AGING PROBLEMS AND RESIDUAL LIFE TIME EVALUATION OF THE SPENT FUEL STORAGE BUILDING STRUCTURE

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ABSTRACT

The main goal of this paper is to generalize the specific aging problems and the residual life time evaluation of the spent fuel storage building in Kozloduy NPP, Bulgaria. First of all the different factors and degradation mechanisms are investigated following the procedures given in [1]. Several types of in situ and laboratory tests are performed for specific elements of the civil structures. Based on these results and on the available technical information an evaluation for the condition of the reinforced concrete structure is done. The residual life time evaluation is done on the base of the complex analysis of the all available information from the construction time until now. Several techniques for investigation of the concrete and steel are recommended. Prescriptions are given for the periodical inspections of the important parts and details of the concrete and steel structures. Some specific issues are considered for the instrumental monitoring and the control of the aging mechanisms. Special attention is paid to the monitoring of the structure – geodetic monitoring, monitoring of the stress and strain state of the concrete. A concept is recommended for the future development and modernization of the monitoring systems. Proper measures are suggested for reducing the aging effects which are the basis of the maintenance program for these structures.

INTRODUCTION

The spent fuel storage building is in operation more than 20 years in NPP Kozloduy, Bulgaria. Some specific aging problems appeared during that time and different technical solutions are applied. It is useful to share this experience with the engineering community and to discuss the proper measures for the future exploitation. In the scope of big project for analysis of the engineering safety of the different buildings in NPP Kozloduy some specific issues are considered which are related to aging problems, residual life time (RLT) evaluation, monitoring program and aging management program. In order to assess the residual life time of the spent fuel storage building a complex analysis of big amount of information is done. The process consists of several stages:

- Condition of the concrete and reinforcement;
- Evaluation of the steel structures;
- Condition of the roof structures and drainage system;
- Evaluation of the massive reinforced concrete structures.

The monitoring program consists of two items - monitoring of the condition of the construction materials and structural monitoring. The second one is composed by geodetic monitoring of the structure and monitoring of the stress and strain state of the structure.

DESCRIPTION OF THE STRUCTURE

The spent fuel storage building has dimensions in plan 45/78 m. The structure is composed by different construction systems in separate areas:

- between rows A and V is build three stories part from precast reinforced concrete columns;
- between rows V and G and axes 1-7 is build a part with height 30m above level +7.20m. The structure consists of reinforced concrete columns and roof steel trusses;
- between axes 4 and 14 there are underground stories;
- the fuel pools are made from massive reinforced concrete in the area between axes 7-14 and rows V to G.

The foundation of the above mentioned parts of the structure is as follows:

- single foot steps under columns along axis 1;
- band foundations under the columns along axes 2 and 3;
• foundation plate under the massive walls between axes 4 and 14.
The foundation is fulfilled over the loess-cement layer with thickness 2.0 m.
Schematic cross section of the building structure is given in Fig.1. Fig.2 illustrates the general view of the spent fuel storage building.

![Fig.1: Schematic cross section of the building structure](image1)

![Fig.2: General view of the spent fuel storage building](image2)

LIST OF THE CRITICAL ELEMENTS OF THE CIVIL STRUCTURE

1. Walls and the bottoms of the pools
   The structure of the pools consists of surrounding walls and bottom. They are the most important element of the civil structure of the building. They have to fulfill their function at every possible conditions and loads.

2. Reinforced concrete columns along rows A to G
   The reinforced concrete columns along rows V and G support the roof structure above the pools and support the crane roads for bridge cranes. That is why they are important for pool safety. The columns along rows A and B support the floor structures of auxiliary rooms. The important think is the condition of the joints column-beam and column-wall.
3. Steel roof trusses
   The steel roof trusses are the main element of the roof structure above the pools. As such they are important for the pool exploitation. Particularly substantial is the condition of the joint reinforced concrete column – steel truss.

4. Floor structures
   The condition of the floor structures is important to be evaluated, especially in those rooms where aggressive for civil structures materials are used like solutions for deactivation and so on.

5. Crane girders, rails and joints
   These elements ensure the normal exploitation of the bridge cranes.

6. Hydro-isolation and drainage system
   The protection of the civil structures from unfavorable influence of rain waters and waters with technical origin is of paramount importance to ensure many years exploitation of the structures.

7. Elements of the seismic upgrading
   The elements of the seismic upgrading are important for seismic safety of the building. A big amount of them are in the open space. They are directly exposed to atmosphere influence and naturally ages quickly.

CONDITION OF THE CIVIL STRUCTURES

1. Walls and the bottoms of the pools
   During the visual inspections it was established that the concrete in the walls and the bottoms of the pools work in very favorable conditions. The concrete in the outer walls is protected by air-placed concrete and putty from atmosphere influence. In addition two layered thermal isolation is mounted. Inside the building the walls and the bottoms are protected by epoxy putties which isolate the concrete from contact with the air.

2. Reinforced concrete columns along rows A to G
   The reinforced concrete columns are in good condition. Their surfaces are protected by paint which is favourable from aging point of view. During visual inspections some cracks are detected at levels above crane level – Fig.3. The reason for their appearance is probably dislocation of reinforcing bars from design position or tensile stresses appeared during horizontal excitation. Areas with desorted or stratified concrete are not detected.

3. Steel roof trusses
   The condition of the steel roof trusses is good. Only at several places separation of the protective paint can be seen – Fig.4. This process is more active at places where additional upgrading is performed with reinforcing bars. At these truss elements a tensile stresses appeared after the realization of the welding. These stresses caused deformations which exceeded the possibilities of the cover and some cracks appeared. During the time this process developed and at some places the cover is separated from the metal surface.

4. Floor structures
   Two types of defects are registered during visual inspections – cracks and damages in protective cover. At northern part of the building exists a plate with small cantilever area - Fig.5. Some regular linear cracks are detected.
in this area – Fig.6. Probably the reason is a temperature, because the outside part of the slab is without isolation. At several places at level +0.0 exist some local damages in protective cover of the floors slabs – Fig.7.

5. Crane girders, rails, joints, penetrations and staircases
The condition of the crane girders, rails and joints is good. Additional seismic supports are mounted on the heavy crane, which increase the seismic stability of the crane. The condition of the inspected penetrations is good, there are no traces of leakages, cracks or other defects.
A strong development of corrosion is detected in steel columns of the fire outer staircase – Fig.8. The reason is entering of the rain water inside the box cross section and freezing during winter time.

6. Wall structures
Some regular vertical cracks are registered in rooms between rows A and B – Fig.9. As a rule they appear at crossing of two walls or at joints wall-column. Probably the reason of their appearance is the temperature. At second case the elongation of the two materials (brick masonry and concrete) is different, which leads to separation of the wall from the column.

7. Hydro-isolation and drainage system
Generally the condition of the hydro-isolation of the roof structure is very good. At some places only there is separation of the isolation from the vertical boards. The shafts are clear, without contaminations and with good condition of the ends of the isolation. The hydro-isolation of the boards is fulfilled in two variants. The first one is with galvanized sheet iron, which is corroded everywhere – Fig.11. The second variant is with sheet iron with plastic cover, which is in very good condition – Fig.12. The corresponding detail is more stable and appropriate.
Some clues for leakages are detected at columns at level +12.00 m between rows A and B – Fig.10. The reason for this is some shortcomings at the detail of hydro-isolation of the roof in the area of seismic upgrading.
During the inspections inside the building only one clue for leak (with technical origin) is detected at east part of the pool’s wall.

8. Elements of the seismic upgrading

The steel elements of the seismic upgrading work in very unfavorable conditions. They are directly exposed to the atmosphere influence, which is a precondition for intensive aging. The condition of the protective cover is not good, it is very old and does not protect the metal at all. There are many places with surface corrosion – Fig.13 and some places with intensive corrosion – Fig.14. Some details are designed in a way that they collect rain water and the development of the corrosion is very intensive.
RESIDUAL LIFE TIME EVALUATION

1. Condition of the concrete and reinforcement

The condition of the concrete can be evaluated as very good. From visual inspections of the drilled concrete core samples it is established that they are from healthy compact concrete, without visual cracks, caverns or other defects. The concrete quality is evaluated by nondestructive (in situ) and destructive (in laboratory) methods. The received high values for the compressive strength confirm that the concrete is in very good condition.

The depth of the available carbonation is small and there is no danger for the reinforcement. These results show that the concrete is able to ensure the reliable protection of the reinforcement for a long time.

2. Evaluation of the cracks

Some cracks exist in columns along rows V and G above crane level. These cracks can not be assess like dangerous for the columns but in long term aspect they have to be treated as creating preconditions for appearance and development of corrosion in the reinforcing bars.

Linear regular cracks exist in slab at level +7.20 m in cantilever part. The cracks pass through the cross section of the slab and create preconditions for development of corrosion in reinforcing bars of the slab. The affected area is with small dimensions, located at the end of the room and is without vertical load most of the time. This gives ground to assess that after proper treating of these cracks they will not affect the residual life time for the whole structure.

Some regular vertical cracks exist in rooms between rows A and B. They appear at crossing of two walls or at joints wall-column. Probably the reason of their appearance is the temperature. At second case the elongation of the two materials (brick masonry and concrete) is different, which leads to separation of the wall from the column. The evaluation for these cracks is that they do not hinder the exploitation of the structure for long time period.

3. Evaluation of the reinforced concrete structures

The concrete is able to ensure the reliable protection of the reinforcement, the carbonation is very small. Generally the structures work in good environment. The outer walls of the pools are protected from atmosphere influences by air-placed concrete and putty. Additionally a two layered heat-isolation is mounted. Inside the building the walls and slabs are protected by epoxy putties, which isolated the concrete from contact with the air. The concrete is protected with steel liner in these rooms where different liquid solutions are used. The problem can arise if amount of the solution get into the space between the concrete and the liner. Such incident was registered in the past but after proper rehabilitation the integrity of the structure was restored. Additional repairing measures have been done in underground part of the building in order to eliminate some leakages at walls and floors, caused by underground water.

Based on the results received from the in situ measurements, laboratory tests and visual inspections the condition of the concrete structure can be evaluated as very good.

4. Evaluation of the steel structures

Generally the condition of the steel roof trusses is good. Only at some places can been seen separation of the corrosion and fire protection. This process is more severe at places where additional upgrading with reinforcing bars was performed.

During the visual inspections is established good condition of joint reinforced concrete columns – steel truss and execution according to the design.

The steel elements of the seismic upgrading, which are in the open, are more vulnerable because of the weather factors. Corrosion of the metal is detected at several places. At these places additionally is performed measurement of the depth of the steel. The results confirmed that the main elements still have enough cross sections. Special prescriptions are given to begin urgently total repair of protective cover for all steel elements.

The final evaluation for the steel structures is that they are in relatively good condition. The aging processes are in the beginning and the long term exploitation is possible with periodical repair of protective cover at damaged places.

5. Evaluation of the roof hydro-isolation and drainage system

The final evaluation for the roof hydro-isolation is very good. There are only several small defects – separation of isolation from the vertical board of the roof. The hydro-isolation of the boards is corroded when is built with galvanized sheet iron. The proper solution is a variant is with sheet iron with plastic cover.

There are some clues from leakages from rain water at columns between rows A and B. The reason is some defects at detail for hydro-isolation of the roof in the area of seismic upgrading. It is necessary to fix these defects in order to eliminate the unfavourable influence of the rain water over the concrete of the columns.
The final evaluation is that the condition is good. Some defects are available and they have to be repaired. The question for reliable isolation of the civil structures from the weather factors and especially the rain water is important for aging of the materials and the residual life time evaluation.

6. Seismic safety
The civil structure is classified like structure of first category and is qualified for SSE (Safe Shutdown Earthquake) and local earthquakes. The original structure did not meet these requirements. For this reason additional seismic upgrading was designed and performed.

Conclusion for residual life time for spent fuel storage building
The final conclusion for residual life time for spent fuel storage building is done on the base of complex analysis of all available data. They include the results from in situ and the laboratory tests, visual inspections and analytical investigations. The residual life time for the main building structure is evaluated in the range of 40-45 years. During this period a precise implementation of the monitoring program and the aging management program should be fulfilled.

MONITORING PROGRAM FOR THE STRUCTURE
The monitoring of the civil structures is carried out in two main directions:
- monitoring of the condition of the construction materials – testing and measurements of concrete and steel (reinforcing bars and steel profiles);
- instrumental monitoring of the building – includes the measurement of two main parameters – vertical displacement of different points of the building (geodetic monitoring) and the water level around the building.

AGING MANAGEMENT PROGRAM
The aging management program for the containment structure is composed from several main components [1,2,3]:
- Data base for structural materials;
- Visual inspections in order to control the condition of the civil structure;
- Control on aging processes and reduction of aging effects;
- Recommendations for proper measures for limitation of aging.

Data base for structural materials
The main structural materials used in the spent fuel storage building are concrete, reinforcement steel and steel for metal structures. All available information for material characteristics is advisable to collect in one common data base. It includes the data from the first moment of construction of the structure, all upgradings, repairs and the data from tests (destructive and non-destructive). The big advantage of common data base is the possibility to follow the changes of different characteristics during the time – from the early construction of the building, passing through different periods of its exploitation until the last moment.

The data base must be open, to allow addition of new characteristics since the methods for instrumental investigation have significant development in the last years. New equipment comes into practice which allows the measurement of some new parameters of structural materials.

Visual inspections in order to control the condition of the building structure
The control of the condition of the building structure is conducted by periodic visual inspections. The main goals of the inspections are:
- Establishment of existing defects in the structure like scattered concrete, damaged concrete cover, reinforcement corrosion;
- Detection of cracks in reinforced concrete elements;
- Registration of leakages, inspection of hydro-isolations and drainage systems;
- Choice of suitable places for experimental tests for evaluation of mechanical characteristics of materials (if necessary).

A detailed analysis is done after inspections of all gathered information. It includes evaluation of significance of the detected defects for aging of the whole structure and taking the decisions for proper action (conduction of additional investigations or directly following to repair activity).
Control on aging processes and reduction of aging effects

The control on aging of the reinforced concrete structure is carried on by control of destructive processes in the concrete and corrosion of the reinforcement steel. The degradation of concrete includes cracking of the concrete and chemical reactions in cement paste and aggregates.

The control on aging of the elements of the steel structures is carried on mainly for appearance and development of corrosion.

Recommendations for proper measures for limitation of aging

After analysis of detected defects and evaluations of the residual life time of the civil structure some recommendations for proper measures for limitation of aging are made.

The succession of recommended measures depends on their relative importance for residual life time of the structure. A given priority is suggested for every measure. A three degree scale is used as follows:

- Priority 1: the measure is from first rank importance for RLT of the civil structure. The implementation of the measure must be realized as soon as possible (immediately when is practically possible).
- Priority 2: the measure is important but the implementation can be realized in period of 1 - 1.5 years;
- Priority 3: the measure is important in long term period and the implementation can be realized in period of 1.5 - 2 years.

CONCLUSIONS

Analysis of aging processes is carried out and the residual life time for spent fuel storage building is evaluated. For this purpose different factors and aging mechanisms are considered. The data from the in situ and laboratory tests are analyzed and summarized. Based on the received results and available technical information an evaluation for the condition of the reinforced concrete structures and steel structures is done.

Different parts from the Program for monitoring and Aging Management Program are examined. Specific issues for instrumental monitoring and control of aging processes of structure are commented. Proper measures are suggested for reduction of unfavourable aging effects. These measures represent very important part of Maintenance Program.

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