**AMP 310 GROUND MOVEMENT DUE TO EXPANSIVE SOILS (VERSION 2021)**

**Programme Description**

This AMP applies to ground movement phenomena generated by the volumetric expansion of expansive soils [1], which may affect structures, systems and components of Nuclear Power Plants (NPPs).

In general, during construction and early years, structures undergo ground settlement. Since most NPP foundations rest on firm rock or other non-cohesive material, settlement occurs in the first months after construction and tend to disappear or reduce substantially afterwards. AMP 302, AMP 306, and AMP 307 can be used effectively to manage ageing of such structures due to settlement.

At some NPPs, a phenomenon of continued settlement or up-heave of the terrain, has been detected. Settlement is a well-known phenomenon that has been widely studied. Its ageing effects are managed in AMP 317.

Up-heave phenomenon of ground movement is not so usual and may occur due to swelling of expansive soils in contact with water. Expansive soils are clayey and unsaturated soils (e.g. a calcium carbonate or lime rich mud or mudstone that contains clays and silt between 35 to 65 percent, described in “Ground Movements Surveillance Manual, Ascó 2 NPP” [2]) whose physical proprieties lead them to a volumetric expansion (swelling) in presence of water.

Excavation of the overburden during construction and changes into the soil, like the ground water level, may lead those ground movements to occur during the lifetime of the NPP.

As the expansion is volumetric, the soil undergoes displacements in the three main directions (one vertical and two horizontal). Therefore, structures, as well as systems and components structurally attached to them, founded on a geotechnical profile that comprises an expansive soil layer undergo a ground movement due to the upward soil vertical displacement component (up-heave), and earth pressure on underground walls, buried structures, and retaining walls due to the soil horizontal displacement components.

Those movements are extrapolated to the end of the design life of the plant, by ground movement prediction models. The effect of the extrapolated values on the safety related structures, systems and components is checked.

Actual values of those movements may not match the predicted ones, due to lack of adequate knowledge of foundation material properties, so it is necessary to monitor the phenomenon along that time.

This AMP addresses the activities to be performed during the lifetime of the NPP in order to survey the effects of the soil movements. These surveillance activities include:

1. ‘Soil data collection’, describes the field measurements to be performed, excluding the hydrological measurements. Many devices are available for monitoring up-heave. Vertical movement can be measured by settlement plates or remote settlement gauges like the ones utilizing closed fluid systems. Other examples of instrumentation can be inclinometers;
2. ‘Soil data evaluation’, collects and analyzes the data in order to faithfully establish the condition of the plant and compare it to its current licensing basis, defined by the ground movement prediction models. This activity consists of two parts:
   * Monitoring of ground movements and comparison of the results with the previously developed predicted values;
   * Evaluation of field data in order to determine any preventive measures so that current licensing basis is maintained during the intended period of operation.
3. ‘Hydro-geology’, in order to ensure the effectiveness of the systems that control the entry of water into the silt-clayey layer, an on-site hydro-geological monitoring system as well as data evaluation methods is established. This monitoring system can consist in a net of piezometers. The evaluation takes into account effects of ground temperature in permafrost regions. If a dewatering system is relied upon to control up-heave, further evaluation is recommended to verify its continued functionality during the intended period of long term operation;
4. ‘Geotechnics’, deals with the geotechnical aspects of the ground movement phenomenon. This monitoring system can consist in a net of extensometers;
5. ‘Precautions’, listed in the owner’s instruction manual that are established based on ground movement phenomenon observed during plant operation.

**Evaluation and Technical Basis**

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

This AMP manages the monitoring actions of the foundation media at the site of NPP where the ground movement phenomenon due to expansive soils occurs and evaluates its effects upon safety related systems, structures and components (SSCs).

The scope includes all structures and components that are included in the scope of AMP 302, AMP 305, AMP 307, AMP 318 and AMP 319, that are founded on soils affected by swelling.

For example, for a PWR/BWR, the SSCs included in the scope normally include the following:

* Structures:
  + Containment building;
  + Fuel building;
  + Auxiliary building;
  + Control building;
  + Control and turbine buildings penetrations;
  + Diesel generators building;
  + Solid waste building;
  + Emergency cooling towers;
  + Water control structures.
* Systems and components:
  + Nuclear steam supply system;
  + Fuel management system;
  + New fuel racks;
  + Spent fuel racks
* Fuel building cranes;
* Fuel transfer system.
  + Components handling system;
  + Piping systems inside buildings;
  + Output and input pipes connection between buildings;
  + Expansion joints of air conditioning ducts between buildings;
  + Electrical connections between buildings;
  + Buried pipelines, tunnels and trenches;
  + Structural fire barriers.

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

This AMP addresses the mandatory monitoring programmes for the soil, groundwater level, and structures to evaluate the behavior of an expansive soil aiming at maintaining the integrity of SSCs during the lifespan of the NPP

As a preventive action, the entry of water to the ground on the site is limited to ensure that the ground movement is kept within acceptable limits. In order to achieve this, the NPP may rely on various systems, which may include:

* + Installation of waterproof surfaces and draining system (to collect rainwater);
  + Construction of draining wells (to collect the water that may leak through the waterproof surface);
  + Installation of horizontal draining net around the affected buildings (to collect water that may get in contact with the soil through the draining wells);
  + Construction of waterproof screens (to limit the entry of water from adjacent sources: rivers or lakes);
  + Construction of superficial drainages (to collect water coming down from surrounding slopes);
  + Installation of a drainage dewatering system (to lower site ground water level, especially in sites located near the sea, estuaries lakes or water reservoirs).

This AMP establishes a hydrological monitoring programme to survey the effectiveness of the systems that control the entry of water into the soil beneath the foundations of the affected buildings. These activities allow the surveillance of the groundwater causing the swelling of the soil, thus anticipating the medium to long term evolution of ground movement compared with the in-site previously performed previsions.

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

The approach of this AMP is the ground movement caused by the volumetric expansion of an expansive soil. The volumetric expansion of the soil generates displacements in the three main directions, one vertical and two others horizontal. Therefore, in addition to up-heave, which is the displacement due to the vertical component, there is an excess of earth pressure compared to regular soil condition caused by the horizontal components on buried structures and retaining walls throughout the area comprised by the expansive soil layer.

Aging effects due to this phenomenon include cracking, distortion, loss of foundation strength and tilt of structures.

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

Volumetric expansion of expansive soils is a complex phenomenon whose occurrence depends on the soil saturation by the groundwater. For aiming and evaluating the expansive soil behavior, it is mandatory to implement monitoring programmes for the soil, groundwater and structures. All these monitoring programmes are be carried out during the lifespan of the NPP.

The monitoring parameters are those that let detect what may affect or influence the intended function of safety related SSCs, due to ground up-heave effects.

These parameters include long-term and continuous measurement of movements at key points of the structures using extensometers and other instrumentation. The frequency of the measurement is established based on the overall movement settlement and rate of progression.

According to Spanish operating experience presented in attribute 8, the following monitoring elements may be used:

* Basic measurements system for monitoring the ground movements; including data collection of:
  + Topographic leveling gauges;
  + Extensometers embedded deep into the ground to measure changes in the soil active layers;
  + Mechanical triaxial jointmeters, to measure differential movements between building in three orthogonal directions;
  + Clinometers to measure tilt in structures and buildings;
  + Elongameters to Horizontal displacements measurements of load-retaining walls.
* Complementary measurement system for monitoring the condition of the structures (besides of providing supplementary data, this system constitutes a mean of comparing the data interpretation provided by the basic measurement system). Elements included in this system are:
  + Ultrasonic test in the most solicited beams and columns, according to the structural evaluations, to anticipate possible degradation in other structural elements;
  + Inspection and documentation of cracks in concrete structures. The progress of some active cracks, which may comprise cracks classified as consequence of settlement and earth pressure, is be verified through the measurement of their lengths and openings. To obtain the depth of cracks, complementary ultrasonic non-destructive tests could be performed. AMP 318 provides additional information about the management of cracks.
* Instrumentation for monitoring the groundwater level:
  + A net of piezometers, to measure the excess of pore pressure in the expansive soil layer, through which the groundwater level can be determined when the water pressure is hydrostatic;
  + Groundwater level gauges to directly measure the groundwater level.
  + If a dewatering system is used to lower the site groundwater level and if the design basis credits it, its continued functionality is verified.

Therefore, all instrumentation installed in the plant allows the determination of the benchmark groundwater level, ground surface vertical displacements, foundation differential settlement of structures, displacement between structures, displacement between expansion joints, penetrations, pipes and ducts connections in the three main directions, structural distortion, tilt of structures, horizontal displacements on structure underground walls, buried structure walls, and retaining walls.

The field data isbe compared with the values determined by the prediction models and with those established in the plant design basis aiming at analyzing the SSCs actual conditions and at determining the actions to be taken during the intended period of long term operation of the plant. All information and data obtained is provided in the owner's instruction manual, as suggested in the Spanish experience.

Frequency of the measurement is defined in accordance with the severity of the case and the preventive actions implemented, and can be adjusted after a trend is established, based on some consecutive inspections.

In Spanish experience, for instance, if ground movements differ from the predicted ones, the frequency of the basic and complimentary measurements are to be evaluated by qualified structural engineers knowledgeable and experienced in the design of nuclear power plant structures. Furthermore, frequency of measurement does not exceed one year if the actual settlements are over 75 percent of the predicted ones at the end intended period of long term operation. The frequency of measurement can be adjusted after a trend is established based on some consecutive inspections.

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

This AMP is a condition monitoring programme, and no generic recommendations are included to mitigate ageing effects. However, if degradation of structures, systems and components is detected that exceeds the acceptance criteria, which usually have some safety margin with the design ones, plant specific mitigation actions can be identified based on detailed monitoring and trending, and structural evaluation to mitigate the root cause of the degradation. This may include installation of flexible supports (snubbers, limit stops, bellows) in piping, penetrations and ducts in areas where these commodities pass from one building to another.

1. ***Acceptance criteria:***

The acceptance criteria for ground up-heave movement are based on predicted values obtained in the original evaluation of the phenomena that define the design values of it. Acceptance values have some safety margin (e.g. 20%) from the design ones. If actual measured values exceed the predicted values, a specific study and evaluation is performed to determine the root cause and ability of the structures to meet the current licensing basis during the intended period of long term operation.

1. ***Corrective actions:***

Evaluations are performed for any ground up-heave movement measurements that do not satisfy its acceptance criteria. Corrective actions are initiated in accordance with the corrective action programme if the evaluation results indicate there is a need for a repair or replacement. In addition, the corrective actions include assessment for mitigating the root cause of the degradation. In absence of any plant specific requirements for corrective actions, the requirements in the US Code of Federal Regulations, 10 CFR Part 50, Appendix B [3], 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 ageing management.

Appropriate source of external operating experience is Ageing Management of Concrete Structures in Nuclear Power Plants, IAEA Nuclear Energy Series No. NP-T-3.5, 2016 [4].

Ground movement (up-heave) phenomenon was first detected, studied and modeled in the early 1980s in one unit of a Spanish NPP. It happens due to expansive soil layers consists of a calcium carbonate or lime rich mud or mudstone that contains clay and silt fraction between 35% to 65%.

As a result of these studies, a “Ground Movements Surveillance Manual, Ascó 2 NPP” [2], against the effects of ground up-lifting for the SSC of that NPP, was approved in 1984, which has been of strict compliance since that date.

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

1. ***Quality management***

Site quality assurance procedures, review and approval processes, and administrative controls are implemented in accordance with the different national regulatory requirements (e.g., 10 CFR Part 50, Appendix B [3]).

### References

[1] SALAS, J.A.J. y ALPAÑES, J.L.J., Geotecnia Y Cimientos – Propiedades de los suelos y de las rocas. Editorial Rueda, 2ª Edition, 1975.

[2] Spanish Nuclear Safety Council (CSN), Ground Movements Surveillance Manual, ASCO 2 NPP, 1984.

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

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Ageing Management of Concrete Structures in Nuclear Power Plants (IAEA Nuclear Energy Series No. NP-T-3.5, 2016.