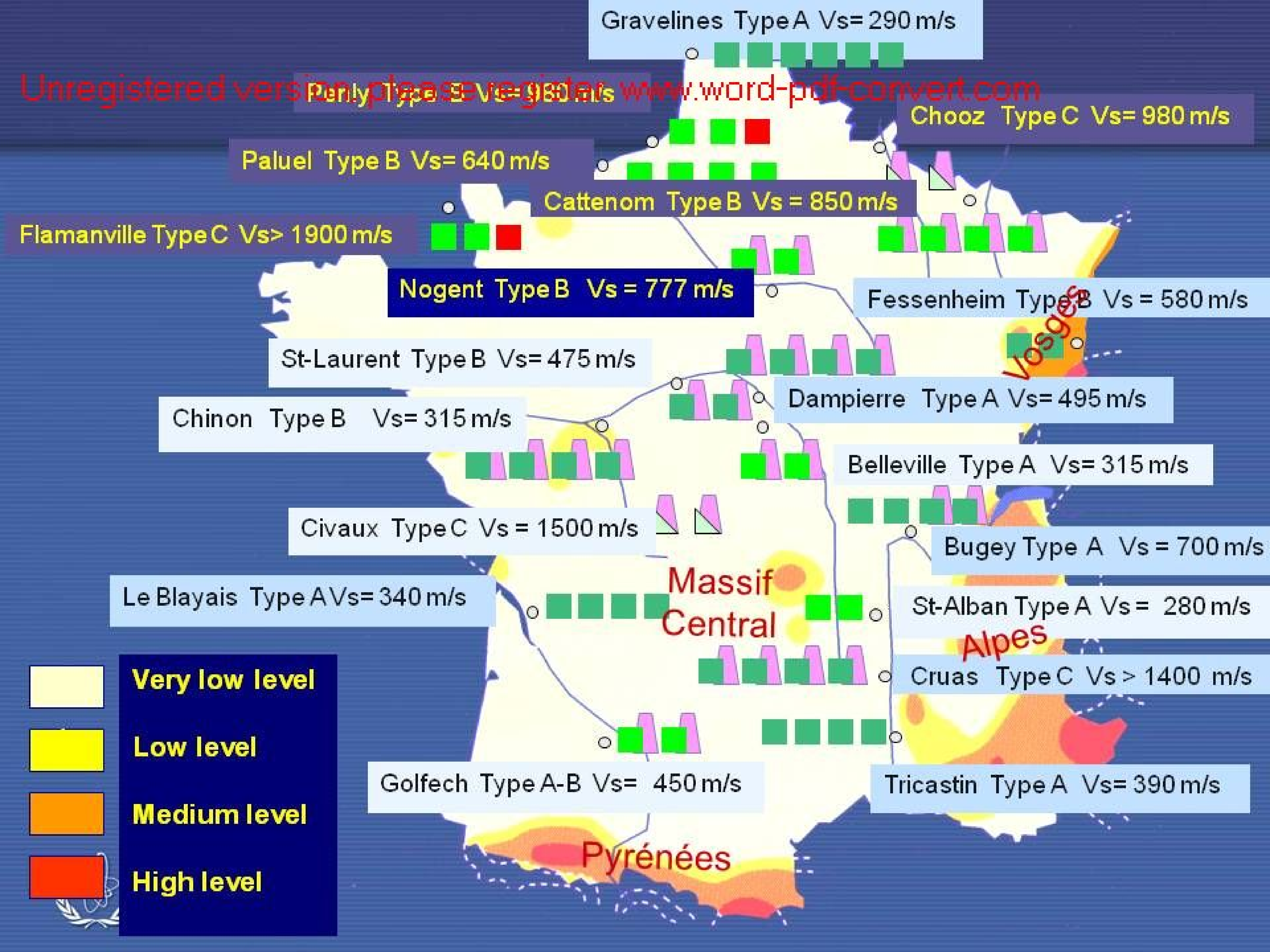
Gravelines Type A Vs= 290 m/s
Penly
Chooz Type C Vs= 980 m/s
Paluel Type B Vs= 640 m/s
Cattenom Type B Vs = 850 m/s
Flamanville Type C Vs> 1900 m/s
Nogent Type B Vs = 777 m/s
Fessenheim Type B Vs = 580 m/s
Vosges
St-Laurent Type B Vs= 475 m/s
Dampierre Type A Vs= 495 m/s
Chinon Type B Vs= 315 m/s
Belleville Type A Vs= 315 m/s
Civaux Type C Vs = 1500 m/s
Bugey Type A Vs = 700 m/s
Massif Central
Le Blayais Type A Vs= 340 m/s
St-Alban Type A Vs = 280 m/s
Alpes
Cruas Type C Vs > 1400 m/s
Very low level
Low level
Medium level
High level
Golfech Type A-B Vs= 450 m/s
Tricastin Type A Vs= 390 m/s
Pyrénées

Other Remarks on sites classification

- We know that a NPP designer prefers hard soil conditions than soft soil conditions for many reasons.
- The classification of the sites in 1,2 and 3 categories is not sufficient if it's not associated with the seismic level of DBE. This is particularly important for the category 3 site.
- If the seismic level is important, a site category 3 can become unacceptable because it generates too huge and expensive works in terms of design justifications (beyond standard methodologies).
- In addition, this classification is also dependent of the type of reactor one intends to install. As an example, a site with a DBE scaled to a PGA of 0.3g can be acceptable for one type of reactor and not for an other due to his foundation type.

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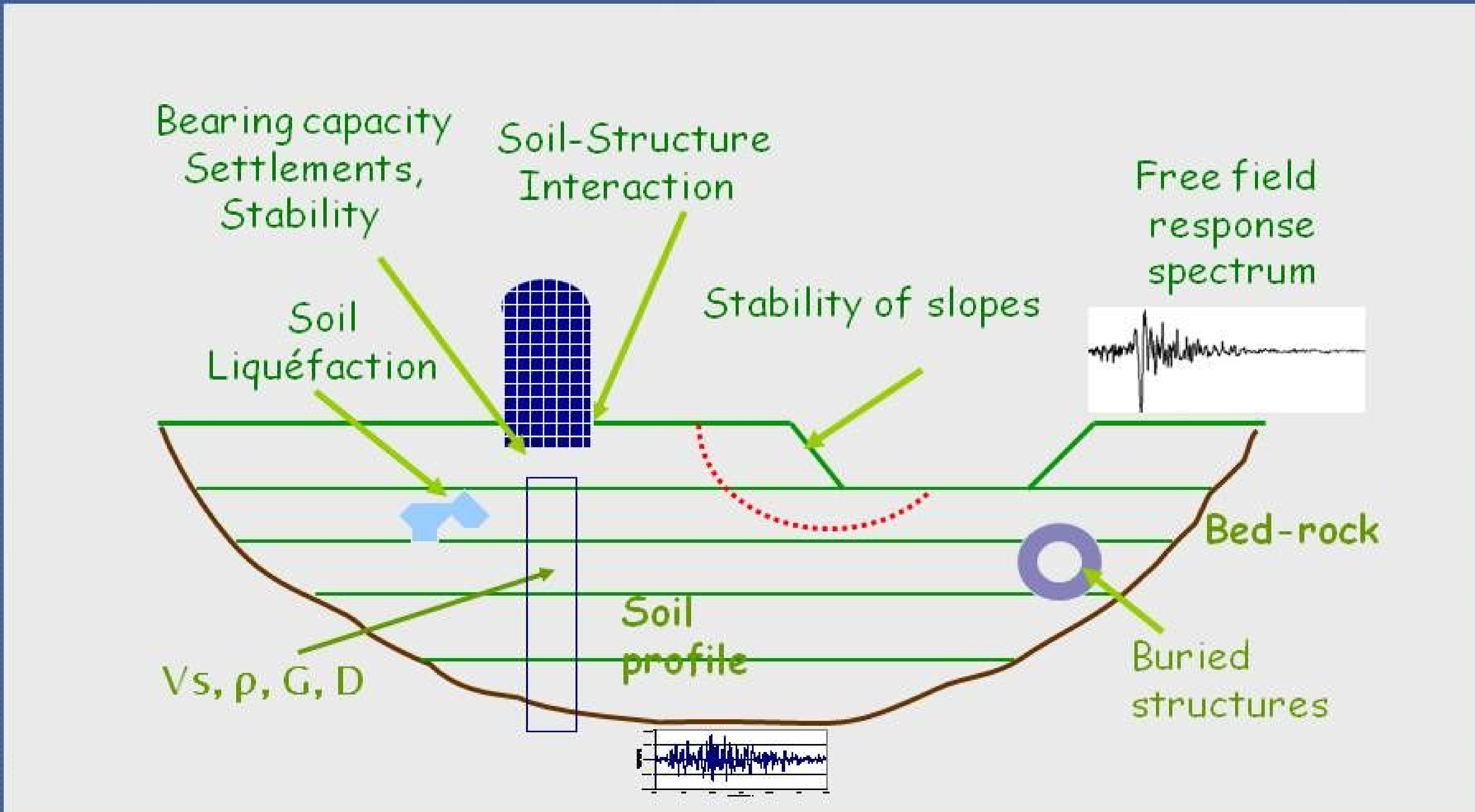
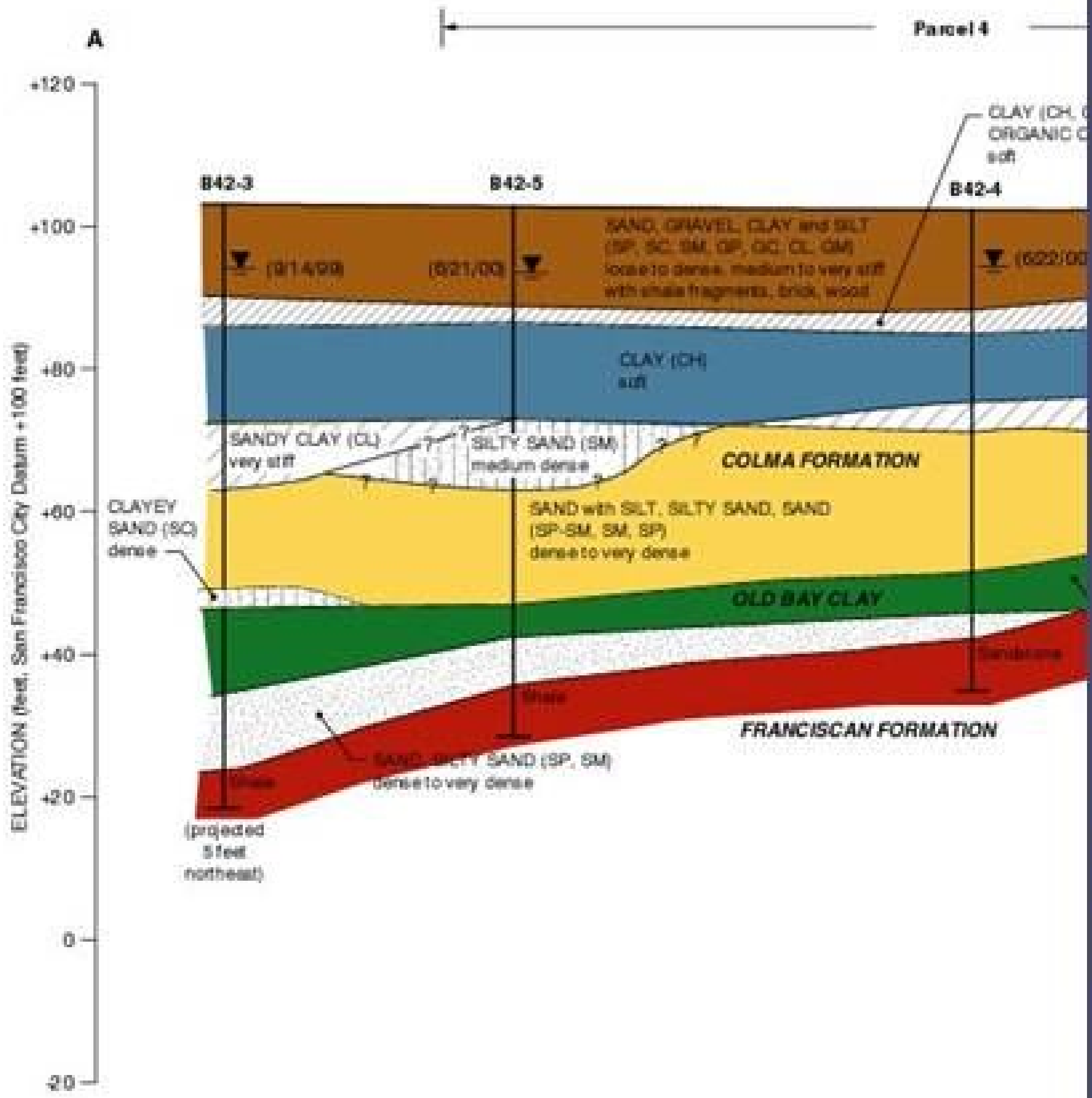
Safety related topics to be examined



The profile



Notes: 1. The above profile represents a generalized soil cross section interpreted from widely spaced borings. Soil deposits may vary in type, strength, and other important properties between points of exploration.

- Geometrical description, such as subsurface stratigraphic descriptions, lateral and vertical extent, number and thickness of layers,
- Physical and chemical properties of soil and rock and their values used for classification,
- S - and P - wave and other mechanical properties obtained by in situ test;
- Mechanical properties parameters, stress-strain relationships, static and dynamic strength properties obtained by laboratory tests,
- Groundwater table,

Site response Modeling

The following model of soil is acceptable:

- A viscoelastic soil system overlying a viscoelastic half-space,
- A horizontally layered system ,
- Materials that dissipate energy by internal damping ,
- Vertically propagating body waves (shear and compression waves),
- Non-linear effects may be approximated by equivalent linear methods.

The equivalent linear model (s) of soil constitutive relationship should be consistent with the strain level induced in the soil profile by the response to the input ground motion. This leads generally to an iterative process.

- Softwares available: SHAKE, CYBERQUAKE …

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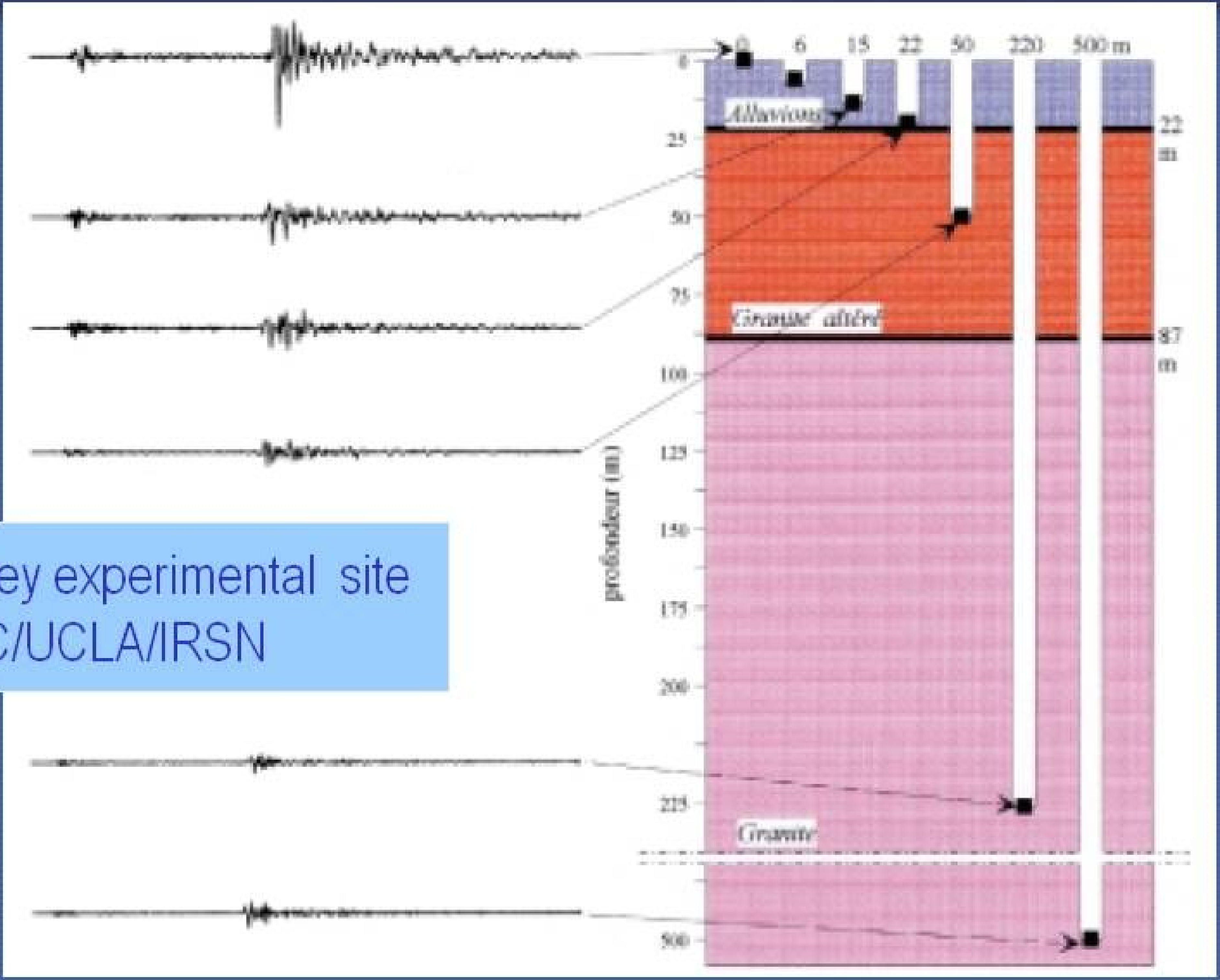
Illustration of site effect



Garner Valley experimental site
NRC/UCLA/IRSN

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Site effects

Eurocode 8 give a subsoil classification scheme . In particular five different subsoil classes (A-E) are defined. Their distinguishing coefficient is the average shear wave velocity $V_{s,30}$ dominating in the first 30 m of the subsoil layers.

The site effect is to be considered if $V_{s,30}$ is less than 300 m/s.

Ground type	Description of stratigraphic profile	Parameters		
		$v_{s,30}$ (m/s)	N_{SPT} (blows/30cm)	c_u (kPa)
A	Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface	> 800	_	_
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of m in thickness, characterised by a gradual increase of mechanical properties with depth	360 – 800	> 50	> 250
C	Deep deposits of dense or medium-dense sand, gravel or stiff clay with thickness from several tens to many hundreds of m	180 – 360	15 - 50	70 - 250
D	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil	< 180	< 15	< 70
E	A soil profile consisting of a surface alluvium layer with v_s values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with v_s > 800 m/s			
S_1	Deposits consisting – or containing a layer at least 10 m thick – of soft clays/silts with high plasticity index (PI > 40) and high water content	< 100 (indicative)	_	10 - 20
S_2	Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types A – E or S_1			

Free Field Seismic Response and Site Specific Response Spectra

- The seismic input level considered is the SL-2 level (as defined in the Requirements on site evaluation),
- Except for type 1 sites, a computation of site response under free field conditions should be carried out , for settlement or liquefaction assessment as well as for soil-structure interaction analyses , with the following data:
  - Input ground motion (as resulting from other procedures),
  - Appropriate model of the site, based on the following data,
    - geometrical description of the soil layers, the S and P waves velocities in each layer, the relative density of the soil in each layer, the G-g and h-g curves for each layer
  - The above mentioned parameters should be described versus depth,

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Free Field Seismic Response and Site Specific Response Spectra (ctd)

- The input ground motion may be representative of the ground surface motion either on the site or at a hard outcrop,
- For sites 2 and 3, in the case of a input ground motion provided at surface level, a deconvolution computation of the input motion in free field conditions should be carried out,
- If the input ground motion has to be determined, it should be chosen with allowance for earthquake intensity, magnitude, epicentral distance, maximum acceleration, duration, frequency content and other parameters,
- Uncertainties in the mechanical properties of the site materials should be taken into account through parametric studies (at least on the shear modulus value). One method is to vary the shear modulus (with G best estimate value) in the range [G $(1+C_v)$, G$(1+C_v)$] and the minimum value of C_v is 0.5.

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LIQUEFACTION OF SOIL

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Figure 1. Sand boiling caused by liquefaction of underlying sediments during the 1978 Miyagi-ken-Oki, Japan earthquake (original source unknown).

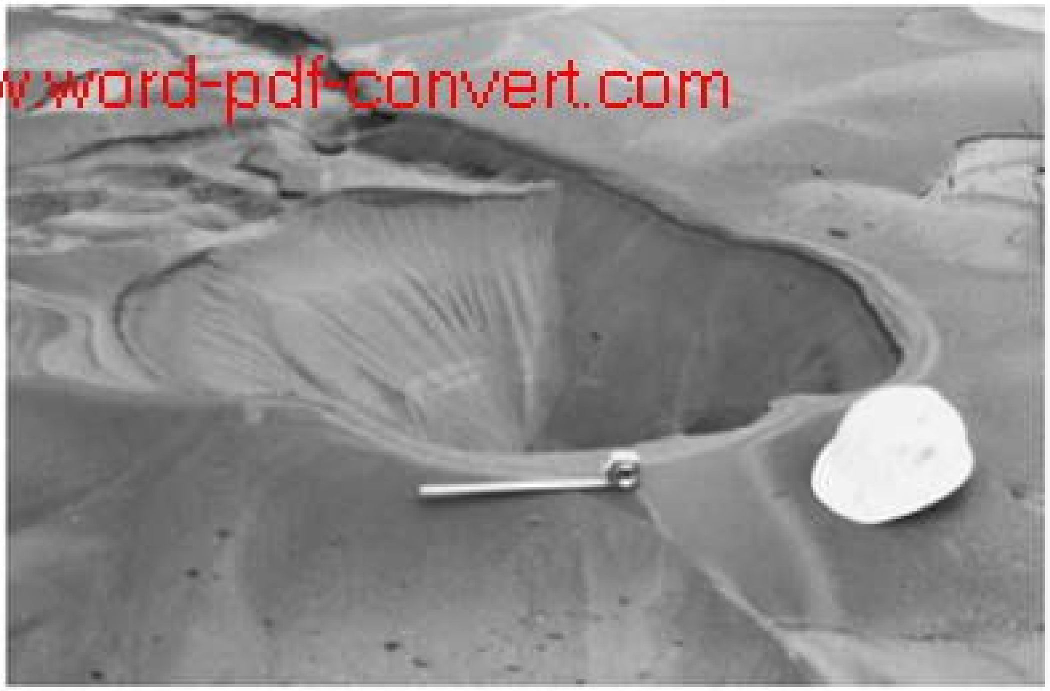

Figure 2. Sand boil after liquefaction-induced boiling from the 1989 Loma Prieta, California earthquake has ceased.

Figure 3. Tilting of apartment buildings caused by the 1964 Niigata earthquake (photo: National Information Service for Earthquake Engineering, EERC, University of California, Berkeley).

Figure 4. Floating of buried tank in liquefied ground, caused by the 1964 Niigata earthquake (photo: Kawasumi 1968).

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Liquefaction Potential

- Design profile for liquefaction potential
  - Grain size distribution.
  - Standard penetration tests (SPT)
  - Cone penetration tests (CPT)
  - Relative density
  - Undrained cyclic strength
  - Strain-dependency of soil properties
  - Other soil properties
- Evaluation of liquefaction potential
  - An empirical approach,
  - A conventional analytical approach.
  - A sophisticated analytical approach

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Empirical approach

Correlating the stress ratio determined with SPT or CPT penetration resistance which were empirically established based on the past liquefaction case histories.

Conventional analytical approach

- Establishment of the cyclic strength characteristics of the foundation material in each layer (*Correction factors to convert laboratory results to field conditions are necessary*).
- Choice of a set of appropriate accelerograms.
- Calculation in each layer of the stresses induced by the accelerograms, which are transformed into numbers of equivalent uniform cycles.
- Determination of the liquefaction potential by comparing the cyclic strength characteristic with the computed equivalent cycles

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Sophisticated analytical approach

- A constitutive model of soil is incorporated in a nonlinear time history analysis based on finite elements model to directly evaluate the pore-pressure buildup and the dynamic ground response
- Results quite variable due to different input motions, constitutive models, etc.. the final assessment should be made considering the extent of variability.

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Comparison between the 3 approaches

The comparison of the above analytical results provides the safety factors :

- The analytical approach provides a lower bound solution using conservative assumptions for the design profile parameters.
  - For loose sands, a slight increase in the seismic stresses may bring the soil into an unstable condition with possible large deformations,
  - while in medium to dense sands even a large increase in seismic stresses generates only a limited deformation despite 100% pore-pressure buildup.
- Acceptable safety factors cannot be specified a priori but they should be specified on a case by case basis using the results derived as above.
  - **in such a way that dynamically induced strain or residual strain does not impair the foundation performance.**

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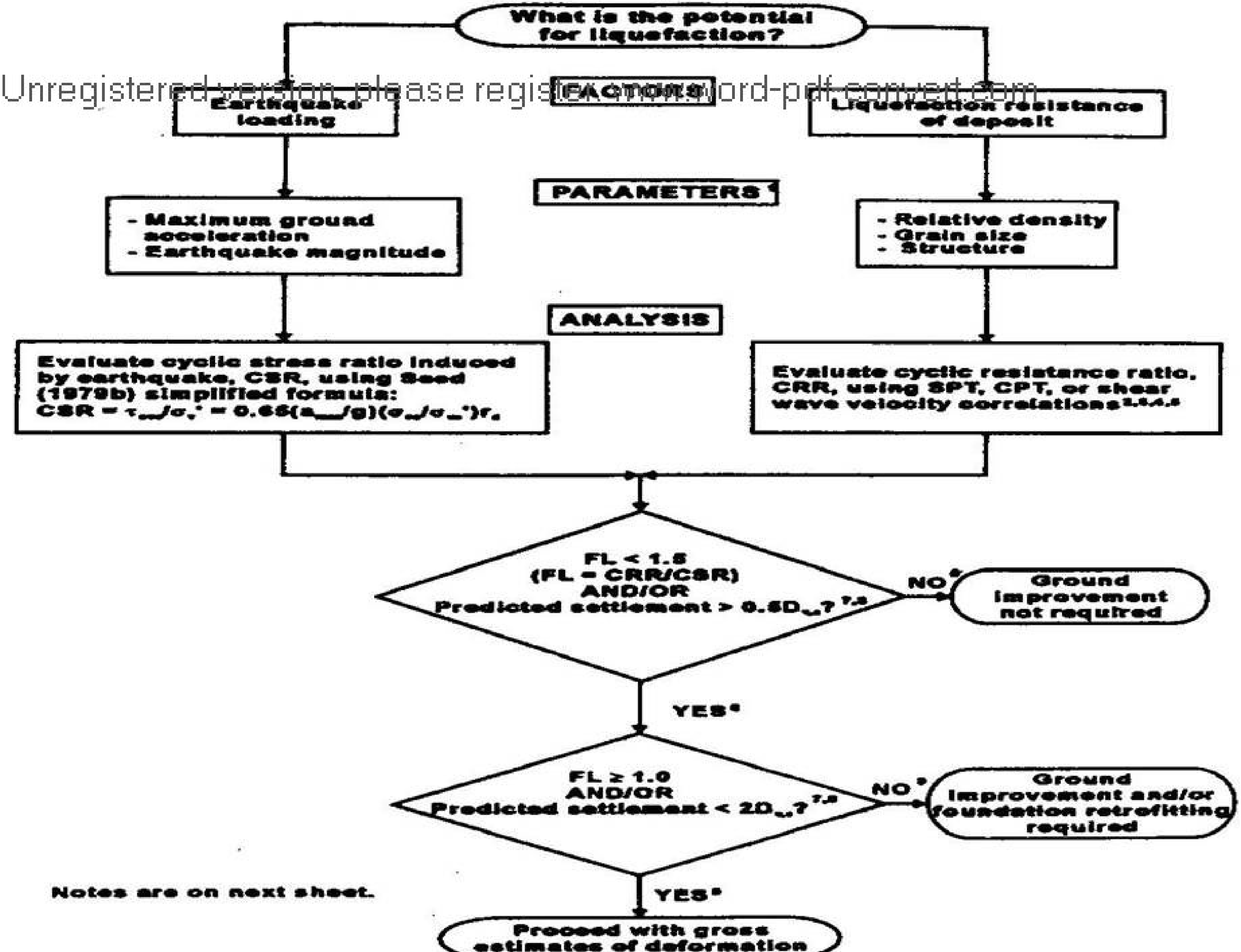

Notes are on next sheet.

Contents

- Introduction
- Site investigation
- Site considerations
- Foundation Considerations
- Earth structures
- Buried structures
- Monitoring of geotechnical parameters
- Quality insurance

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Foundations considerations

- Foundation work
  - Preliminary foundation work
  - Improvement of foundation conditions
  - Choice of foundation system and construction
- Soil-structure interaction
  - Static Analysis , Dynamic Analysis , Analysis methods
- Stability
  - Bearing capacity , Overturning , Sliding
- Settlements and heaves
  - Static analysis , Dynamic analysis
- Induced vibration effects

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Preliminary Foundation Work

- Prototype testing (including test fills, verification of foundation material improvement techniques)
- Excavations for foundations or foundation systems
- Dewatering and its control
- Dental work in rock
- Mapping of excavations
- Foundation materials improvement (including such items as material modification, drainage, etc)
- Structural backfill placement
- Mud mat placement or any type of protection layer

Improvement of Foundation Conditions

- Improvement of the foundation conditions should be carried out when:
  - The foundation material is not capable of carrying the building loads with acceptable deformation (settlements)
  - There are cavities that can lead to subsidence
  - There are heterogeneities, on the scale of building size, which can lead to tilting and/or unacceptable differential settlements
  - Expansive soil or collapsing soil, sensitive clay or dispersive clay
  - Site susceptible to liquefaction
  - Slope instability
  - Seepage problems

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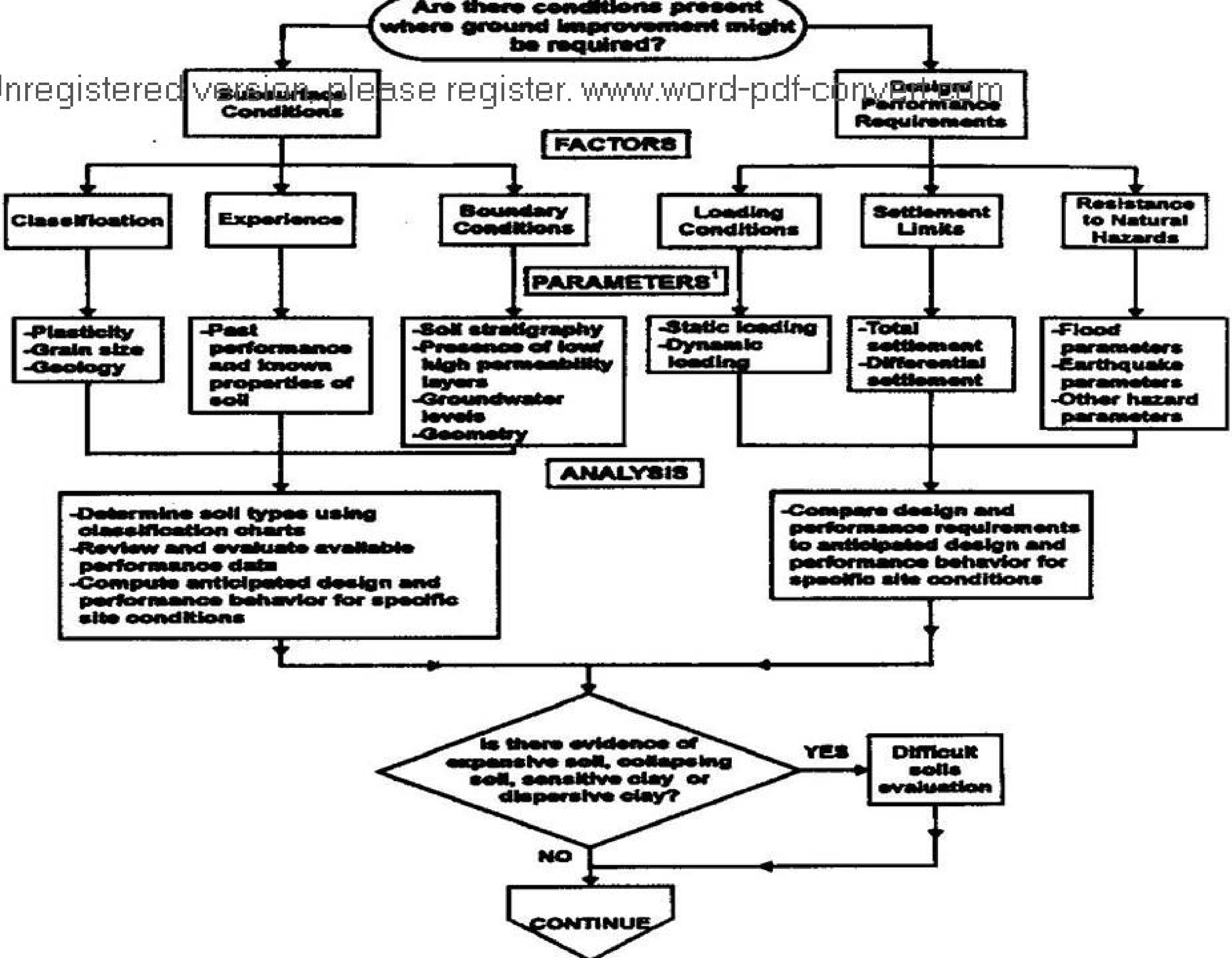
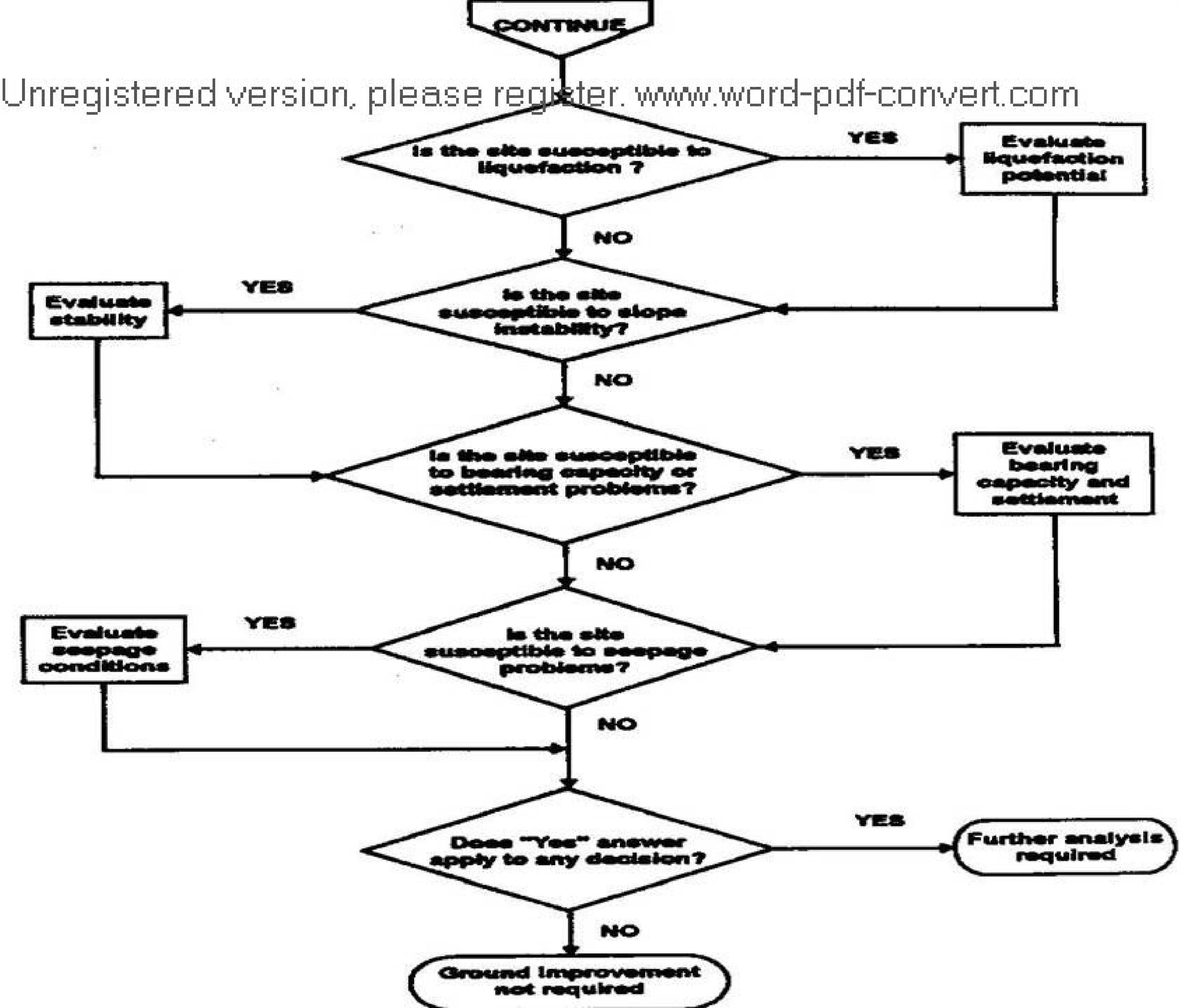
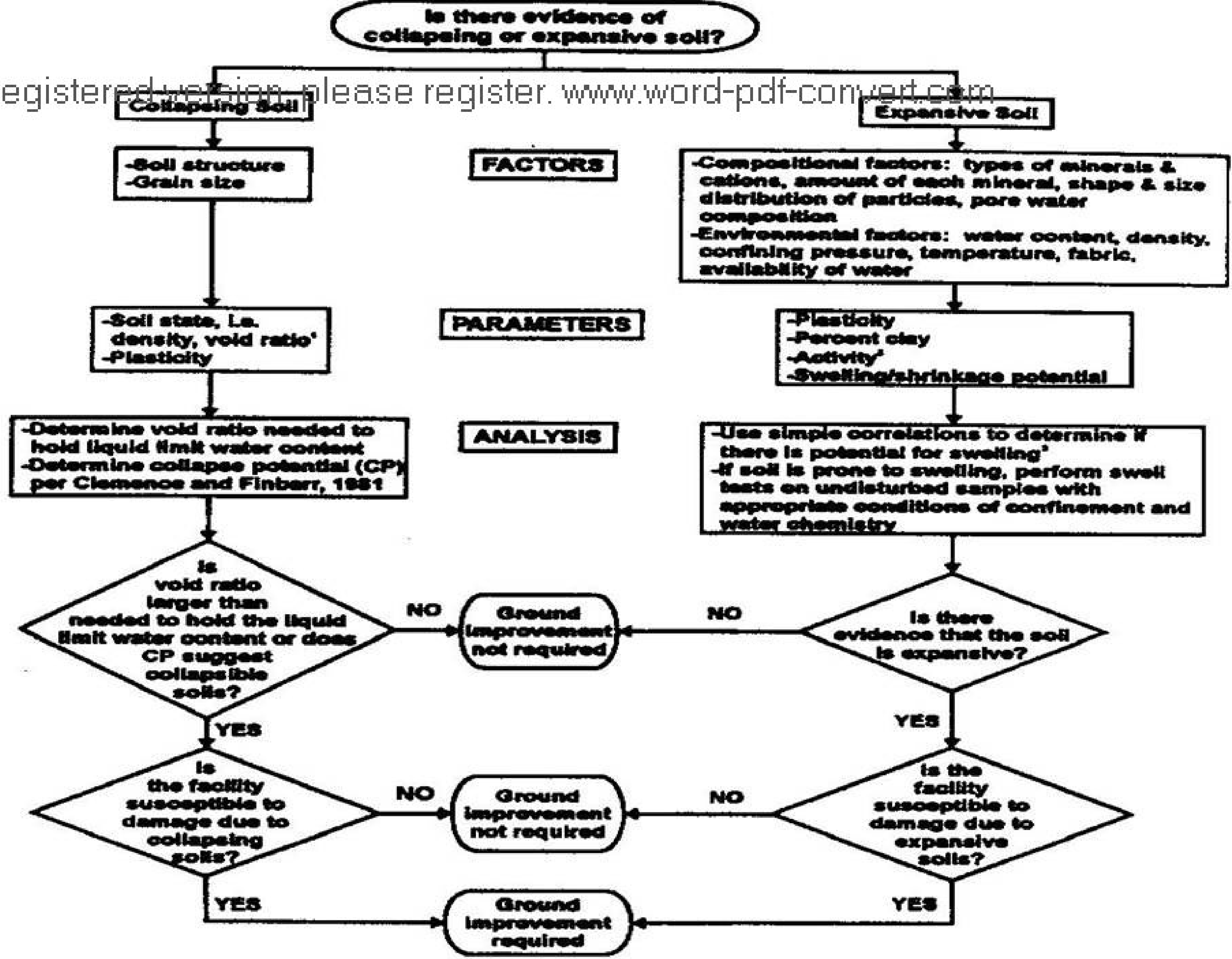


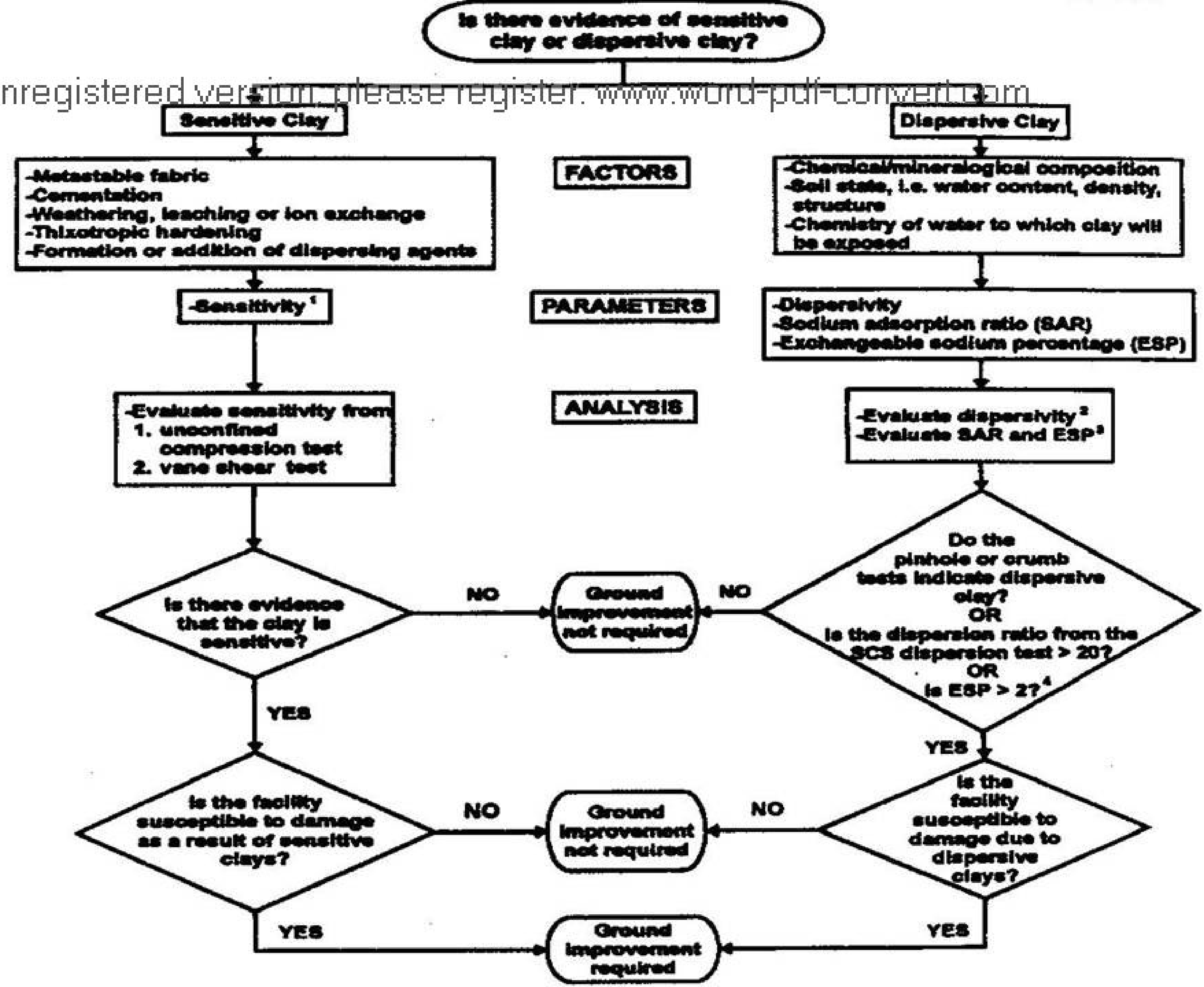
Are there conditions present where ground improvement might be required?
Subsurface Conditions
Design/ Performance Requirements
FACTORS
Classification
Experience
Boundary Conditions
Loading Conditions
Settlement Limits
Resistance to Natural Hazards
PARAMETERS[1]
-Plasticity
-Grain size
-Geology
-Past performance and known properties of soil
-Soil stratigraphy
-Presence of low/ high permeability layers
-Groundwater levels
-Geometry
-Static loading
-Dynamic loading
-Total settlement
-Differential settlement
-Flood parameters
-Earthquake parameters
-Other hazard parameters
ANALYSIS
-Determine soil types using classification charts
-Review and evaluate available performance data
-Compute anticipated design and performance behavior for specific site conditions
-Compare design and performance requirements to anticipated design and performance behavior for specific site conditions
Is there evidence of expansive soil, collapsing soil, sensitive clay or dispersive clay?
YES
Difficult soils evaluation
NO
CONTINUE


CONTINUE
Is the site susceptible to liquefaction ?
YES
Evaluate liquefaction potential
NO
Is the site susceptible to slope instability?
YES
Evaluate stability
NO
Is the site susceptible to bearing capacity or settlement problems?
YES
Evaluate bearing capacity and settlement
NO
Is the site susceptible to seepage problems?
YES
Evaluate seepage conditions
NO
Does "Yes" answer apply to any decision?
YES
Further analysis required
NO
Ground improvement not required



Is there evidence of collapsing or expansive soil?
Collapsing Soil
Expansive Soil
-Soil structure
-Grain size
FACTORS
-Compositional factors: types of minerals & cations, amount of each mineral, shape & size distribution of particles, pore water composition
-Environmental factors: water content, density, confining pressure, temperature, fabric, availability of water
-Soil state, i.e. density, void ratio¹
-Plasticity
PARAMETERS
-Plasticity
-Percent clay
-Activity²
-Swelling/shrinkage potential
-Determine void ratio needed to hold liquid limit water content
-Determine collapse potential (CP) per Clemence and Finbarr, 1981
ANALYSIS
-Use simple correlations to determine if there is potential for swelling³
-If soil is prone to swelling, perform swell tests on undisturbed samples with appropriate conditions of confinement and water chemistry
Is void ratio larger than needed to hold the liquid limit water content or does CP suggest collapsible soils?
NO
Ground improvement not required
NO
Is there evidence that the soil is expansive?
YES
YES
Is the facility susceptible to damage due to collapsing soils?
NO
Ground improvement not required
NO
Is the facility susceptible to damage due to expansive soils?
YES
Ground improvement required
YES

Notes:


Is there evidence of sensitive clay or dispersive clay?
Sensitive Clay
Dispersive Clay
FACTORS
-Metastable fabric
-Cementation
-Weathering, leaching or ion exchange
-Thixotropic hardening
-Formation or addition of dispersing agents
-Chemical/mineralogical composition
-Soil state, i.e. water content, density, structure
-Chemistry of water to which clay will be exposed
PARAMETERS
-Sensitivity 1
-Dispersivity
-Sodium adsorption ratio (SAR)
-Exchangeable sodium percentage (ESP)
ANALYSIS
-Evaluate sensitivity from
1. unconfined compression test
2. vane shear test
-Evaluate dispersivity 2
-Evaluate SAR and ESP 3
Is there evidence that the clay is sensitive?
NO
Ground improvement not required
NO
Do the pinhole or crumb tests indicate dispersive clay?
OR
Is the dispersion ratio from the SCS dispersion test > 20?
OR
Is ESP > 2? 4
YES
YES
Is the facility susceptible to damage as a result of sensitive clays?
NO
Ground improvement not required
NO
Is the facility susceptible to damage due to dispersive clays?
YES
Ground improvement required
YES

Potentially applicable Ground improvement methods

Purpose	Method	
• Increase resistance to liquefaction • Reduce movements	• Vibrocompaction, vibrorod • Stone columns • Deep dynamic compaction • Explosive compaction • Gravel drains	• Deep soil mixing • Penetration grouting • Jet grouting • Compaction grouting • Sand and gravel compaction piles
• Stabilize structures that have undergone differential settlement	• Compaction grouting • Penetration grouting	• Jet grouting • Mini-piles
• Increase resistance to cracking, deformation and/or differential settlement	• Compaction grouting • Penetration grouting	• Jet grouting • Mini-piles
• Reduce immediate settlement	• Vibrocompaction, vibrorod • Deep dynamic compaction • Explosive compaction • Compaction grouting	• Deep soil mixing • Jet grouting • Sand and gravel compaction piles
• Reduce consolidation settlement	• Precompression • Jet grouting • Compaction grouting	• Stone columns • Deep soil mixing • Electro-osmosis
• Increase rate of consolidation settlement	• Vertical drains, with or without surcharge fills • Sand and gravel compaction piles	
• Improve stability of slopes	• Buttress fills • Gravel drains • Penetration grouting • Compaction grouting	• Jet grouting • Deep soil mixing • Soil nailing • Sand and gravel compaction piles
• Improve seepage barriers	• Jet grouting • Deep soil mixing	• Penetration grouting • Slurry trenches
• Strengthen and/or seal interfaces between embankments/abutments/foundations	• Penetration grouting	• Jet grouting

Summary of available methods

- Dissipation of excess pore pressure
  - Gravel drains
  - Sand drains
  - Wick or paper drains
- Densification through vibration and compaction
  - Sand compaction piles
  - Deep dynamic compaction
  - Vibration/ vibro flotation
  - Stone columns
  - Preloading
  - Compaction grouting
  - Timber displacement piles
- Restraining effect through inclusions
  - Deep soil mixing
  - Diaphragm walls
- Stiffening through chemical cement addition
  - Jet grouting
  - Chemical grouting

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Ground Improvement Design program

The following steps can be followed to design the ground improvement program:

1. Select potential improvement methods.
2. Develop and evaluate remedial design concepts.
3. Choose methods for further evaluation.
4. Perform final design for one or more of the preliminary designs.
5. Compare final designs and select the best one.
6. Field test for verification of effectiveness and development of construction procedures.
7. Develop specifications and QA/QC programs.

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Choice of Foundation System

- Two systems of foundations are available for transmitting the superstructure loads to the soil: **shallow foundations** and **deep foundations** and the criteria leading to the choice are **:**
  - **the forces due to the structures should be transmitted to the soil without any unacceptable deformation,**
  - **the soil deformations induced by the earthquake should be compatible with the design requirements of the structure,**
- **Uncertainties** of the seismic response evaluation should be considered in the design and construction of the foundation system
- One single type of foundation should be used per structure
- The choice of the type of foundation depends on the type of building. **Basemat** should be used for nuclear island because:
  - **provides homogeneous settlements under static and dynamic loads**
  - **barrier between the environment and the buildings inside**

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Examples of Deep Foundations in NPP

NPP	ROBINSON 2	POINT BEACH 1&2	FORT CALHOUN 1	PICKERING 1, 2, 3 & 4	DOEL 3	ANGRA 2
LOCATION	USA South Carolina	USA Wisconsin	USA Nebraska	CANADA Ontario	BELGIQUE Antwerpen	BRESIL Rio de Janeiro
TYPE & POWER	PWR 740 Mw	PWR 497 Mw	PWR 477 Mw	Heavy Water 508 Mw	PWR 1000 Mw	PWR 1300
Date	1967	1967- 68	1968	1964 à 1966	1974- 75	1977-
Date of Com.	09/70-03/71	08/72 pour la 2	1973	1971 à 1973	06/1982	1982
SSE	0.2 g	0.12 g	0.17 g	~ 0	0.1g	0.1g
Soil profile	Loose to slightly dense fine sand on 16.5m with clayed slices, hard clay on 140m up to the bedrock.	Glacial and lake deposit sands and silt or clayed lenses on 20- 30 meters	Loose sand on 20m Deterioreted limestone on 2m Schistous limestone with cavities on 8m Good limestone after 30m	Soft clay on 10m Hard clay on 5 to 8m Bedrock from15 to 18m	Gray sand and peat on 6.40m then clayed sand on 8.6m, bed rock à 15m	Soft clay layer (Vs< 100m/s) of 36 m thickness.
Type of foundations	923 tubular steel piles 0m30 diameter and 15m length.	H steel piles 20 à 30m length (304 piles under RB).	Tubular steel piles 0m50 diameter and 22 à 27m length.	H steel piles 10 à 18m length : 1000 under RB's, 1000 under the others + ...	450 concrete piles of 0m66 diameter and 18m50 length + 111 piles of 0m70 et 11m de length + 60 piles of 0m70 de 18m5 under and around reactor pit.	146 head piles of 1,30 m diameter, 56 of 1,10m and 40 m length and 88 floating piles (80 from 1,80 m and 8 from 1, 30m)
Miscellenaous	48 pile tests carried out (compression, tension, shear)	-	Ground improvement by vibratory floatation. Cathodic protection for 40 years.	Uplift problems during piles beating	?????	Apparently, big problems on site (delays)

Design of the foundations

- A static analysis is performed in order to estimate the contact pressure distribution beneath the foundations and the stresses induced in the subsurface materials,
  - A knowledge of the stress history of the subsurface materials should be obtained in order to predict **settlements** (geological stress history and resulting pre-consolidation stress load-unload history due to operations..),
  - Under the mat foundation, the subsurface foundation material can be modeled by the finite element technique (continuum representation) or by representing it by means of a series of springs . Solutions are also available from the literature,

This process lead to the choice of foundation type, shallow or deep, or a ground improving solution.

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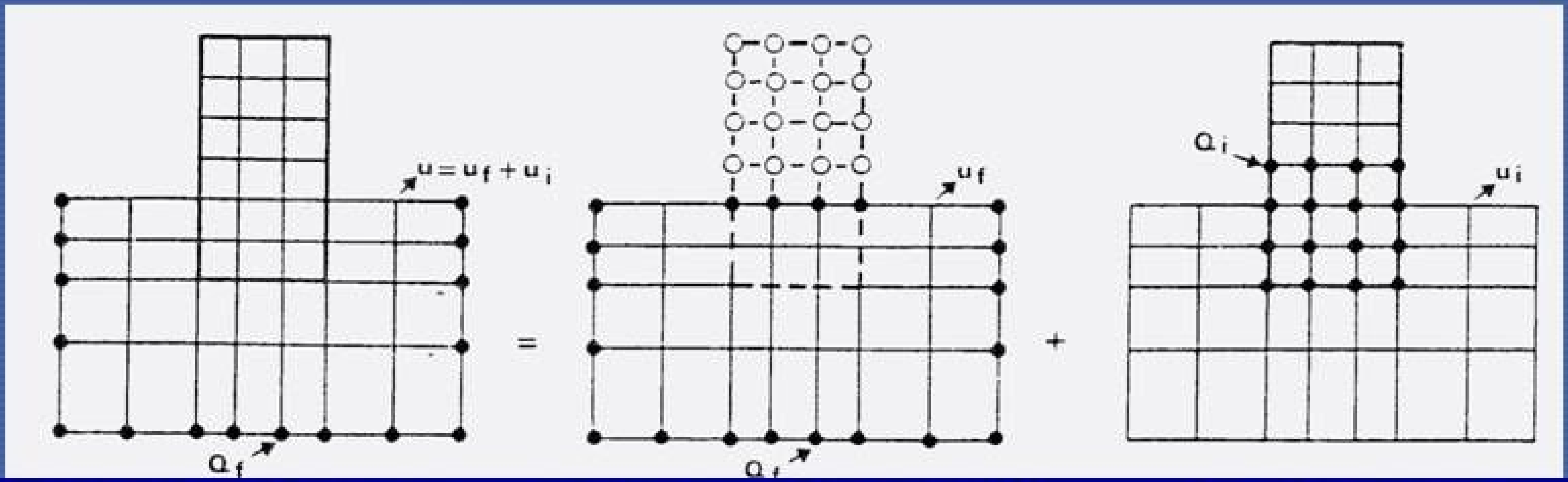
Dynamic Soil- Structure Interaction

- The objective of the dynamic soil structure interaction analysis is to determine the dynamic response of the structure taking into account the effects of the coupling between the structure and the supporting foundation medium ,
- They should be performed for investigating the following effects:
  - The effect of the foundation soil conditions on the dynamic response of the structure (the softer the soil is, the greater are the SSI effects)
  - The effect of buried structure (e.g. wave scattering effects),
  - The effect of dynamic pressures and deformations on the buried structure,
  - The uplift of the foundation,
  - The structure-soil-structure interaction effects (nuclear island).
- The results would envelope the response of the soil-structure interaction system accounting for uncertainties.

Problem formulation

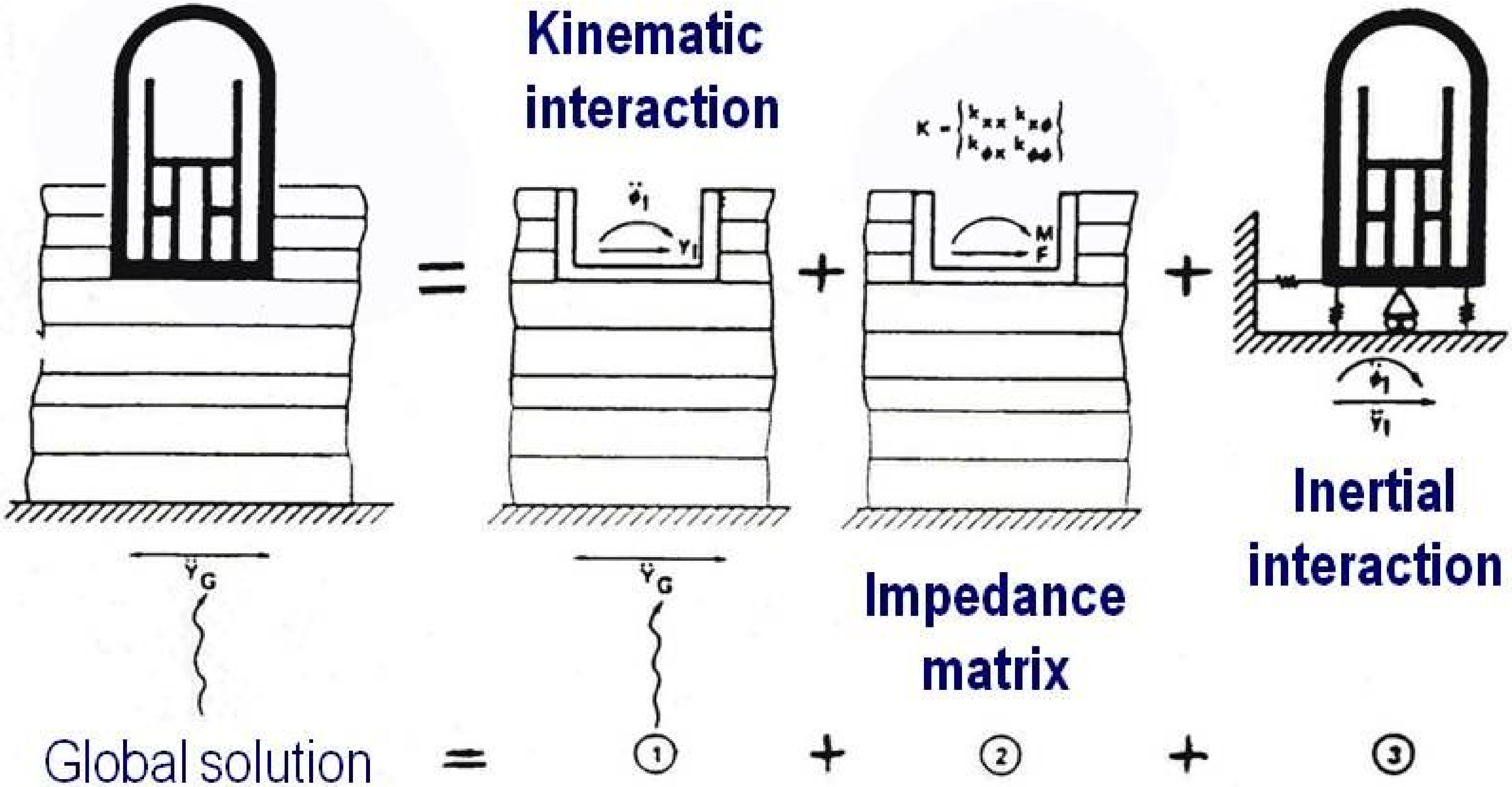


GLOBAL PROBLEM = FREE FIELD PROBLEM + SSI PROBLEM

Main steps:

- Free field ground motion definition (spectrum, time history)
- Bed rock motion definition (if no bed rock, far depth from the foundation)
  - Deconvolution
- Integration of the structure
- Time history at the structure base calculation

Sub structure methodology



This is the basis of all the different methods used in SSI analysis

Stability

- The study should be carried out under static loads and under a combination of static and dynamic loads (induced by earthquake) and should includes consideration of bearing capacity, overturning and sliding.
- Input parameters
  - The cyclic seismic forces generated in the foundation material by earthquake input computed by an appropriate dynamic method ,
  - uplifting and overturning of the mat and lateral loads on sub-surface and retaining walls .
- Bearing capacity
  - Classical procedures for computing the ultimate load bearing capacity are acceptable if the subsurface material is relatively uniform ,
  - In case of heterogeneous sub-surface condition, the sliding surface method should be employed and analyzed under the initial static and dynamic load .
- Safety Factors
  - Not be lower than 3.0 under static loads, and than 1.5 under SL-2 seismic input

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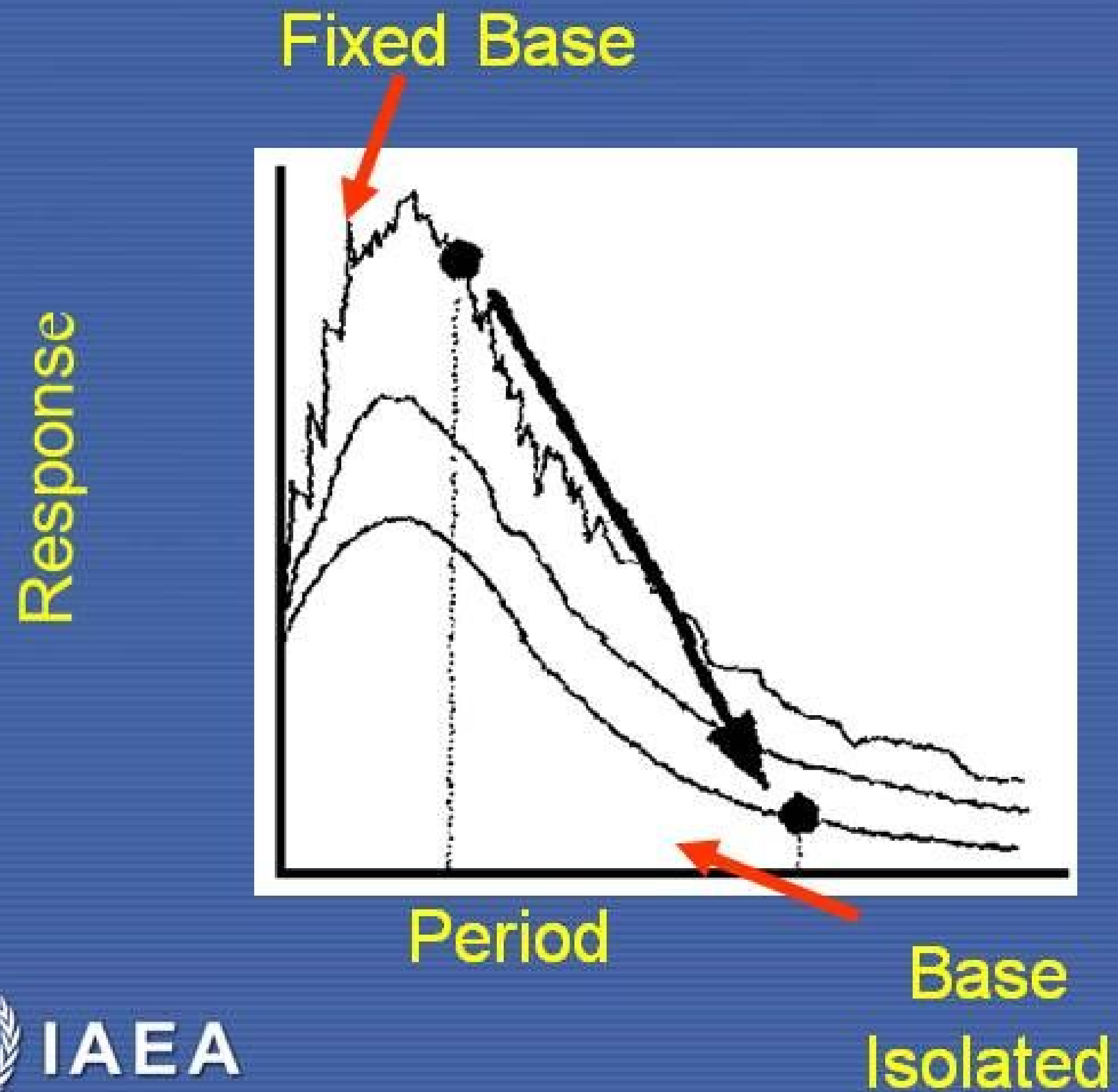
Stability (ctd.)

- Overturning
  - Under certain combinations of ground motion, groundwater level and geometrical configuration of the building, conventional procedures may lead to a potential uplift ,
  - In case the estimated surface of the uplift foundation is larger than 30% of the total surface of the foundation, a more sophisticated method should be used in dynamic soil structure interaction analysis.
- Sliding
  - The sliding safety evaluation of the nuclear power plant foundation should include an assessment of the balance of dynamic forces and the dynamic displacement during and after design earthquake ground motion .

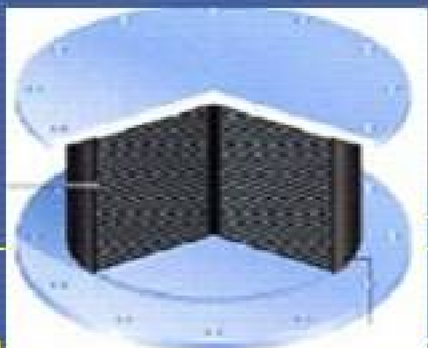
The Concept of Base Isolation

Create one artificial interface (isolators) between the soil and the building which dissipates the energy travelling from the soil with the seismic waves



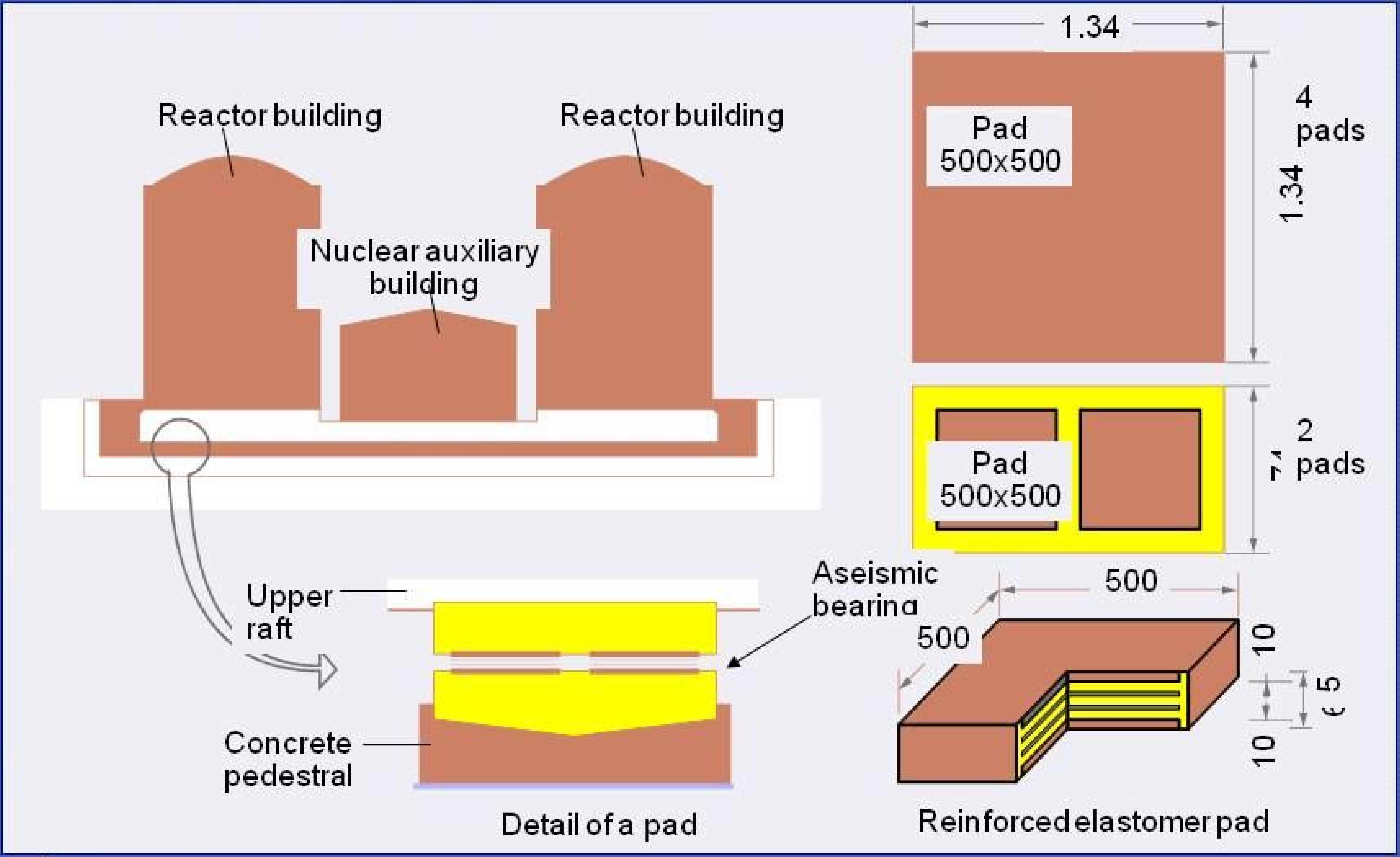
Significantly increase the period of the structure and the damping so that the response is significantly reduced

Most Common Types of Isolators °



- **Isolation Devices**
  - **Elastomeric Isolators**
    - Natural Rubber Bearings
    - Low-Damping Rubber Bearings
    - Lead-Plug Bearings
    - High-Damping Rubber Bearings
  - **Sliding Isolators**
    - Resilient Friction System
    - Friction Pendulum System

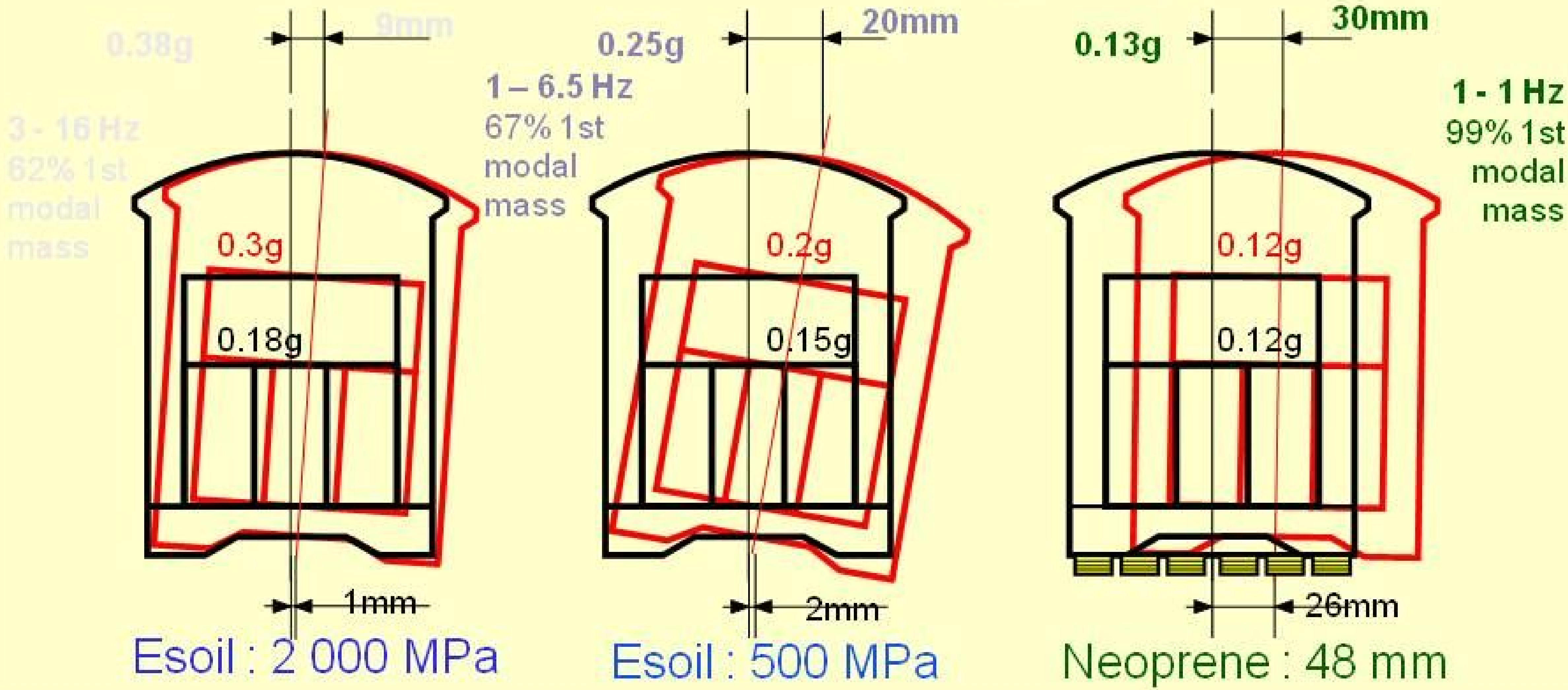
Use of isolators for NPP in France



Effects of isolators on reactor behavior

The use of isolators in Cruas NPP and Koeberg was the most economical way to adapt the 900 MW standard to the particular conditions of soil and seismic level of the 2 sites .

Aseismic bearings effects on reactor building for 0.1 g acceleration :



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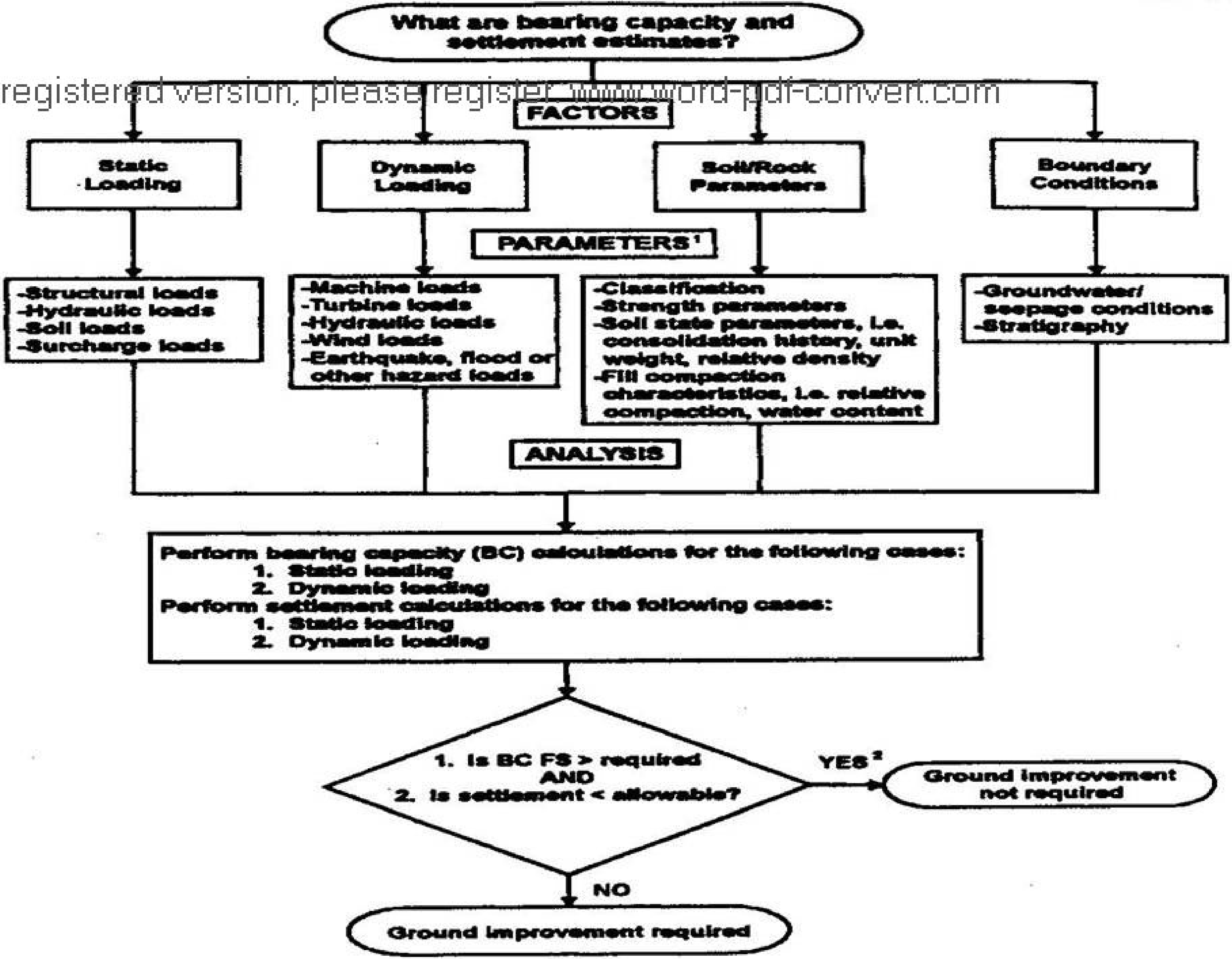
What are bearing capacity and settlement estimates?
FACTORS
Static Loading
Dynamic Loading
Soil/Rock Parameters
Boundary Conditions
PARAMETERS[1]
-Structural loads
-Hydraulic loads
-Soil loads
-Surcharge loads
-Machine loads
-Turbine loads
-Hydraulic loads
-Wind loads
-Earthquake, flood or other hazard loads
-Classification
-Strength parameters
-Soil state parameters, i.e. consolidation history, unit weight, relative density
-Fill compaction characteristics, i.e. relative compaction, water content
-Groundwater/ seepage conditions
-Stratigraphy
ANALYSIS
Perform bearing capacity (BC) calculations for the following cases:
1. Static loading
2. Dynamic loading
Perform settlement calculations for the following cases:
1. Static loading
2. Dynamic loading
1. Is BC FS > required
AND
2. Is settlement < allowable?
YES[2]
Ground improvement not required
NO
Ground improvement required

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Earth Structures

- General principles
  - Design of earth structures, which are related with the NPP safety, should be consistent with the design of the NPP itself (Level of the seismic safety).
  - Particularly the design against external hazards should be carried accordingly to the events that are selected in the design of the NPP, the return period of which is consistent with the ones of the meteorological events selected in the design of the NPP
  - The list of events should be supplemented by specific events, if any, that may challenge the safety of these structures .

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Natural Slopes

- It is important to differentiate potentially hazardous slopes depending on distance to NPP, slope angle, height, geology, water content and other geotechnical conditions of slope material,
- External effects of earthquakes and heavy rain-falls should be considered in assessing the potential hazard ,
- A stability analysis should be made considering the seismic effect as an equivalent static inertia force; the safety factor should be equal or larger than **1.5** ,
- If the safety factor thus evaluated is low enough to indicate a potential for a major sliding failure, a countermeasure for strengthening the slope or preventing the debris from reaching the safety related structures should be designed .

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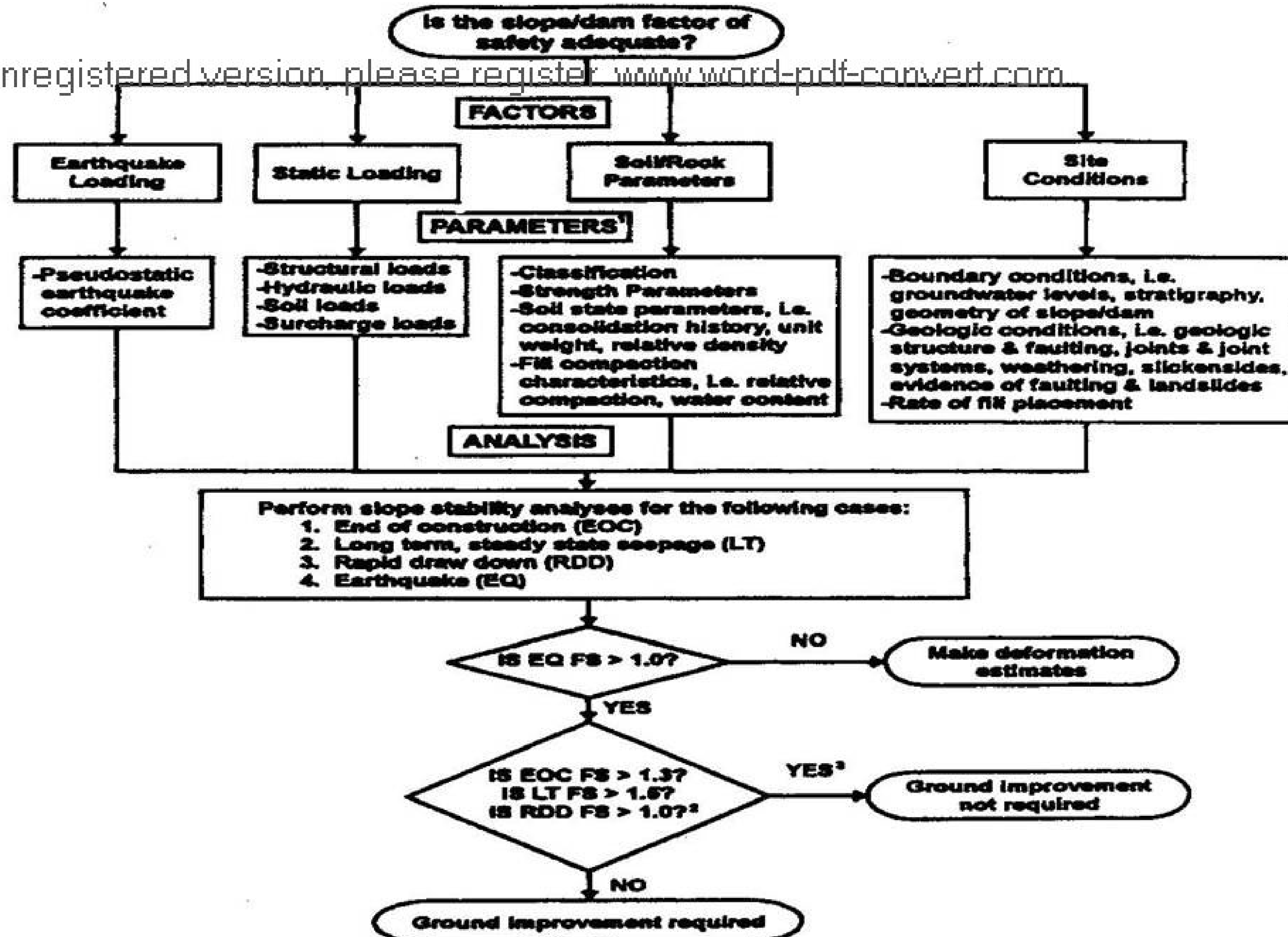
Is the slope/dam factor of safety adequate?
FACTORS
Earthquake Loading
Static Loading
Soil/Rock Parameters
Site Conditions
PARAMETERS[1]
-Pseudostatic earthquake coefficient
-Structural loads
-Hydraulic loads
-Soil loads
-Surcharge loads
-Classification
-Strength Parameters
-Soil state parameters, i.e. consolidation history, unit weight, relative density
-Fill compaction characteristics, i.e. relative compaction, water content
-Boundary conditions, i.e. groundwater levels, stratigraphy, geometry of slope/dam
-Geologic conditions, i.e. geologic structure & faulting, joints & joint systems, weathering, slickensides, evidence of faulting & landslides
-Rate of fill placement
ANALYSIS
Perform slope stability analyses for the following cases:
1. End of construction (EOC)
2. Long term, steady state seepage (LT)
3. Rapid draw down (RDD)
4. Earthquake (EQ)
IS EQ FS > 1.0?
NO
Make deformation estimates
YES
IS EOC FS > 1.3?
IS LT FS > 1.5?
IS RDD FS > 1.0?[2]
YES[3]
Ground improvement not required
NO
Ground improvement required

Notes:

Dikes and Dams

- Dikes : structures running along courses of water,
- Dams: earth structures higher than 15m,
- Special attention should be paid to the permeability of the site close to the areas of the foundations,
- The design of dikes and dams in term of safety, should be consistent with the design of NPP (natural hazards) and consistent with the international regulations for design of dams issued by ICOLD (International Commission on Large Dams
- In the design of earth structures two important phenomena should be considered :
  - the pore pressure inside the embankment ,
  - the internal erosion which is caused by water flows inside the embankment.

Sea-walls, Breakwaters

- Sea-walls, breakwaters, revetments are civil engineering structures to protect NPP against wave action of an ocean or a lake during storms and tsunami,
- These structures should be properly designed so that they can prevent soil erosion, floodings and structural failures, and the sustainability of safety functions should be properly evaluated,
- Material properties of sea-walls, breakwaters, revetments and backfill materials which include concrete blocks, rubbles and other large size particles should be properly estimated,
- The failure consequences on these structures on safety related ducts, pipes and other underground facilities (side-effects) passing near or through the facilities should be appropriately considered.

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Buried Structures

- Retaining walls
  - Gravity walls
  - Embedded walls (as sheet walls)
- Embedded structures
  - The interaction of the underground walls with the surrounding ground is significant
  - Effects of groundwater on embedded structures should be taken into account in design (leaks)
  - The effects of embedment on impedance of the foundation and on soil-structure interaction should be taken into account if the backfill has been compacted according to the state of the art.

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Buried Pipes, Conduits & Tunnels

- Investigation program
  - to identify areas of discontinuities or changes in the foundation material along the route of the pipe ,
- Construction Considerations
  - sufficient depth to prevent damage due to surface loading (e.g. traffic loads) or alternatively should be designed,
  - well-compacted granular material over competent foundation material such that no damage or distortion of the piping ,
- Design Considerations
  - Long, buried piping systems are primarily subjected to relative displacement-induced strains (rather than inertial effects),
  - These strains are induced primarily by seismic wave passage and by differential displacement between a building attachment point (anchor point) and the ground surrounding the buried piping ,

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Buried Pipes, Conduits & Tunnels (ctd)

- Analysis Considerations
  - Relative deformations imposed by seismic waves travelling through the surrounding soil or by differential deformations between the soil and anchor points,
  - Lateral earth pressures acting on the cross section,
  - Intersections move with the surrounding soil and that there is no movement of the buried structure relative to the surrounding soil.
  - Axial deformations which depends on the wave type ,
  - Forces and strains due to the maximum relative movement between ,
  - For deep tunnels and shafts, hoop stresses and strains developed by travelling seismic waves should be considered in the design,

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Monitoring of Geotechnical Parameters

- Purpose of Monitoring
  - provide parameters and site characteristics suitable for predicting the performance of foundation systems under various loading conditions.
  - The monitoring of actual loads and deformations permits a field check of the predicted behavior of the foundations and earth structures
- Guidelines for Monitoring
  - The soil behavior should be monitored during excavation, backfilling and building construction.
  - The groundwater regime under buildings and in adjoining areas should be monitored
  - The monitoring devices should be carefully chosen so that the monitoring system provides the expected information for the life duration of the installation. The choice and number of the devices should rely on feedback experience with regards to their expected failure ratio.

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Monitoring Devices

Type of device	Principles	Location	Parameter measured	Purpose
Piezometers	Hydraulic pressure	Boreholes	Pore pressure, water table	Monitoring of water table
GPS	Aiming by satellite	Site	Topography of the site	Site evaluation
Settlement monuments	Topographic aiming	Ground surface	Displacements Settlements	Settlements of structures
Gammagraphy Photogrammetry	Superposition of picture	Ground surface	Deformation of topography	Deformation of structures
In situ settlement plates	Topography	Ground surface	Displacements	Settlements of structures
Inclinometers	Mechanic	Bore holes	Verticality	Stability of slopes
Tiltmeters		Bore holes	Verticality	Stability of slopes
Seismometers	Accelerometers, triggers	Free field, buildings	Time histories in accelerations	Verify the operability of plants
Hydraulic devices	Hydraulic U- tube	Base mat	Base mat deformations	Behaviour of soil-structure system

References

- Safety Guide NS-G-3.6 : Geotechnical Aspects of Site Evaluation and Foundations for Nuclear Power Plants .
- RG 1.132: Site Investigations for Foundations of Nuclear Power Plants.
- ETC-C: EPR Technical Code for Civil Works - édition de 11/09
- Eurocode 7 –part 1 &2 : Geotechnical Design
- US Army- Corps of Engineers- Guidelines on ground improvement for structures and facilities – Feb. 1999.

QUALITY ASSURANCE

- A Quality Assurance program should be established to control the execution of the site investigations and assessments and engineering activities being performed during the different stages of the site evaluation activities for the NPP.
- This program should cover the organization, planning, work control, personnel qualification and training, verification and documentation of the activities.
- This program should be established at the earliest possible time consistent with the site evaluation activities for the NPP .
- The process of establishing site related parameters and evaluations involves technical and engineering analyses and judgments which requires extensive experience and knowledge .

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Thank you for your attention

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