IAEA
International Atomic Energy Agency
Atoms for Peace and Development

GEOTECHNICAL HAZARDS ASSESSMENT – NS-G-3.6

Interregional Workshop on Graded Approach for Site Evaluation for SMRs in Haikou, China

6-11 November, 2023

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International Atomic Energy Agency (IAEA)

Contents

INTRODUCTION

Introduction

Selection of a suitable site and proper characterization of selected site, good design and engineering safety features to provide safety margins, diversity and redundancy are part of "defense in depth" concept in addition to effective management system and comprehensive operational procedures and practices for preventing and mitigating the consequences of an accident.

To determine site suitability and its complete characterization for a nuclear installation an overall site investigations campaign is required. The geotechnical investigation is a major part of this campaign, that is carried out for each stage of siting process and site evaluation process with a variable scope.

Introduction (Cont'd…)

Geotechnical investigations deal with the engineering behaviour of earth materials including minerals, rock, soil and water.

Geotechnical studies provide geotechnical based hazard assessment, support to design and construction by carrying out testing and analyses to assess risk from natural as well as human induced external events.

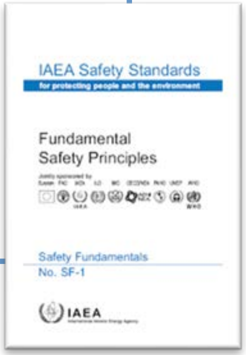
Geotechnical engineering provides link between nuclear installation and site, geology of the site area and its region, hydrology, hydrogeology, seismology.

IAEA SAFETY STANDARDS RELATED TO SITE EVALUATION

IAEA Safety Standards Related to Site Evaluation

Safety Fundamentals

- SF-1

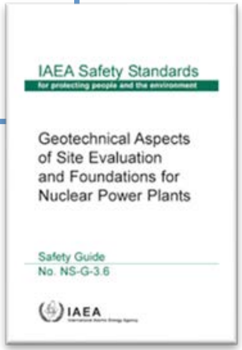


Safety Requirements

- **<u>SSR-1</u>**
- SSR-2/1
- SSR-3
- SSR-4
- GSR Part 2

Safety Guides

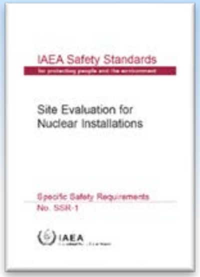
- SSG-35
- NS-G-3.1
- NS-G-3.2
- SSG-9 Rev.1
- SSG-18
- **<u>NS-G-3.6</u>**
- SSG-21
- GS-G-3.5

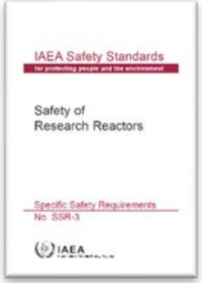


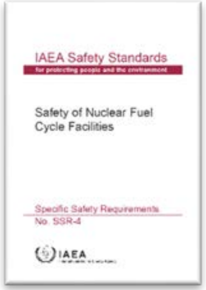
IAEA Safety Standards Related to Site Evaluation

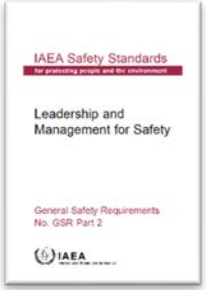
IAEA Safety Standards:

- ➢ Fundamental Safety Principles, No. SF-1.
  - Site Evaluation for Nuclear Installations, No. SSR-1, (Rev. 1).
  - Safety of Nuclear Power Plants Design, SSR-2/1 (Rev. 1).
  - Safety of Research Reactors, SSR-3.
  - Safety of Nuclear Fuel Cycle Facilities, SSR-4.
  - Leadership and Management for Safety, GSR Part 2.





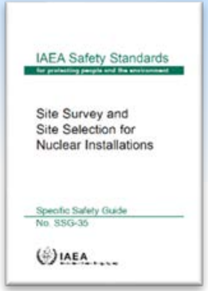




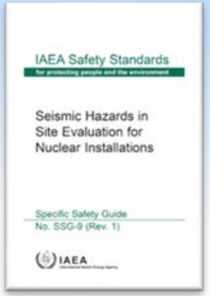
IAEA Safety Standards Related to Site Evaluation (Cont'd…)

IAEA Safety Standards:

- Site Survey and Site Selection for Nuclear Installations, No. SSG-35.
- External Human Induced Events in Site Evaluation for Nuclear Power Plants, No. NS-G-3.1.
- Dispersion of Radioactive Material in Air and Water and Consideration of Population Distribution in Site Evaluation for Nuclear Power Plants, No. NS-G-3.2.

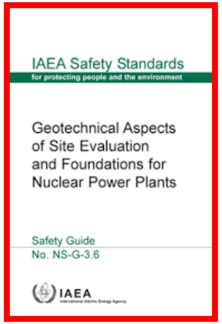


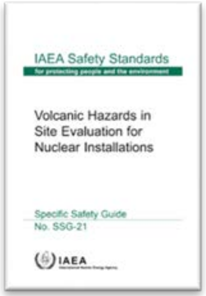
IAEA Safety Standards Related to Site Evaluation (Cont'd…)



<u>IAEA Safety Standards:</u>

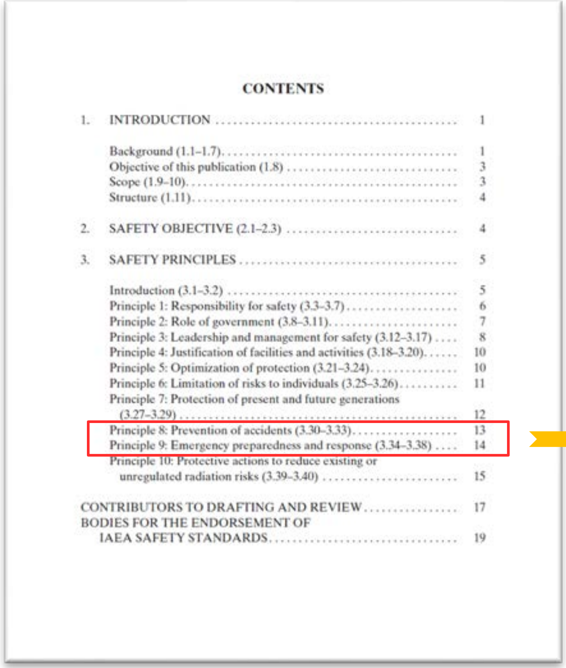
- Seismic Hazards in Site Evaluation for Nuclear Installation, No. <u>SSG-9 Rev.1</u>.
- Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations, <u>SSG-18.</u>
- Geotechnical Aspects of Site Evaluation and Foundations for Nuclear Power Plants, No. <u>NS-G-3.6</u>.
- Volcanic Hazards in Site Evaluation for Nuclear Installations, No. <u>SSG 21</u>.





SSR-1 REQUIREMENTS FOR GEOTECHNICAL HAZARD ASSESSMENT

Geotechnical Hazard Assessment – SSR-1 Requirements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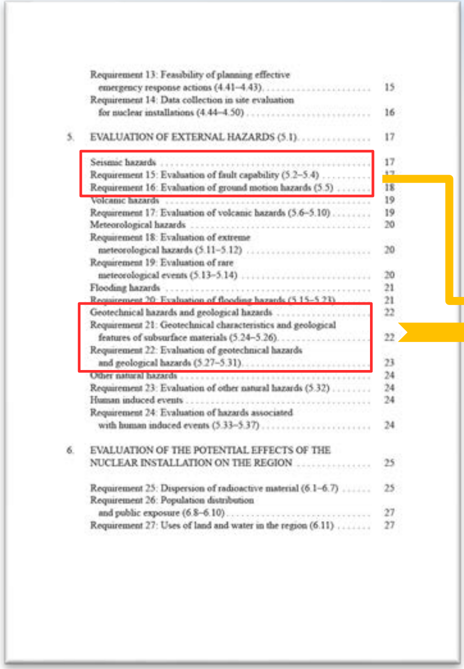

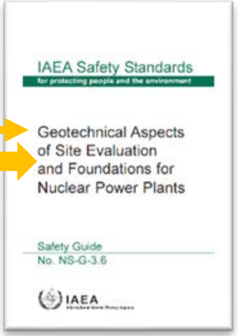

Geotechnical Hazard Assessment – SSR-1 Requirements (Cont'd…)

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GEOTECHNICAL HAZARDS AND GEOLOGICAL HAZARDS

Requirement 21: Geotechnical characteristics and geological features of subsurface materials

The geotechnical characteristics and geological features of subsurface materials shall be investigated, and a soil and rock profile for the site that considers the variability and uncertainty in subsurface materials shall be derived.

5.24. The static and dynamic geotechnical characteristics and geological features of subsurface materials at the site, including any backfill, shall be established. Laboratory and field based methods shall be used, in conjunction with appropriate sampling techniques and sufficient repetition of each test, to characterize each parameter of the subsurface materials at the site.

5.25. The stability and bearing capacity of foundation materials shall be assessed, including consideration of the potential for excessive settlement under static and seismic loading.

5.26. The physical and the geochemical properties of the soil and groundwater shall be studied by appropriate methods and taken into account in the evaluation of the subsurface material at the site.

Requirement 22: Evaluation of geotechnical hazards and geological hazards

Geotechnical hazards and geological hazards, including slope instability, collapse, subsidence or uplift, and soil liquefaction, and their effect on the safety of the nuclear installation, shall be evaluated.

Slope instability

5.27. The site and the site vicinity shall be evaluated to determine the potential for slope instability (such as landslides, rock fall and snow avalanches), caused by natural or human induced phenomena, which could affect the safety of the nuclear installation. In the evaluation of slope instability, the configuration of the site during and after site preparation activities shall be addressed. The evaluation of slope stability shall also take into account extreme meteorological conditions and rare meteorological events.

5.28. The potential for slope instability resulting from seismic loading shall be evaluated using parameters appropriate for describing the seismic hazards and the soil and groundwater characteristics at the site.

Collapse, subsidence or uplift of the site surface

5.29. The potential for collapse, subsidence or uplift of the surface that could affect the safety of the nuclear installation over its lifetime shall be evaluated using a detailed description of subsurface conditions obtained from reliable methods of investigation.

Soil liquefaction

5.30. The potential for liquefaction and non-linear effects of the subsurface materials at the site shall be evaluated using parameters appropriate for describing the seismic hazards and geotechnical properties of the subsurface materials at the site.

5.31. The evaluation of soil liquefaction shall include the use of accepted methods for field and laboratory testing in combination with analytical methods to assess the hazards.

SAFETY GUIDE NS-G-3.6 GUIDANCE FOR GEOTECHNICAL HAZARD ASSESSMENT

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines

IAEA

This safety guide provides guidance on:

- Dealing with geotechnical engineering aspects of the subsurface conditions;
- Methods and procedures for analyses for safety assessment of the site, particularly for the assessment of the effects of an earthquake on the site i.e., determination of site-specific response spectra and estimation of liquefaction potential, effects of dynamic and static interaction between soil and structure, bearing capacity, settlement;
- Foundation works including geotechnical profiles and parameters, possible improvements of foundation materials and choice of foundation system based on site soil capacities;
- Earth structures, including natural slopes and buried structures;
- Monitoring of geotechnical parameters.

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

SITE INVESTIGATIONS

Investigations Programme:

- This investigation is important at all stages of the site evaluation process;
- It provides information and basic data for the types and suitability of subsoil materials;
- Specific data requirements vary from stage to stage;
- Necessary data is classified as:
  - Geological information (stratigraphical and structural);
  - Description of the extent and nature of subsurface materials;
  - Properties of soil and rock;
  - Information on groundwater;

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

SITE INVESTIGATIONS

Investigations Programme:

- Methods of investigations are:
  - Use of current and historical documents;
  - Geophysical surveys;
  - Geotechnical investigations (in situ and laboratory testing);
  - These investigations are applicable to all stages of site evaluation process, but with the variation in extent.

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

SITE INVESTIGATIONS

<u>Source of Data</u>:

- Historical and Current Data
    - Topographic maps;
    - Geological and engineering geological maps;
    - Soil maps;
    - Geological reports and other geological literature;
    - Geophysical maps;
    - Geotechnical reports and other geotechnical literature;
    - Earth satellite imagery and aerial photographs;
    - Water well reports and water supply reports;
    - Oil and gas well records;

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

SITE INVESTIGATIONS

Source of Data:

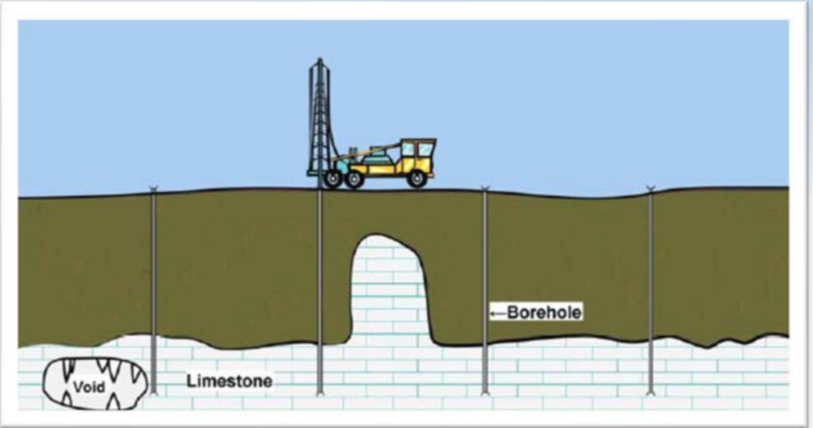
- Historical and Current Data
  - Hydrogeological maps, hydrological and tidal data, flood records, and climate and rainfall records;
  - Mining history, old mine plans and subsidence records;
  - Seismic data and historical earthquake records;
  - Existing records of landslides, floods, earthquakes, subsidence and other significant geological events;
  - Records of the performance of structures in the vicinity ;
  - Individual observers ;
  - Geology and engineering departments institutions;
  - Government geology survey and engineering authorities, etc.

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont’d)

SITE INVESTIGATIONS

Source of Data:

- In Situ Exploration



  - Geophysical surveys
    - The information obtained from geophysical tests are inferred by back analysis of the test results within the elastic deformation limit;
    - These methods cover large depth and surface area and provide only rough estimates for thickness of the layers and their mechanical properties;
    - These methods are useful to supplement the geotechnical methods for additional information/data.

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

SITE INVESTIGATIONS

Source of Data:

- In Situ Exploration
  - Geophysical tests

TABLE 1. TECHNIQUES FOR GEOPHYSICAL INVESTIGATIONS OF SOIL AND ROCK SAMPLES

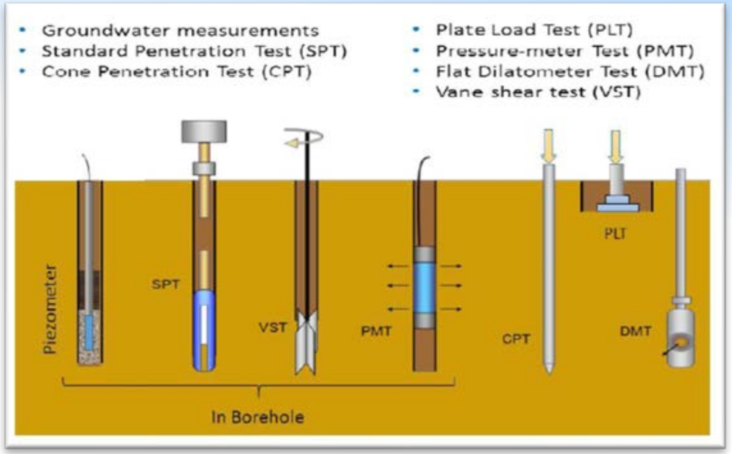
Type of test	Parameter measured	Types of problems	Observations
Seismic refraction/ reflection	Deformation time propagation	Site categorization	For surface investigation
Cross-hole seismic test	Dynamic elastic properties	Site categorization, soil–structure interaction	For deep investigations: one hole for emission, one hole for reception
Uphole/downhole seismic test	Dynamic elastic properties	Site categorization, soil–structure interaction	For deep investigations: one hole for both emission and reception
Nakamura method	Low level (ambient noise) vibrations	Site categorization, soil–structure interaction	
Electrical resistivity	Liquid table content	Internal erosion	Available for surface or deep investigation
Nuclear logging	Water content, density		Necessitates expensive logging techniques
Microgravimetry	Acceleration due to gravity	Sinkholes, heterogeneities	Complex subsurface
Georadar	Speed of propagation	Cavities	Complex subsurface
Magnetic techniques	Magnetic field intensity	Areas of humidity	Maintenance of dykes and dams

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

SITE INVESTIGATIONS

Source of Data:

- In Situ Exploration



  - Geotechnical tests
    - Geotechnical methods address near field area i.e. to a certain depth below foundation level;
    - Different techniques including drilling of boreholes and working directly from the ground are available;
    - Types of tests are selected in accordance with the specific subsurface conditions.

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

SITE INVESTIGATIONS

<u>Source of Data</u>:

- In Situ Exploration
  - Geotechnical tests

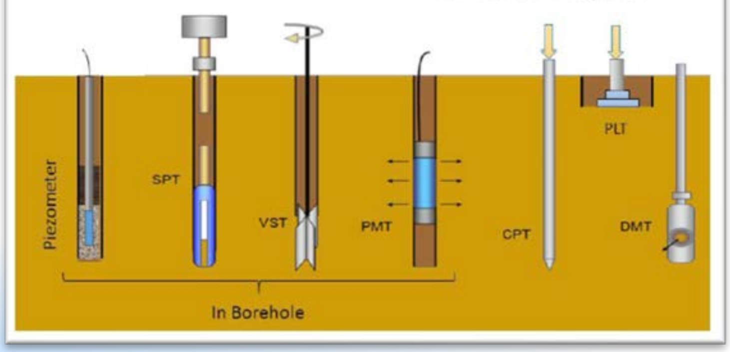


TABLE 2. TECHNIQUES FOR GEOTECHNICAL INVESTIGATIONS OF SOIL AND ROCK SAMPLES

Type of test	Type of materials	Parameter measured	Types of problems	Comments
Flat jack test	Rock	In situ normal stress	Deformability, convergence	Questionable results in rock with strongly time dependent properties
Hydraulic fracturing test	Rock	In situ stress state	Deformability, convergence	Affected by anisotropy of tensile strength
Direct shear stress test	Rock	Shear strength	Stability problems	Usually requires a sufficient number of tests for statistical control
Plate bearing tests	Clay, sand, gravel, rock	Reaction modulus	Compaction control; settlement	Used for excavations and embankments
Pressure meter test	Clay, sand, gravel, rock	Elastic modulus; compressibility	Settlement; bearing capacity	Needs a preliminary hole
Static penetrometer test	Clay, sand, gravel	Cone resistance; undrained cohesion; shear strength	Settlement; bearing capacity	Including cone penetrometer test
Dynamic penetrometer test	Clay, sand, gravel	Cone resistance; relative density	Liquefaction	Including standard penetration test
Vane shear test	Soft clay	Shear strength	Bearing capacity, slope stability	Not suitable for silt, sand or soils with appreciable amounts of gravel or shells
Pumping test	Clay, sand, gravel	Field permeability	Transmissivity of soil	Needs piezometers

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

SITE INVESTIGATIONS

Source of Data:

- Laboratory Tests
  - Laboratory tests are performed on samples obtained from field explorations;
  - Sample recovery, treatment, handling, field storage and transport to the laboratory require careful attention.
  - Samples are obtained from boreholes, pits, excavations and trenches;
  - Laboratory testing supplements and confirms the in situ test data;
  - Results of in situ and laboratory tests should be consistent with each other. Any discrepancies should be investigated and reconciled.

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

SITE INVESTIGATIONS

Source of Data:

- Laboratory tests

TABLE 3. TECHNIQUES FOR LABORATORY INVESTIGATIONS OF SOIL AND ROCK SAMPLES

Characteristics investigated	Type of soil	Test	Parameter measured	Purpose
Soil index and classification	Clayed soil	Atterberg limits	Water content (through liquidity and plasticity indexes)	Compressibility and plasticity
Physical and chemical properties of soils	All types	Dietrich–Frühling 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[a] test (relative density)	Humid and dry densities, water content, saturation ratio, relative density	Settlement, consolidation, bearing capacity
Consolidation and permeability characteristics	All types	Oedometer	Oedometric, Young's modulus, consolidation coefficient	Settlement, consolidation

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont’d)

SITE INVESTIGATIONS

Source of Data:

- Laboratory tests
  - Also included are grain size analysis, unit weight, unconfined compression, swell potential, specific gravity, permeability, minerology, uniaxial compression test for rock & slake durability etc

TABLE 3. TECHNIQUES FOR LABORATORY INVESTIGATIONS OF SOIL AND ROCK SAMPLES

Characteristics investigated	Type of soil	Test	Parameter measured	Purpose
Shear strength and deformation capability of soil	All types	Shear test box, triaxial compression tests	Young’s modulus, Poisson’s ratio cohesion and fiction angle under drained and undrained conditions	Settlement, bearing capacity
Mechanical properties of rock	Rock	Shear test, biaxial or triaxial compression tests	Young’s modulus and Poisson’s ratio	Stability, strengthening
Dynamic characteristics of the soil	All types	Cyclic triaxial tests, resonant column	Dynamic Young’s modulus, Poisson’s ratio, internal damping, pore pressure	Site categorization, soil–structure interaction, liquefaction

[a] ASTM International, formerly known as the American Society for Testing and Materials (ASTM).

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

SITE INVESTIGATIONS

Investigations for Complex Subsurface Conditions:

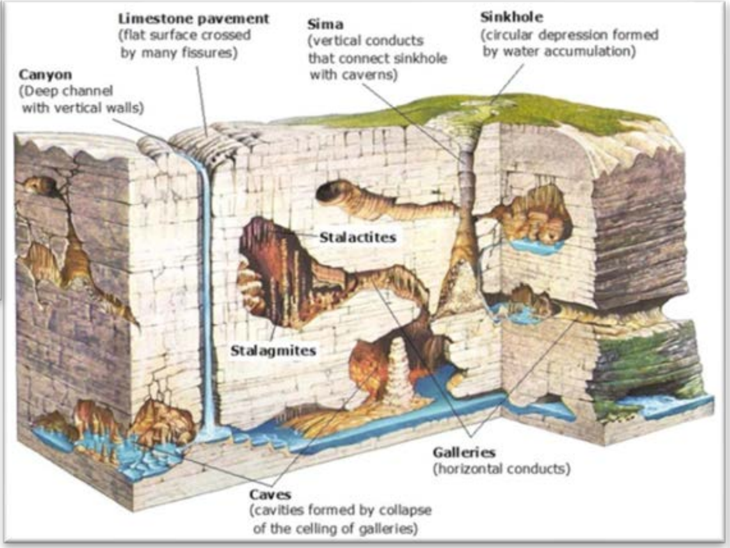
- It includes presence of subsurface cavities and possibility of the ground collapse;
- For prediction of cavities following factors are important:
  - Presence of solution process/karstic phenomena can pose potential hazard of ground collapse;
  - Regional and site geology can provide indications of potential ground collapse;
  - The sedimentary rocks such as limestone, dolomites, and gypsum etc. are soluble in water or in carbonate type acidic solutions;

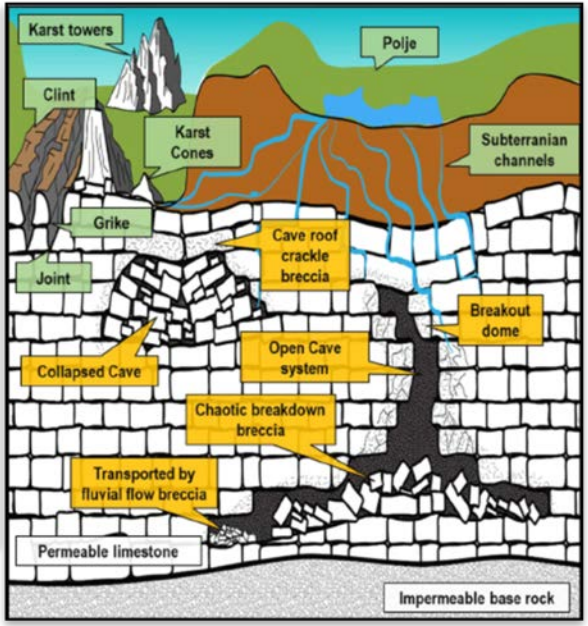
Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

SITE INVESTIGATIONS

Investigations for Complex Subsurface Conditions:

Formation of caves in limestone due to chemical weathering





Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

SITE INVESTIGATIONS

Investigations for Complex Subsurface Conditions:

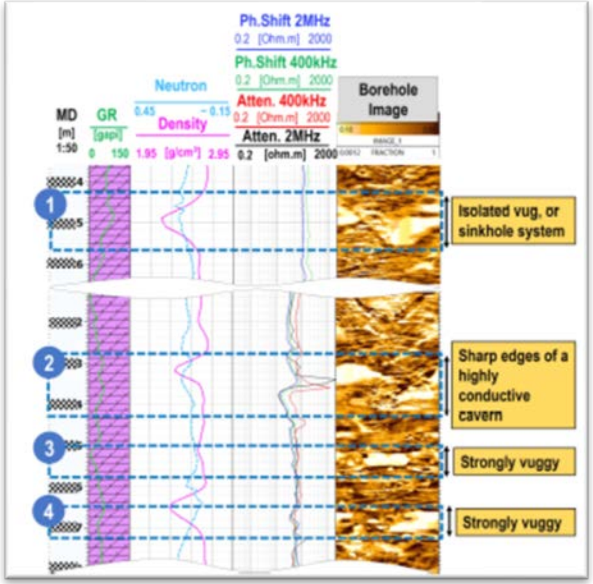
- Detection of subsurface cavities:
  - The routine site exploration methods including hydraulic pressure tests, remote sensing, drilling, sampling, excavation, borehole logging and geophysical surveys are applicable;
  - For reconnaissance to detect subsurface cavities geophysical methods such as surface electrical resistivity profiling, microgravimetry, seismic refraction surveys, seismic fan shooting and ground probing radar methods are useful.

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

SITE INVESTIGATIONS

<u>Investigations for Complex Subsurface Conditions</u>:

- Detection of subsurface cavities:
  - To determine depth, size and geometry of subsurface cavities more advanced methods such as cross-hole seismic survey, cross-hole radar methods, electrical resistivity survey, seismic refraction, high resolution seismic reflection and ground probing radar are available.



Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

SITE INVESTIGATIONS

Investigations for Complex Subsurface Conditions:

- Evaluation and Treatment of Complex Subsurface Conditions:
  - Greatest risk is posed to foundation when cavities are found within stress zone of the foundation;
  - The stability of natural cavities below the foundation level should be considered;
  - An increase in the vertical pressures due to the structural loads could cause instability of the roof of the cavity.
  - A site that is underlain by a potentially large and complex cavity system should be avoided.

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

SITE CONSIDERATIONS

Site Categorization:

- For seismic response analysis following site categorization is used:
  - Type 1 sites: Vs > 1100 m/s (rock site);
  - Type 2 sites: 1100 m/s > Vs > 300 m/s (stiff soil/soft rock site);
  - Type 3 sites: 300m/s > Vs (Soft soil site).

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

SITE CONSIDERATIONS

Parameters of the Soil Profiles:

- The design profile is based on physical and mechanical properties of the subsurface materials;
- The design profile should include:
  - Classification of subsurface strata, number of layers and thickness of each layer;
  - The physical and chemical properties of soil and rock and the values used for classification;
  - S and P wave velocities, stress–strain relationships, static and dynamic strength properties, consolidation and permeability etc.;
  - Groundwater table (design level and max. water level due to PMF).

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

SITE CONSIDERATIONS

Parameters of the Soil Profiles:

- Specific design profiles for different purposes are adopted:
  - Site specific response spectrum;
  - Liquefaction potential;
  - Stresses in the foundation ground;
  - Foundation stability;
  - Soil–structure interaction;
  - Settlements and heaves;
  - Stability in earth structures;
  - Earth pressure and deformation in buried structures.

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

SITE CONSIDERATIONS

Site response and site specific response spectra :

- Free field site response analysis should be performed for site category Type 2 and Type 3 sites;
- Site response may be needed for the assessment of settlement, liquefaction, soil–structure interaction analyses and developing specific site response spectra;
- Data important for site response analysis are:
  - The input ground motion (outcrop or deconvolution)
  - Model of the site
    - The geometrical description of the soil layers;
    - The S and P wave velocities for each layer;
    - The modulus degradation (G–ɣ) and damping ratio (ζ-ɣ) curves

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

SITE CONSIDERATIONS

Site response and Site Specific Response Spectra :

- Following data is important for site response analysis:
  - Mathematical model of site response analysis;
    - Visco-elastic
    - Horizontal layering
    - Internal damping
    - Non-linear or equivalent linear
- Uncertainties in the site materials properties should be taken into account, at least on the shear modulus value.
- For a Type 3 site, site specific response spectra should be determined.

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

SITE CONSIDERATIONS

Liquefaction Potential:

- Soil liquefaction occurs in loose, saturated cohesionless soils (such as sands, gravels and silts) and sensitive clays when a sudden loss of strength and stiffness is experienced during an earthquakes;
- Liquefaction beneath and in the vicinity of a nuclear installations foundation can result in localized bearing capacity failures, lateral spreading, and excessive settlement that can pose serious threat on the integrity of nuclear installation.

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

SITE CONSIDERATIONS

Liquefaction Potential:

- First step to assess the potential of liquefaction is to determine whether or not soils of liquefiable nature are present at the site.
- Factor affecting liquefaction are:
  - Geologic age and origin;
  - Fines content and plasticity index;
  - Saturation;
  - Depth below ground surface;
  - Soil Penetration Resistance;
  - Peak Ground Acceleration;
  - Earthquake Magnitude.

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

SITE CONSIDERATIONS

<u>Liquefaction Potential</u>:

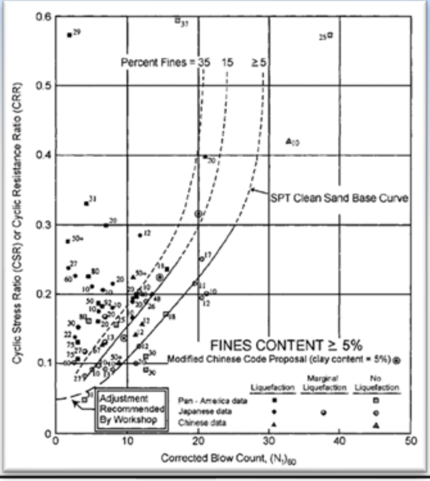
- For soils of liquefiable nature, following data for design profile is needed:
  - Groundwater table;
  - Grain size distribution;
  - SPT/ CPT values;
  - Relative density;
  - Undrained cyclic strength;
  - Strain dependent soil properties;
  - Past history of liquefaction.

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

SITE CONSIDERATIONS

Liquefaction Potential:

- Methods for evaluation of the liquefaction potential:
  - Empirical approach:
    - Compare performance during past earthquake to SPT,CPT, BPT & Vs results;
    - Application of different field tests for assessment of liquefaction potential (modified after Youd et al., 2001).



Feature	Test Type: SPT	CPT	BPT	Vs
Past measurements at liquefaction sites	Abundant	Abundant	Sparse	Limited
Type of stress-strain behavior influencing test	Partially drained, large strain	Drained, large strain	Partially drained, large strain	Small strain
Quality control and repeatability	Poor to good	Very good	Poor	Good
Detection of variability of soil deposits	Good for closely spaced tests	Very good	Fair	Fair
Soil types in which test is recommended	Nongravel	Nongravel	Primarily gravel	All
Soil sample retrieved	Yes	No	No	No

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

SITE CONSIDERATIONS

<u>Liquefaction Potential</u>:

- Methods for evaluation of the liquefaction potential:
  - Classical analytical approach:
    - Cyclic resistance from laboratory tests;
    - Shear stress induced in each layer is converted to number of equivalent uniform cycles;
    - Liquefaction potential is determined by comparing computed equivalent number of cycles with the cyclic strength.
  - Rigorous analytical approach:
    - Coupled site response – pore pressure development analysis in effective stresses.

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

CONSIDERATIONS FOR THE FOUNDATIONS

Foundation work:

- Improvements of foundation conditions can be achieved by:
  - Soil compaction;
  - Total replacement of loose/soft material by an improved material;
  - Soil treatment by adding materials to improve soil behaviour.
- Improvement of foundation conditions required, if:
  - Bearing capacity of subsurface materials is not sufficient to carry loads from structures within permissible settlement;
  - There exist cavities that can cause subsistence;
  - There are nonuniform soil conditions on the footprint of the foundation that can cause tilting and/or differential settlement.

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

CONSIDERATIONS FOR THE FOUNDATIONS

Foundation work for improvement:

- Tasks required for improvements of foundation conditions:
  - Determination of the existing in situ profile;
  - Determination of the required profile for foundation material;
  - Selection of suitable techniques for improvements;
  - Carrying out a prototype testing programme;

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

CONSIDERATIONS FOR THE FOUNDATIONS

Foundation work:

- Choice of foundation system and construction:
  - Shallow foundations;
  - Deep foundation.

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

CONSIDERATIONS FOR THE FOUNDATIONS

Foundation work:

- Choice of foundation system and construction:
  - Deep foundation used for NPPs

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 slghtly 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)

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont’d)

CONSIDERATIONS FOR THE FOUNDATIONS

Soil-Structure Interaction:

- Static Analysis:
  - Input parameters are soil stiffness, soil strength, groundwater table, stiffness of the structure;
  - Simplified analysis are available using published results for rigid foundation and flexible foundation;
  - For actual stiffness of structures computer-based FEM analyses are used.

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

CONSIDERATIONS FOR THE FOUNDATIONS

Soil-Structure Interaction:

- Dynamic Analysis:
  - Dynamic soil-structure interaction (SSI) analysis is performed to determine the seismic response when combined system of the structure and supporting foundation soil is subject to an earthquake ground motion;
  - SSI analysis should be preformed for site conditions of Type 2 and Type 3.
  - Fixed based seismic response analysis may be assumed for Type 1 sites.

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

CONSIDERATIONS FOR THE FOUNDATIONS

Soil-Structure Interaction:

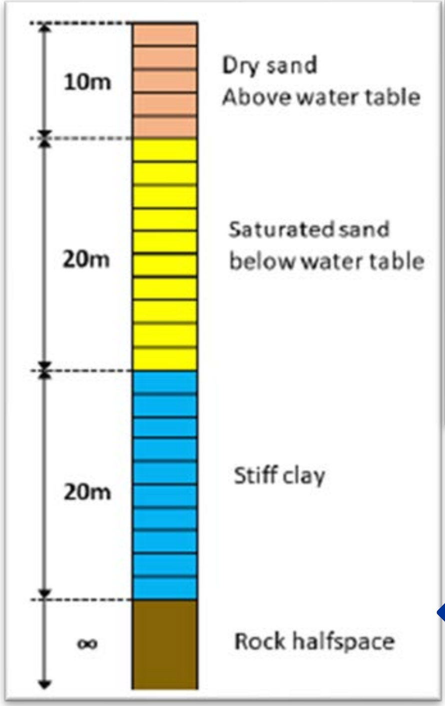
- Dynamic Analysis:
  - Input parameters for SSI analysis design profile:
    - Best estimate values of S and P wave velocities with a range of variation to cover uncertainties in soil properties;
    - Number and thickness of soil layers above half-space.
    - Shear modulus and the damping versus shear strain relationships for each of the soil layers;
    - Water table information, total unit weight of each soil layer;
    - The embedment depth, dimension and geometry of the foundation;
    - The mass, stiffness and damping of foundation mat and superstructure.

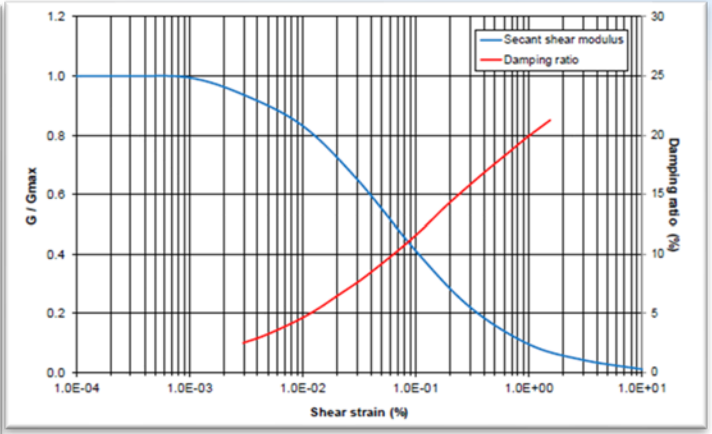
Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

CONSIDERATIONS FOR THE FOUNDATIONS

Soil-Structure Interaction:

- Dynamic Analysis:
  - Soil profile for 1-D site response analysis
  - Nonlinear properties of soil.





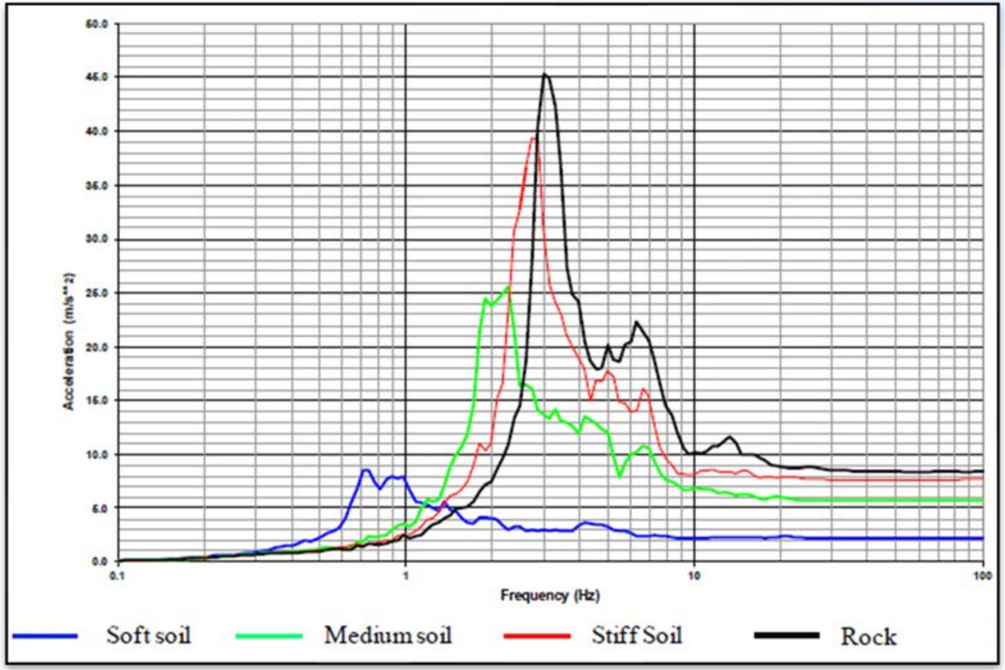
Vs, Vp, unit wt., G–ɣ and ζ-ɣ curves for each layer

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

CONSIDERATIONS FOR THE FOUNDATIONS

Soil-Structure Interaction:

- Dynamic Analysis:
  - Effect of soil stiffness on in-structure response of a typical NPP structure.



Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

CONSIDERATIONS FOR THE FOUNDATIONS

Stability:

- Stability of foundation is checked against bearing capacity failure, overturing and sliding;
- Input parameters include:
  - Foundation geometry;
  - Loads and load combinations;
  - Subsoil properties including unit weight, shear strength (drained/undrained), water table, foundation – soil interface resistance.

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont’d)

CONSIDERATIONS FOR THE FOUNDATIONS

Stability:

- Safety Factors (SF) for stability analysis:
  - For bearing capacity, SF ≥ 3.0 under static loads case;
  - For overturning, SF ≥ 1.5 under combination of loads including SL-2 seismic input;
  - For sliding, SF ≥ 2.0 under combination of loads including SL-2 seismic input.

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

CONSIDERATIONS FOR THE FOUNDATIONS

Settlement and heaves:

- Assessment under static loads;
  - Immediate;
  - Consolidation;
  - Creep.
- Dynamic Analysis:
  - Total and differential settlement;
  - Structure-soil-structure interaction (SSSI);
  - Residual settlement for a soft soil site after an earthquake (dissipation of pore pressure).

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

EARTH STRUCTURES

Natural Slopes:

- Safety evaluation depends on separation distance and the features of a slope;
- Effects of an earthquake and heavy rainfall should be considered for assessing potential hazard from natural slopes;
- Appropriate analysis should be considered for slope that can pose hazard at the site;
- The safety factor should be SF ≥ 1.5. If safety is not large enough dynamic response analysis should be performed;
- In case of low SF, suitable slope improvements and protection measures should be considered. Otherwise, plot plan of plant site should be altered.

Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

MONITORING OF GEOTECHNICAL PARAMETERS

- The parameters are monitored to confirm/revise design basis and verify performance of foundation and earth structures;
- Monitoring should be started from beginning of siting activites and continued to construction and lifetime of the structures;
- Monitoring data is used for review of site conditions as part of periodic safety review;
- Monitoring parameters include:
  - Groundwater table;
  - Deflection and displacement of safety related structures;
  - Seismic response of the site and structures;
  - In situ Pore water pressure.

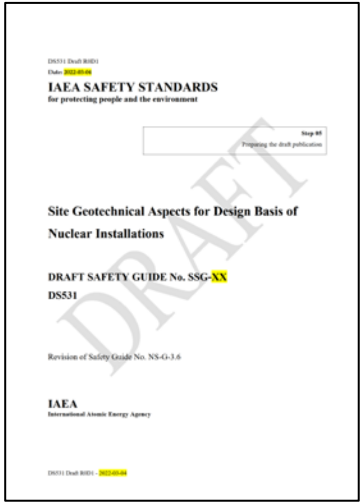
Geotechnical Hazard Assessment – Safety Guide NS-G-3.6 Guidelines (Cont'd)

MONITORING OF GEOTECHNICAL PARAMETERS

- Monitoring devices

Type of device	Principle	Location	Parameter measured	Purpose
Piezometers	Hydraulic pressure	Bore holes	Pore pressure, water table	Monitoring of water table
Global positioning system	Aiming by satellite	Site	Topography of the site	Site evaluation
Settlement monuments	Topographic aiming	Ground surface	Displacements, settlements	Settlement of structures
Gammagraphy, photogrammetry	Superposition of picture	Ground surface	Deformation of topography	Deformation of structures
In situ settlement plates	Topography	Ground surface	Displacements	Settlement of structures
Inclinometers, tiltmeters	Mechanic	Bore-holes	Verticality	Stability of slopes
Seismometers	Accelerometers, triggers	Free field, buildings	Accelerations time histories	Operability of plants; seismic behaviour of structures; floor response spectra.
Hydraulic devices	Hydraulic U-tube, Glötzl cells	On basemat and beneath	Deformations and stresses of the basemat	Behaviour of the soil–structure system

APLLICATION OF A GRADED APPROACH FOR GEOTECHNICAL INVESTIGATIONS AND CHARACTERIZATIONS – DS531


IAEA SAFETY STANDARDS
for protecting people and the environment

Step 05
Preparing the draft publication

DRAFT

Site Geotechnical Aspects for Design Basis of Nuclear Installations

DRAFT SAFETY GUIDE No. SSG-XX
DS531

Revision of Safety Guide No. NS-G-3.6

IAEA
International Atomic Energy Agency

Geotechnical investigation and characterization

Section 8 of DS531 provides general guidance about possible graded approaches for nuclear installations other than regular NPPs

- ✓ General principle : **To commensurate with SSR-1**

8.1. For nuclear installations other than nuclear power plants, geotechnical site investigation and characterization may be graded according to Requirement 3 in IAEA SSR-1 [1]. Grading[1] should be based in the general principle given in para. 4.3 of IAEA SSR-1, which establishes that "the level of detail in the evaluation of a site for a nuclear installation shall be commensurate with the risk associated with the nuclear installation and the site and will differ depending on the type of nuclear installation".

[1] 'Grading' is an open concept and, therefore, there is not a single way to grading: there can be several possible graded approaches and all of them can be equally valid. The only condition is that final safety objectives are met. Those objectives can ultimately be expressed as maximum acceptable doses to workers and to the public, even though, for simplification purposes, they are usually introduced in the design and safety assessment framework using surrogate objectives or conditions. The surrogate objectives have been 'tuned' based on the large body of experience available for regular commercial light water reactors (LWR) and may be overly conservative for other types of nuclear installations.

Geotechnical investigation and characterization

Section 8 of DS531

- ✓ *<u>Risk-informed performance-based</u>* <u>philosophy</u> (Para. 8.3): risk goals and reliability targets

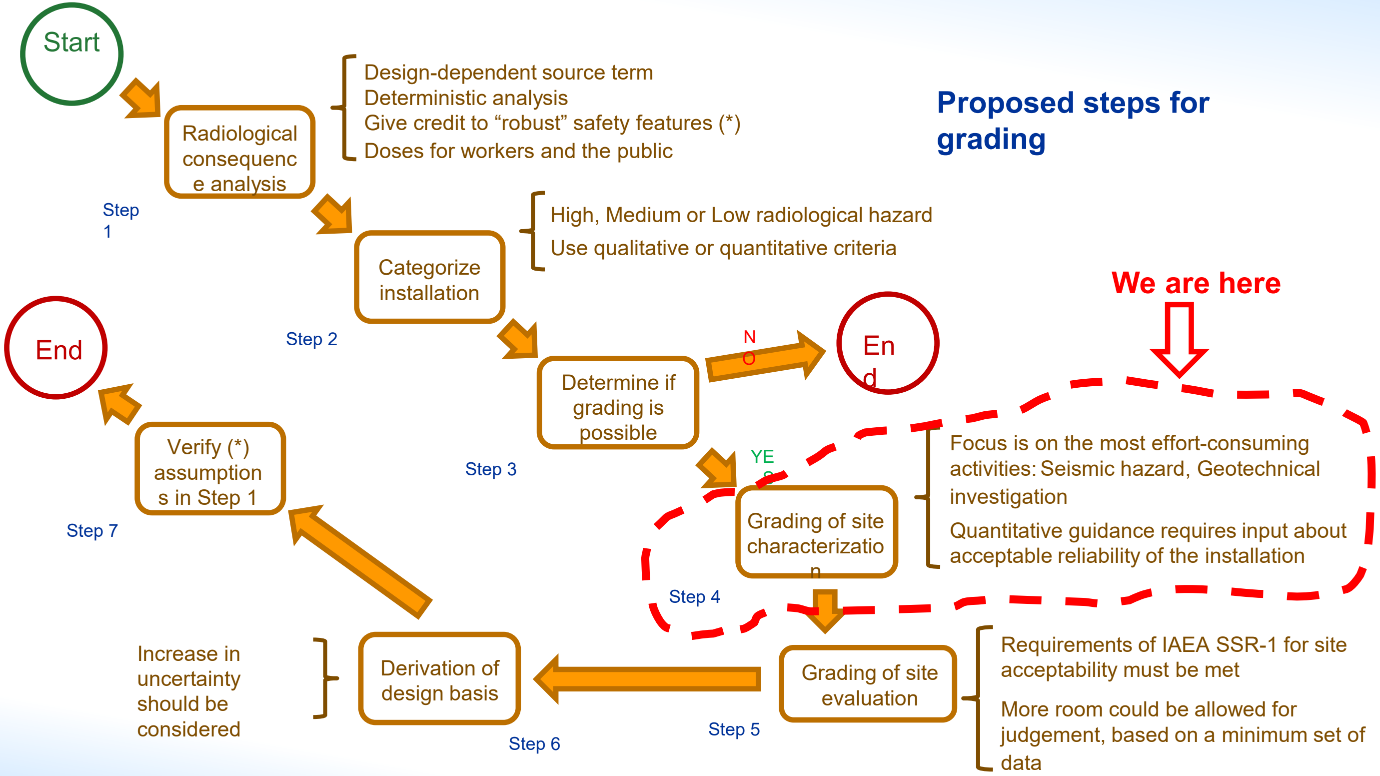
  Risk goals (in terms of doses) cannot be graded, but…

  Radiological consequences of failure may be so small that reliability levels lower than those in regular NPPs could be accepted while keeping compliance with the risk goals.

  In the present context, ‘reliability’ may be understood as the probability that the nuclear installation meets its fundamental safety functions for a specified period of time.

A possible approach for grading siting activities

IAEA



Proposed steps for grading

Geotechnical investigation and characterization

Section 8 of DS531

- ✓ Categorization process (Para. 8.5): a process for categorizing the installation in terms of radiological hazard should be undertaken

  The criteria for categorization should be based on the radiological consequences of a radioactive release from the installation

  Consequences depend not only on the nuclear installation, but also on the characteristics of the site: installation-site interaction should be considered

- ✓ Radiological hazard categories (Para. 8.4): Four categories are defined

  High hazard category → Do the same as for regular NPPs (i.e. no grading)

  Medium hazard category → Grading is possible

  Low hazard category → Grading is possible

  Conventional industrial facilities → Do the same as for conventional

Only qualitative guidance is provided to define the limits

Geotechnical investigation and characterization

Section 8 of DS531

✓ Consequence analyses (Para. 8.6 & 8.7): two levels of effort

First screen (Para. 8.6): unmitigated release of the full radiological inventory

If the first screen fails (i.e. consequences are unacceptable), credit may be taken for some engineered safety features, as far as "robustness" is demonstrated later on (Para. 8.7)

8.7. Consequence analyses for radiological hazard categorization, in which a design-dependent set of source terms is used, and credit is taken for some engineered mitigating features, should be considered acceptable, as far as the source terms reasonably envelop all potential accident scenarios in the nuclear installation, and the robustness of the mitigating features can be clearly demonstrated for the design basis events[3].

[3] Robustness of these features can be 'clearly demonstrated', for instance, by showing a design margin up to several times the design basis event.

Geotechnical investigation and characterization

Section 8 of DS531

✓ Grading of site investigation and characterization (Para. 8.10):

1. For a ‘Medium’ hazard category installation, grading of the scope that would be used for a ‘High’ hazard category installation should be considered.

2. For a ‘Low’ hazard category installation, an upgrade of the scope that would be used for a ‘Conventional’ hazard category installation should be considered.

Note that possible grading is defined in relative terms, with respect to what would be have done for regular NPPs or for conventional facilities.

This is so because site investigation and characterization is so site-dependent, that no absolute guidance can be given.

Geotechnical investigation and characterization

Section 8 of DS531

- ✓ Importance of judgement (Para. 8.11): site-dependence emphasizes the importance of judgement when defining the level of grading

8.11. The grading of the geotechnical site investigation and characterization with respect to a ‘High’ hazard category scope depends on the foundation requirements for the nuclear installation and on the complexity of subsurface conditions. The appropriate grading should be determined by the judgment of qualified geotechnical engineers[4].

[4] Even though general rules may prove to be invalid por a particular site, it might be expected that the number, spacing, and depth of site penetrations (borings, cone penetrometers); number and type of soil samples obtained; and associated testing program for a ‘Medium’ hazard category installation is in the order of one-half of the effort for a ‘High’ hazard category installation. *(Perhaps, we need to include an Annex to provide a basis for this assertion. This is to be discussed)*

Geotechnical investigation and characterization

8.12. As a minimum, a graded geotechnical site investigation and characterization should address the following items:

(a) Geotechnical structure of the subsurface materials, with a description of the stratigraphic sequence of soil or rock strata, nature and dimensions in plan and depth of the different formations;

(b) Static and dynamic geotechnical properties of subsurface materials, as necessary to assess the stability and bearing capacity, and to define design basis parameters;

(c) Potential presence of complex subsurface conditions, such as underground cavities or expansive soils or rocks;

(d) Hydrogeological conditions at the site, including the presence and thickness of aquifers, the groundwater regime, groundwater levels, the amplitude of fluctuations, as well as the chemical composition of groundwater and their aggressiveness in relation to the materials of underground structures.

Grading may affect the level of detail (e.g. number of boreholes, number of laboratory and field tests, etc.) used in the investigation of these items, but the scope of the geotechnical site investigation should always include these items[5]. Variability and uncertainty in subsurface materials should always be addressed.

[5] Defining an appropriate geotechnical site investigation programme for a nuclear installation is very site-specific and seldom can it be developed in a single phase. It is common that the programme is developed in several phases, in which the level of detail is progressively increased, based on the outcome of the previous phase. Appropriate grading may be achieved by eliminating or reducing the effort in the final phases.

These items are required for site safety evaluation
(IAEA SSR-1)

Geotechnical investigation and characterization

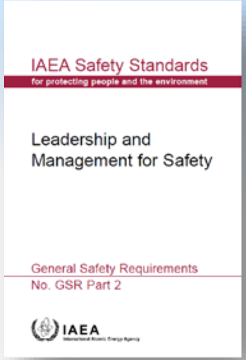
Section 8 of DS531

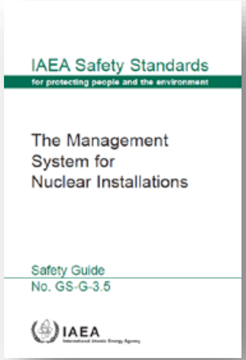
- ✓ Increased level of uncertainty resulting from grading (Para. 8.15): it should be considered when defining design basis geotechnical parameters. This is a price to be paid because of grading.

8.15. The result of grading the geotechnical site characterization is an increased level of uncertainty in the geotechnical parameters to be included as design basis for the design of buildings and other civil structures. This larger uncertainty should be taken into account when defining the design basis, and it will normally result in a reduction of strength parameters with respect to the ones that would have been derived using an ungraded approach[6].

[6] Sometimes, grading by the reduction of the number of boreholes, samples, tests, etc. can be consider a sampling theory problem, for which confidence intervals for the true mean value can be defined. The lower end of the, for instance, 95% confidence interval can be used to define the design basis parameter. The smaller the number of elements in the sample, the larger the confidence interval will be and, therefore, the smaller will be the lower end of it. In addition, estimates for the standard deviation of the mean value are larger as well.

APPLICATION OF MANAGEMENT SYSTEM FOR GEOTECHNICAL HAZARD ASSESSMENTS





Application of Management System for Geotechnical Hazard Assessments

- The site investigations should be addressed in the overall management system for the nuclear installation project;
- The management system 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;
- Site investigations should include a proper quality assurance program developed by the operating body and contractors involved in these tasks, as part of the management system, covering each activity that could affect site safety hazard assessment;

Application of Management System for Geotechnical Hazard Assessments (cont'd)

- This program should cover the organization, planning, work control, personnel qualification and training, verification and documentation of the activities;
- Technical procedures for specific field, laboratory and office activities should be developed to facilitate execution and verification of these tasks;
- The geotechnical investigations report shall should sufficient detail to permit an independent review;
- Evaluation of geotechnical hazards and site-specific design basis geotechnical parameters should be independently peer reviewed.

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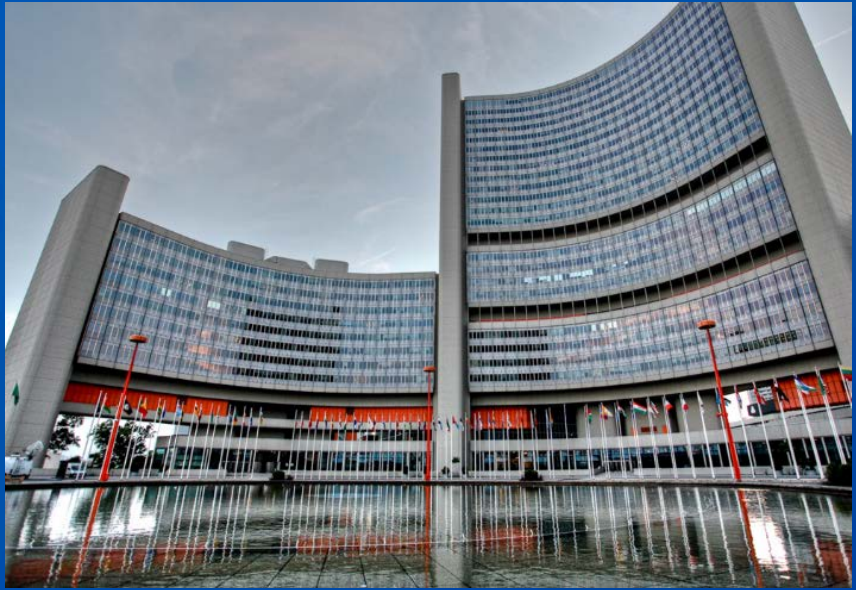

Thank you!

Questions?

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