**AMP 307 Water control Structures (VERSION 2020)**

**Programme Description**

This ageing management programme provides guidance for in-service inspection of structures related to Water-control Systems associated with emergency cooling water System or flood protection system of nuclear power plants (NPPs). These systems comprise various items such as dikes, dams, slopes, canals and associated facilities, embankments, spillway, retaining walls, intake and outlet structures of the cooling towers. Concrete portions of the water-control structures may also serve as load bearing components.

The effects of water itself are to be carefully addressed due to both negative influence on ageing mechanism (environment), and the fact that these structures cannot be easily inspected. The behavior of earth works with time is particularly important and is investigated with a dedicated surveillance programme which is intended to detect seepage, settlements erosion, sediment deposit, earth movements, and detrimental corrosion. For concrete parts in water-controlled structures there are several ageing mechanism e.g. corrosion, leaching, frost, Alkali Aggregate Reaction/Alkali Silica Reaction, etc. [1-4].

The periodic inspection, monitoring and maintenance programme of water-control structures is important because of its role in prevention or mitigation of the consequences of age-related deterioration and degradation in a timely manner. The programme is based on periodic inspection, settlement measurements, underground water level recording, engineering data compilation and technical evaluation. Some specific structures such as cooling towers, retaining walls or submerged concrete structures may need additional inspections.

For the parts of structures that are not in permanently contact with water, (dry part of pump houses), AMP 306 applies, and AMP 312 applies where concrete expansion reaction occurs even if it is a water-control structure.

For dams, depending on their height or capacity, they may be subjected to additional inspections based on national regulations.

### Evaluation and Technical Basis

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

This Ageing Management Programme applies to the structures related to water-control systems (e.g. sea or river), important to safety. The water-control structures considered in this AMP include, but are not limited to, embankment structures, dikes, dams and associated facilities, spillway and other discharge structures, retaining walls, submerged parts of pumping stations, intake and outlet-structures, tunnels or galleries permanently full of water, reservoirs, channels and canals, etc. The cooling towers can be included in the scope, if they can threaten the plant safety, either directly in case of collapse on safety structure, or indirectly if the released water can lead to detrimental effects on other buildings or external equipment flooding.

The scope of the programme also includes structural steel and structural bolting associated with water-control structures, steel or wood piles and sheeting required for the stability of embankments and channel slopes, and miscellaneous steel, such as metallic water gates, sluice gates and trash racks. The boundary between this AMP and AMP 306 (for concrete, steel and anchorages) has to be understood and it is based on the presence of water during normal operation. Nevertheless, for the concrete expansion reaction AMP 312 applies in any environment condition. Coated structures (e.g., with silane impregnation) within the scope of this programme are visually inspected.

The flow blocking due to biofouling in the in-scope SSCs is managed in AMP 124.

If degradation of protective coatings for any structures included in the scope of this programme can affect safety functions of it, monitoring programme is to address protective coating monitoring and maintenance.

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

This is a condition monitoring programme. The programme is augmented to include preventive actions.Several actions can be undertaken to prevent ageing effects such as:

* Lubricants and/or sealant to be put in place on anchorage;
* Corrosion protection on tie rods;
* Riprap on sea or river to control sediment deposit (by diversion);
* Sealants to avoid water infiltration;
* Impregnating agent to avoid high chloride content water from infiltrating the structure;
* Coating to prevent corrosion or concrete ageing;
* Clearance of brushwood or limitation of vegetative growth on dikes;
* Elimination of burrowing animals on dikes and earth dams;
* Cathodic protection system to prevent corrosion of reinforcement or other steel components [5-6];
* Proper selection of bolting material, lubricant, appropriate installation torque or tension cracking of high-strength bolts to ensure structural bolting integrity [7-8].

1. ***Detection of Ageing Effects:***

Ageing degradation mechanism for water control structures include loss of strength, loss of material, loss of bond, cracking, changes in material properties, expansion, delamination, increasing porosity and permeability, e.g., for concrete structures, loss of preload of bolt, corrosion in steel, sealing function of elastomer sealants and loss of form for earthen structures.

This AMP specifies that inspection of water-control structures is conducted under the direction of qualified personnel in the investigation, design, construction, and operation of these types of facilities. Visual inspections are primarily used to detect degradation of water-control structures. In some cases, instruments have been installed to measure the behavior of water-control structures. The available records and readings of installed instruments are to be reviewed to detect any unusual performance or distress that may be indicative of degradation. In the submerged zone visual inspections maybe complemented with Non Destructive Testing and/or Destructive Testing to dectect non visual degraderation, for example corrosion of rebars.

For each structure/ageing effect combination, the specific parameters monitored or inspected depend on the particular structure, structural component, or commodity. Parameters monitored or inspected are commensurate with industry codes and standards [1-2, 9-12] and guidelines [13-16] and also consider industry and plant-specific operating experience and evaluation accounts also for seasonal variations.

The programme addresses detection of ageing effects for inaccessible (described in attribute 3 of AMP 306), below-grade, and submerged concrete structural elements. The areas which are inaccessible are evaluated for existing or potential concrete degradation mechanisms. These degradations may be caused by chemical and physio-chemical processes in the concrete and deterioration due to environmental conditions including, but not limited to, aggressive chemical attack, erosion and cavitation, corrosion of embedded steel, freeze-thaw, leaching of calcium hydroxide, reaction with aggregates (more details are provided in AMP 312), increase in permeability or porosity, and combined effects.

For plants with non-aggressive raw water and groundwater/soil (for example in some countries, pH > 5.5, chlorides < 500 parts per million [ppm], and sulfates < 1500 ppm), the programme requires

(a) evaluation of the acceptability of inaccessible areas when conditions exist in accessible areas that could indicate the presence of, or result in, degradation to such inaccessible areas and

(b) examination of representative samples of the exposed portions of the below-grade concrete when excavated for any reason. Submerged concrete structures are inspected during periods of low tide or when dewatered and accessible.

For plants with aggressive environment raw water (pH < 5.5, chlorides > 500 ppm, or sulfates > 1500 ppm) or ground water/soil and/or where the concrete structural elements have experienced degradation, a plant-specific AMP accounting for the extent of the degradation experienced is implemented to manage the concrete ageing during the period of extended operation. The inspection periodicity is adapted to the soil or the structure condition depending on the phenomenon being inspected, (for example 1 year for sedimentdeposit, 5 years for overall inspection, up to 10 years for certain settlement measurement or sub aquatic examinations).

In [1], a 5-year frequency is given as appropriate to monitor groundwater. However, seasonal variations are accounted for on a plant-specific basis. All plants may experience seasonal variations in groundwater chemistry, and the sampling is used to identify the possible variation.

Some relevant examples are given here after which can be used as guidelines for typical water-control structures. Local plant-specific conditions and regulatory requirements determine the scope of each inspection programme.

* Retaining walls:

For large retaining walls (concrete or steel), the top of the wall movement is measured and trended.

For sheet-pile retaining walls, steel thickness measurements may be performed in areas of alternate wetting and drying based on representative sampling. Anchorage tie-rods may be visually inspected to check the presence of excessive corrosion or other degradation mechanism in every location.

* Dikes and dams:

The measurements of settlements of earth works may be undertaken at typical points which can characterize the soil movements. Massive structural inclusion in earth work is inspected and every abnormal phenomenon is characterized by topographic measurement: the movements of such structures may be broken down in axial displacement, rotation and internal deformation in order to allow for their analysis. Slope stability is examined. And if any, slope protection is examined including risk of erosion, wave protection and other current function.

Seepage is visually detected and trended on dikes and dams: optical fiber sensors can be used to detect leaks based on measurement of earth temperature. For large scale detection Infrared ray camera can be used in order to cover long dikes the failure of which can threaten the plant safety.

The drainage system is examined in order to check that the discharge water is not carrying foundation material and also that the system is working as designed.

The sealing material of joints is examined to determine any abnormal movement or indication of distress or leakage.

* Spillway, intake or outlet concrete work, and other concrete structures:

The concrete surfaces are examined to detect cracking, corrosion, seepage, abnormal deflection or misalignment. Joints seals are examined to check if they can perform their design function. Water passage section functionality is checked. Submerged concrete sections are examined to establish if there is degradation (special attention to rebar corrosion) beyond the acceptance criteria. This examination could be done by use of a NDT-method or visually by physically exposing rebars (DT) to detect void in concrete or excessively corroded rebars.

* Intake basin:

Sediment deposit is measured to check that water can be admitted in the plant network with acceptable turbidity for safety function. To cope with this risk, the deposit measurement frequency may be at 1 year intervals, or even more frequent if necessary.

* Cooling towers:

Settlement of cooling towers may be periodically measured. The distortion of the shell shape is checked to confirm detrimental movement has not ocurred: photogrammetric measurement is a relevant technique that allows a comparison with the theoretical or initial shape. These two measurements may be complemented by cracking and corrosion detection as the cooling towers are submitted to both humidity and thermal cycles that can accelerate concrete and steel ageing.

* Bolting and anchorages:

The programme is augmented to require monitoring of bolted connections for loss of material and loose bolts and nuts and other conditions indicative of loss of preload. High-strength structural bolting (actual measured yield strength greater than or equal to 150 ksi or 1,034 MPa) susceptible to stress corrosion cracking (SCC) is monitored for SCC. Other structural bolting and anchor bolts are monitored for loss of material, loose or missing nuts, and cracking of concrete around the anchor bolts. An example of checks for anchor bolts and signs of impaired conditions to look for (caveats) is given in [15]. These include condition of the anchor bolt, nut, baseplate, underlying grout (if present), required bolt torque, concrete condition in the vicinity.

* Common recommendation:

Further special inspections are recommended to be performed immediately following the occurrence of significant natural phenomena, such as large floods, earthquakes, hurricanes, tornadoes, and intense local rainfalls, etc.

The qualified personnel for this programme evaluates raw water and ground water chemistry that is sampled from a location that is representative of the water in contact with structures.

If a dewatering system is relied upon to control settlement, further evaluation is recommended to verify the continued functionality of the dewatering system during the subsequent period of extended operation.

Indications of groundwater infiltration or through-concrete leakage are assessed for ageing effects. This may include engineering evaluation, more frequent inspections, or destructive testing of affected concrete to validate existing concrete properties, including concrete pH levels. When leakage volumes allow, assessments may include analysis of the leakage pH, along with mineral, chloride, sulfate and iron content in the water.

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

Water-control structures are monitored by parameters measured and periodic inspection. Changes in areas with significant degradations from prior inspections, such as earth settlements, growth of an active crack or extent of corrosion, are trended until it is evident that the change is no longer occurring or until corrective actions are implemented in accordance with national regulation.

Numerous parameters can be monitored depending on the kind of structures. Some examples are listed below.

For earth works, these parameters are:

* Settlements;
* Slope or backfill incline;
* Drainage flow;
* Ground water level.

For concrete structures:

* Settlements;
* Inclination;
* Corrosion of rebars;
* Cracked areas.

For retaining steel sheet:

* Steel thickness

For intake basin

* Sediment thickness

For concrete dams:

* Concrete strains

1. ***Mitigating Ageing Effect:***

This AMP is a condition monitoring programme and no generic recommendations are included to mitigate ageing effects. However, if degradation of structures and components is detected that 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. A typical mitigation action for leaking dikes the tightness of which cannot be easily repaired is a drainage system that can maintain or improve the earth work stability (such a modification is designed by an engineer specialist in water-control earth work in order to control the risk due to erosion of foundation material).

1. ***Acceptance Criteria:***

The structures monitoring programme calls for inspection results to be evaluated by qualified engineering personnel based on acceptance criteria selected for each structure/ageing effect to ensure that corrective actions is identified and implemented before loss of intended functions.

The criteria are derived in accordance with industry codes, standards and practice of each country, and design bases codes and standards, as applicable by considering industry and plant operating experience. Generally, for earth structure, examination of design data if any and intervention by engineer specialist in geotechnical aspect of water-control structure are necessary steps in order to assess acceptance criteria. As an example, increase of ground water level significantly above the current level (based on measurement at the same time of other similar point) is a warning criterion that needs further investigation to understand this increase; in the same way, significant leakage of dikes or eroded foundation material in the drainage system need investigation, and correctives actions. Settlement measurement results need comparison to geotechnical prediction, taking into account uncertainties.

For example, the “Evaluation Criteria” provided in Chapter 5 of ACI 349.3R-18 [1] provide acceptance criteria (including quantitative criteria) for determining the adequacy of observed ageing effects and specifies criteria for further evaluation.

Loose bolts and nuts, cracked high strength bolts, and degradation of piles and sheeting are examined by engineering evaluation and subject to corrective actions: engineering evaluation is documented and based on codes, specifications, and standards such RCSC specifications [12], RCC-CW AFCEN-2019 [11] and those referenced in the plant’s current licensing basis.

The European standard EN 1504-9 [14] is an example for condition assessment which is a necessity if the acceptance criteria can not be contained

1. ***Corrective Actions:***

This AMP recommends that when inspection findings indicate that significant changes from the normal design condition have occurred, the conditions are to be evaluated. This includes a technical assessment of the causes of distress or abnormal conditions, an evaluation of the behavior or movement of the structure, and recommendations for remedial or mitigating measures.

Typical corrective actions can be the followings:

* Leakage elimination in dikes (below the acceptance criteria) performed by appropriate action that can be temporary and then definitive;
* Clearance of obstructed drainage system or construction of new ones;
* Injection of soil when settlement trend lead to value beyond acceptance criteria;
* Strengthening of sheet pile (due to excessive loss of thickness);
* Strengthening of concrete and steel structures by various sustainable techniques;
* Dredging of sediment deposit;
* Replacement of anchorages with excessive corrosion;
* Replacement of chloride initiated degraded concrete;
* Installation of sacrificial or impressed cathodic protection system.

1. ***Operating experience feedback and feedback of research and devolpment 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 [17].

In US, Degradation of water-control structures has been detected, through NRC AMP XI.S7 [4] and RG 1.127 [13] programmes, at a number of nuclear power plants, and, in some cases, it has required remedial action. NRC NUREG-1522 [18] described instances and corrective actions of severely degraded steel and concrete components at the intake structure and pump houses of coastal plants. Other degradation described in the NUREG include appreciable leakage from the spillway gates, concrete cracking, corrosion of spillway bridge beam seats of a plant dam and cooling canal, and appreciable differential settlement of the outfall structure of another. No loss of intended functions has resulted from these occurrences.

In Europe significant experience has been encountered on sea side plants and corrective actions are regularly performed, for example for sheet piles or spillway due to ageing effects detected with AMP similar to the present one. Premature collapse of a cooling tower has been observed in France due to rebars corrosion (without strong wind action).

In Sweden there has been many observed concrete damages in the sea water splash zone (inlet/outlet tunnels, shafts) with excessive spalling and cracks in concrete due to choloride induced corrosion [19]. Signs of degradation are commonly easy to dectect in the splash zone due to the corrosion of reinforcement. In the submerged zone, signs of corrosion can be hard to detect with visual. In sea water submergred zones there has been some cases with totally corroded reinforcement and no signs of cracks or spalling on the concrete surface [19]. Corretive actions and repairs has been conducted on the plants the last 10-15 years.

Appropriate source(s) of R&D related to this AMP are:

Cathodic protection of concrete structures with thermally sprayed sacrificial zinc anodes, ENERGIFORSK R&D report [20]. In summary, all investigations performed within the R&D project have shown that cathodic protection of concrete structures with thermally sprayed zinc provides a fully adequate cathodic protection as long as the zinc layer remains on the concrete surface.

Corrosion of steel in concrete at various moisture and chloride levels, ENERGIFORSK R&D report [21]. In the present study, samples made of steel cast in chloride containing mortar were exposed to different moisture conditions. The moisture condition was either static at a certain relative humidity or dynamic where the relative humidity was cycling between 75 % and 100 %. The lowest chloride concentration which caused initiation of corrosion was 1 % Cl by mass of cement and was measured for samples exposed to 97 % RH. At higher or lower moisture conditions than 97 % RH, the corrosion rate was lower. For samples exposed to dynamic moisture conditions, the lowest chloride concentration which initiates corrosion was measured to be 0.6 % Cl by mass of cement. Based on these results it was suggested that the chloride threshold level is lower than 1 % Cl by mass of cement for samples exposed to static moisture conditions and even lower chloride concentration can initiate corrosion in dynamic moisture conditions.

Water repellent agents for concrete in Nuclear Power Plants are discussed in ENERGIFORSK R&D report [22]. This report presents a preliminary study designed to answer if there are areas within the waterways of nuclear power plants that can benefit from the use of water repellent agents and identify if it is possible to use the method. The report lists the key factors for a successful treatment and also illustrates the importance of knowing the condition of the structure with respect to ongoing degradation mechanisms. An accelerated experiment of the function of a water repellent treatment under pressure showed that the method is effective as a chloride barrier at a depth of 10 meters. Concentrations of chloride ions are found to be significantly lower in the treated samples and equivalent to what is usually seen in for example road environment, 70-80 % reduction or more. Measurements of humidity in the concrete of a waterway and material analysis from several showed that it is possible to dry out some waterways in nuclear power plants when they are drained and that a large proportion of these also are possible to treat. The inspection of the waterways showed that it is not likely to lower the level of moisture in the concrete by means of the water repellent treatment. Alternatively, where the environment is too moist for the water repellent agent to penetrate, hydrophobic additives can be used in for example shotcrete.

The effect of salts on concrete, chemical and physical impact is discussed in ENERGIFORSK (former ELFORSK) report [23]. Attack might be purely chemical, at which components in the concrete are attacked. It might also be purely physical, e.g. salt-frost damage or crystal growth. A presentation of these two types of attack is made in the report.

The main cause of deterioration of marine structures is ingress of chloride ions from sea water, which in time will cause rebar corrosion. In some countries, tidal variations are quite small with the result that splash zones essentially remain in a permanent state of high moisture content (i.e. no significant drying period). This may inhibit oxygen ingress, thus reducing the risk of corrosion. Submerged structures normally have a low risk of rebar corrosion due to low oxygen levels. If, however, concrete is of poor quality (e.g. a high water to cement ratio and low resistivity) a macrocell may be created between above and below water reinforcement. Reinforcement above water will receive atmospheric oxygen and fuel the corrosion process at the submerged anodic reinforcement.

Cooling towers situated close to a marine environment can experience degradation because they use aggressive marine water for cooling. It is sometimes difficult to differentiate between aggressive water and an aggressive environment. However, cooling towers located in coastal areas often show severe degradation on the outer side of the shell (not in contact with the aggressive water). Water intake structures and structures exposed to lake or sea water undergo degradation primarily from aggressive marine water [24].

Results in Sweden from potential mapping of bridge piers in a marine environment indicate that there may be a linear relationship between measured chloride content and observed half-cell potential [25].

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, [26]).

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