### AMP 316 SUBSURFACE Engineered backfill materials (VERSION 2020)

### Programme Description

This ageing management programme (AMP) provides guidance for developing a plant specific ageing management programme for subsurface engineered backfill materials in order to ensure there is no loss of intended function for embedded structures during operation. This is done by confirming that the results of soil-structure interaction analyses conducted during the design and construction stage remain valid.

The ageing effects include the change of key geotechnical characteristics, such as changes in material properties of in-situ engineered backfill materials. The AMP consists of in-situ tests on engineered backfill in which the foundations of nuclear safety related structures are embedded. In-situ tests are supplemented by conducting mechanical tests and visual inspections on representative samples. Test involving analyzing the chemical composition of groundwater are also conducted using similar procedures as covered in AMP 306 and AMP 307. All tests are performed by suitably qualified and experienced personnel. The representative samples are made of the same material as the in-situ materials. They are also stored and handled to ensure that they are exposed to the same ageing conditions as in-situ materials. Tests are performed to obtain both static and dynamic properties in order to evaluate the ability of subsurface engineered backfill materials to limit vibratory ground motion in such a way that all structures and equipment important to safety fulfill their intended function during and after a seismic event. Examples of static characteristics include Saturated Density, Dry Density, Cohesion, Internal Angle of Friction, static Young’s Modulus (E), Poisson’s Ratio, Vertical Stiffness and Horizontal Stiffness. Examples of dynamic characteristics are dynamic Young’s Modulus, dynamic Poisson’s Ratio, Reference Strain, Damping Factor, dynamic Vertical Stiffness and dynamic Horizontal Stiffness. Visual inspections are performed to detect degradation of subsurface materials or changes in material properties of subsurface engineered backfill materials.

### Evaluation and Technical Basis

1. ***Scope of the ageing management programme based on understanding ageing:***

The scope of the programme includes subsurface engineered backfill materials located underneath (or surrounding) the concrete foundation of nuclear island structures performing intended functions (i.e. the AMP covers safety related structures in nuclear island). This AMP specifically addresses engineered backfill layers underneath (or surrounding) the nuclear island concrete foundation. An engineered backfill material could for example consist of a compacted soil-binder mix having a specified binder content. Typical degradation mechanisms include loss of density, leaching out of binder material from the engineered backfill material, erosion, etc. The concrete foundation members are not covered in this AMP and are inspected in accordance with AMP 306.

1. ***Preventive actions to minimize and control ageing degradation:***

The subsurface engineered backfill materials monitoring programme is a condition monitoring programme. However, preventive actions (if any) such as limiting exposure to adverse environmental conditions that could lead to ageing degradation can be implemented if necessary.

1. ***Detection of ageing effects:***

In-service examinations (that can include visual inspections, testing and monitoring) and surveillance are essential elements for detection of ageing effects, including loss of resistance to liquefaction. The primary inspection method for subsurface engineered backfill materials is visual examination complemented by mechanical tests on representative samples, where such samples exist. In some member states, test samples, in the form of small diameter cores, are extracted from in-situ engineered backfill materials and subjected to chemical analysis and mechanical testing. In-situ tests are also performed by some member states. Following the occurrence of a seismic event, in situ geophysical tests are mandatory.

The samples are evaluated by assessing the physical condition of each sample by visual examination and determining the volume and density of each core. The external cylindrical surface of each sample is examined for the occurrence of features such as changes in surface profile, surface texture, leaching, erosion, color and diameter. The data for each sample is expressed in terms of measured volume and calculated density and includes percentages of the original value as obtained from the licensing basis documents. The data is used for the purposes of trending and understanding the changes in volume and density of the samples.

Parameters of the engineered backfill material are monitored commensurate with relevant national industry codes, standards, recommended guidelines and testing manuals (for example [1, 2, 3]), and in particular with the ageing hypotheses assumed for the plant design limits. Depending on the specific design of the foundation and superstructures, typical examples of parameters monitored may include, elastic moduli and Poisson’s ratio of subsurface engineered backfill materials and their variation with depth and with strain level., etc.

Seismic cross-hole tests are performed on in-situ materials at the intervals defined in the licensing basis. The frequency of the periodic test depends on the results of the different campaigns: generally, this frequency is higher when trending indicates anomalies or changes in material properties.

The frequency for visual inspections depends on safety significance and condition of the foundation system. In general, visual inspections are performed at specific intervals (for example, every 2-5 years to be consistent with structures monitoring – AMP 306) on representative samples and or in-situ subsurface engineered backfill materials. The visual inspection is performed to determine the visual effect of leaching and other superficial degradation mechanisms, such as erosion, etc. The scope of inspections also includes ground water quality tests using similar procedures as covered in AMP 306 and AMP 307. This is done to detect the development of ambient and environmental conditions that may have an adverse impact on the integrity and long-term performance of subsurface engineered backfill materials. Exceptional events such as flooding, or earthquakes may require specific inspections (more than visual) depending of the importance and type of event. Flooding only affects the soil stress state until the groundwater level reaches the ground surface. After this point, it doesn’t matter anymore. Therefore, to consider flooding as an event that affects the soil, the groundwater level must be very low. Following the occurrence of a seismic event, in situ geophysical tests are mandatory.

1. ***Monitoring and trending of ageing effects:***

The ageing management programme consists of the following elements:

* Visual Inspection: Visual inspections are performed by examining the condition of representative core samples; these inspections are intended to keep track of the condition of the in-situ subsurface engineered backfill materials and detect any deterioration in their condition. Visual inspection is augmented by volume and density measurements.
* Seismic Cross-hole Tests: In-situ tests on subsurface engineered backfill materials are performed periodically to measure compressional (P) and shear (S) wave velocities of subsurface engineered backfill materials, and to determine whether these parameters are still within the design basis throughout the period of operation. The test results obtained are trended and extrapolated. The values obtained after extrapolation are compared to the design values as documented in the licensing basis documents.
* Mechanical Tests: One or more mechanical tests may be performed on representative samples of subsurface engineered backfill materials to evaluate various mechanical properties used as a basis for design such as Static Modulus, Static Poisson's Ratio, Dynamic Modulus, Dynamic Poisson's Ratio, Density, Dynamic Shear Modulus, spectral amplification factors (damping, acceleration, velocity and displacement), shear modulus reduction as a function of shear strain, etc.
* Water Quality Tests: Groundwater samples are collected from the boreholes and piezometers embedded in subsurface engineered backfill materials up to the depth of interest beneath the nuclear island foundation. The tests performed on the samples include, water level, pH, Temperature and Chemical analysis in accordance with AMP 306.
* Changes in hydrological conditions: Changes in hydrological characteristics for the site (i.e. changes in the direction of seepage) over the life of the plant are also monitored and evaluated against acceptance criteria defined in the licensing basis.
* Inspections following an extreme external event: A special inspection or special investigations may be performed on a case by case basis following the occurrence of a significant natural phenomenon such as flooding, earthquake, landslides or intense local rainfall. After the occurrence of a seismic event, such as an earthquake that exceeded the SSE of the plant, new geotechnical investigation are carried out, consisting of laboratory and in situ tests, to evaluate or determine new static and dynamic parameters of the soil as well as in situ tests for rocks.

1. ***Mitigating ageing effects:***

This AMP is a condition-monitoring programme and neither general nor specific recommendations are provided to mitigate ageing effects. However, if the extent of degradation observed or detected exceeds the acceptance criteria, plant specific actions can be identified based on detailed monitoring and trending, and structural evaluation to mitigate the root cause or source of degradation or and to evaluate the impact on structural performance. Mitigation actions could include reinforcing the soil by injecting a cement grout under the foundation.

1. ***Acceptance Criteria:***

The subsurface engineered backfill materials ageing management programme calls for inspection results to be evaluated by qualified engineering personnel based on acceptance criteria selected for engineered backfill material to ensure that the need for corrective actions is identified before loss of intended functions. The criteria are derived in accordance with industry codes and standards of each country, and design bases codes and standards, as applicable, and consider industry and plant operating experience.

From the seismic design viewpoint, three aspects of subsurface engineered backfill materials are of interest:

* Durability;
* Mechanical characteristics;
* Strength margin.

**Durability**

The cohesion must not be impaired by chemical attack from potentially deleterious matter in the engineered backfill material and/or the groundwater or from potential alkali-aggregate reaction. Thus, any significant changes in groundwater chemistry and/or hydrology (i.e. changes in the direction of seepage) over the life of the plant are monitored and evaluated against acceptance criteria defined in the licensing basis.

**Mechanical properties**

The following characteristics needed for the dynamic analysis are monitored and evaluated against acceptance criteria defined in the licensing basis to ensure there is no significant modification of mechanical characteristics to be accounted for during the life span of the plant:

* Strength;
* Density;
* Dynamic Young's modulus;
* Poisson's ratio;
* Variation of shear modulus with shear strain.

**Strength margin**

The strength of the engineered backfill material and its resistance to liquefaction is obtained through:

* Compaction to higher density and ensuring that the effects of compaction are permanent and not subject to chemical degradation or other deleterious effects;
* Inherent cohesion (and or cohesion introduced by the addition of binder material(s) if any).

The stress analysis under different load cases, including earthquake, should result in a reasonably large safety factor such that there is a considerable safety margin beyond the required minimum factor of safety.

Durability is assessed by performing visual inspections (on representative samples) and by conducting water quality tests. The acceptance criteria are based on qualified engineering assessment concluding that there is no potential degradation due to erosion, discoloration, leaching, unfavorable changes in the ground water regime, etc. Acceptance criteria for mechanical properties and strength margin are determined based on the limiting values used at the design stage. The test results are compared with the limiting values used in the design basis. In case the conditions do not meet the acceptance criteria and thus indicate a potential for degradation, this will be included into the corrective action programme of the plant for further evaluation.

1. ***Corrective Actions:***

Evaluations are performed for any inspection results that do not satisfy established criteria. Corrective actions are initiated in accordance with the corrective action process if the evaluation results indicate there is a need for corrective action measures. In addition, the corrective actions include assessment for mitigating the root cause of the degradation. In the absence of any plant specific requirements for corrective actions, the requirements in [4] can be used to address the corrective actions.

1. ***Operating experience feedback and feedback of research and development results***

This AMP addresses the industry-wide generic experience. Relevant plant-specific operating experience is considered in the development of the plant AMP to ensure the AMP is adequate for the plant. The plant implements a feedback process to periodically evaluate plant and industry-wide operating experience and research and development (R&D) results, and, as necessary, either modifies the plant AMP or takes additional actions (e.g. develop a new plant-specific AMP) to ensure the continued effectiveness of the ageing management.

For the Koeberg Nuclear Power plant site in South Africa, in-situ sand overlying the bedrock was judged to be potentially liquefiable under certain levels of earthquake-induced ground motion. This risk was catered for by providing a non-liquefiable sub-foundation between the bedrock level and the underside of the lower raft foundation. The sand was excavated down to bedrock and replaced by a soil-cement sub-foundation. The soil-cement backfill was prepared with the 'upper sands' of the site. Results obtained over the years by conducting cross hole seismic tests showed a decline in the P and S-Wave velocities during the initial 10-15 year period after construction followed by a steady increase in the P and S-Wave velocities during the subsequent period.

In Belgium, the Licensee had to construct a new underground gallery connecting an existing building with a new building housing mechanical safety related equipment at Tihange Nuclear Power Station Unit 1. This was part of plant modifications for long-term operation. The Licensee used a construction technique called jet grouting that breaks the ground using a high kinetic energy jet and mixes lose ground with a cementitious grout. The choice of this technique was based on the soil characteristics mentioned in the Safety Analysis Report (SAR) and on the fact that the technique had been previously used without incidents at the site. However, after 10 underground columns had been built using jet grouting, a visual inspection revealed several damages on the ground floor of the existing building including cracks across floor slabs in rooms housing the turbine-driven pump of the auxiliary feedwater system and compressors of the instrument air system. Unit 1, which was at full power operation, was shut down and jet grouting activities were interrupted to allow for an investigation. Geotechnical and mineralogical investigations carried out by the Licensee revealed the presence of heterogeneous backfill. The results revealed also that the soil characteristics were different from the information provided in the SAR, which indicated the presence of compacted alluvium and of stabilized backfill. After performing necessary repairs on safety related equipment inside the building and additional local soil reinforcement activities, the unit was allowed to be restarted with agreement of the Regulatory Body after almost 8 months of shutdown.

At the time when this AMP was produced, no relevant R&D was identified.

1. ***Quality Management:***

Administrative controls, quality assurance procedures, review and approval processes are implemented in accordance with the different national regulatory requirements (e.g., [4, 5]).

### References

[1] ASTM D4428/D4428M – 14, 2014, “Standard Test Methods for Crosshole Seismic Testing,” ASTM International.

[2] Day, Robert W.E., 2001, “Soil Testing Manual,” McGraw-Hill Professional.

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Geotechnical Aspects of Site Evaluation and Foundations for Nuclear Power Plants, Safety Standards Series No. NS-G-3.6, IAEA, Vienna (2004).

[4] UNITED STATES NUCLEAR REGULATORY COMMISSION, 10 CFR Part 50, Appendix B, Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants, National Archives and Records Administration, USNRC, Latest Edition.

[5] National Nuclear Regulator (2008), Quality and Safety Management Requirements for Nuclear Installations. RD-0034, Rev 0. Centurion