# CONDITION ASSESSMENT OF CANDU 6 CERNAVODA UNITS 3 & 4 CIVIL STRUCTURES

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## ABSTRACT

Safety-related Nuclear Power Plant (NPP) concrete structures shall be designed and constructed in such a way that, under the expected environmental influences, they maintain their strength, serviceability, durability and acceptable appearance during an explicit or implicit period of time without requiring unforeseen high costs for maintenance and repair, CEB-FIP Model Code (1990).

The purpose of this paper is to provide condition assessment of the NPP Cernavoda Units 3 and 4 existing civil structures and to ascertain that the constructed civil structures meet the functional and performance requirements stipulated in the design requirement documents. The strategy and plan for this condition assessment are primarily based on the reference design dated in the early 1980's against the current codes and standards complemented with site inspection and testing; and gap analysis and design spot checks as described in the paper.

A compliance assessment of the Reference Design against requirements in current Canadian Standard Association (CSA) nuclear standards N287.1-93 (1993), N287.2-08 (2008), N287.3-93 (1993), N289.1-08 (2008) and N291-08 (2008) has been carried out in order to identify major design changes potentially required to the Reference Design.

The purpose of the site inspection and testing assessment was to conduct visual inspections; geometric surveys, Non Destructive Examination (NDE) testing, destructive examination (concrete core sample testing and pre-stressed beam testing) and miscellaneous laboratory tests that were undertaken for all structures at the site.

In addition, gap analysis and design spot checks were carried out. The most critical of the partially built structures are the Unit 3 and 4 reactor buildings (RB) and in particular the prestressed containment structure. The purpose of the gap analysis and design spot check assessment is to evaluate the structural suitability of the existing Cernavoda Unit 3 and 4 RB containment structures and internal structures to meet the new design criteria including new Design Basis Earthquake (DBE).

The inspection and testing results confirmed that the material properties of the investigated structures are in accordance with or exceed the design specifications. The gap analysis and design spot checks of the structures indicate that they have the required capacity against the major failure modes under the new design basis. Strengthening of some structural steel members, however, may be needed.

## INTRODUCTION

Aging of reinforced concrete structures due to service conditions, aggressive environments, or accidents may cause their strength, serviceability and durability to decrease over time. As a part of Plant Life Management (PLiM), in addition to structural evaluation, condition assessment including regular and systematic inspection of the structures and all its components are provided during the intended plant life through an Ageing Management Program (AMP). The Cernavoda Nuclear Power Plants (NPPs), located in Romania consists of four CANDU 6 units. Units 1 and 2 were completed and are now operating nuclear power plants (see Figure 1). The construction of units 3 and 4 was stopped in the early 1990s resulting in a series of buildings at various stages of completion.

Taking into consideration the status of civil completion, the objectives of the assessment of existing civil assets during the Pre-Project phase of Cernavoda Units 3 and 4 were to:

a) Assure licensability of the C3&4 NPPs through detailed verification and documentation of:
   1) Status of civil works completion;
   2) Compliance with the Licensing Basis Document
   3) Compliance with design documentation;
   4) Quality of work and suitability for use during the stipulated service life of the plant.
b) Identify and detail/define the rehabilitation works required for compliance with the design documentation based on the inspection and testing performed at site and laboratory.

Figure 1. View of Cernavoda Nuclear Power Plants

## ASSESSMENT OF THE REFERENCE DESIGN AGAINST THE CURRENT CODES, STANDARDS AND REGULATORY DOCUMENTS

Codes, standards and regulatory requirements applicable to CANDU 6 nuclear reactor design have undergone substantial national and international development from the editions used for the Cernavoda Nuclear Power Plants (NPPs) in the mid 1980s. As part of the Pre-Project Phase scope of work for the Cernavoda NPP Units 3 and 4 Project, the existing plant design is required to be assessed against certain codes, standards and regulatory documentation to identify potential design changes that may be required for Units 3 and 4; assessments committed are high level and not detailed compliance assessments.

This assessment provides the methodology, for reviewing the Canadian and Romanian codes, standards, and regulations, for the assessment of the Reference Design of the Cernavoda NPP Units 3 and 4. The assessment is intended to identify the potential design gaps in plant design where Reference Design does not meet the current requirements and to propose design changes, where required, to bridge the gaps in design.

A two-stage approach is adopted for the assessment of compliance to codes and standards. First stage is to perform a screening of the codes, standards and regulatory documents to identify those that warrant further review and those that are not expected to result in design changes. The second stage of this methodology is to provide guidance on how each detailed review of Reference Design against the requirements is to be carried out.

The objective of this assessment is to provide evaluation of the CSA Civil standards that have any impact on Reference Design for the Cernavoda NPP Units 3 and 4. The assessment is intended to identify the potential major gaps in plant design where Reference Design does not meet the current requirements and to propose design changes, where required in order to fulfill the gaps in design.
The CSA civil Standards outline established practices for the general requirements, material requirements and design requirements, construction, installation, inspection, testing and documentation for CANDU Nuclear Power Plants (NPPs). The scope of this assessment report focuses on the gap of ` the analysis and design requirements when compared with the reference design with the new CSA codes and standards mentioned below. The CSA standards selected for review include N287.1-93 (1993), N287.2-08 (2008), N287.3-93 (1993), N289.1-08 (2008), N289.35-10 (2010) and N291-08 (2008).

The concepts and design requirements sections of the CSA Civil Standards were reviewed to identify more significant changes to the reference design standards. The significant changes may be one of the following:

- Change in general requirements,
- Change in specific quantitative requirements, or
- Addition of new quantitative requirements.

### *Concluding Remarks from Reference Design against the Current Codes and Standards*

- Except CSA Standards N287.3-93 (1993), Design Requirements of Concrete Containment of CANDU Nuclear Power Plants, N289.1-08 (2008), General Requirements for Seismic Design and Qualification of CANDU Nuclear Power Plants, and N291-08 (2008), Requirements for Safety Related Structures for CANDU Nuclear Power Plants, other CSA Standards have no major impacts for the purpose of gap analysis and design changes.
- Since the CSA N291-08 (2008), Requirements for Safety Related Structures for CANDU Nuclear Power Plants is the first edition of this standard and did not exist at the time of Cernavoda Units 3 and 4 projects, the requirements of this standard shall be considered for safety related structures.
- The CSA Standard N291-08 is primarily influenced by CSA Standards A23.3-04 (2004), Design of Concrete Structures and S16-09 (2009), Design of Steel Structures. According to these two standards the design of the structures shall meet the Limit States Design requirements. The existing civil

structures in Cernavoda nuclear power plants were designed based on Working Stress Design methodology.

- The CSA N289.1-08 (2008), General Requirements for Seismic Design and Qualification of CANDU Nuclear Power Plants, has been restructured, revised extensively and a significant number of changes have been incorporated since the 1980 edition.
- The CSA Standard N287.3 (1993), Design Requirements of Concrete Containment of CANDU Nuclear Power Plants, is basically founded on CSA Standard A23.3-04 (2004), Design of Concrete Structures. Therefore, the requirements of CSA A23.3-04 (2004) shall be met.
- The CSA Standard N287.3-93 (1993) has undergone substantial development since 1978 and 1982 editions. The development of the design requirements is mainly due to the development of CSA Standard A23.3 from 1970 to 2004 editions. In addition one of the other major changes appears in CSA Standard N287.3-93 (1993) includes load combinations, load factors and concrete temperature limitations.
- The CSA Standard A23.3-70 (1970) is primarily based on Working Stress design while the current CSA Standard A23.3-04 (2004) is based on Limit States Design requirements.

## SITE INSPECTION AND TESTING

The scope for the site inspections and tests is to obtain sufficient information to define the current conditions and any aging degradation mechanisms that may be present for the existing civil structures.

The information required for assessing a structure's condition and fitness for service are as follows:

- Design information
- Material information
- Construction information
- Information/details defining the current condition
- Information/details of active aging mechanisms

### *Pre-Project Work Plan and Methodology*

A systematic approach was carried out for the inspections and tests to be conducted to obtain the required information, on which a sound civil condition assessment can be based.

The method for assembling the data and information for the civil structural assessments of Cernavoda Units 3 and 4 consists of the following steps:

- Existing documentation review
- Preparation of master list/inventory
- Geometry Surveys
- Visual inspections
- Tests (NDE, DE and including laboratory testing)
- Interviews with site staff

#### *Existing documentation review*

The documentation for the Cernavoda Units 3 and 4 civil structures includes drawings, specifications, mill test reports, calculations, geotechnical investigations and foundation reports, standards and codes in effect at the time of construction, construction records including QA/QS, records of alterations made to the buildings, information on original materials, site records, and records of previous inspections if any.

***Preparation of master list/inventory and geometric surveys***

The inventory/master list contains all the existing structural members of reactor buildings, other buildings and hydro circuit buildings for example containment walls, , baseslab, ring beam, dome, floor slabs, beams, columns, etc. The purpose of the geometric surveys is to determine the as built geometry of structural and non-structural components to demonstrate compliance with the design, and to determine whether there are any significant settlement, and or differential movements of buildings, major/critical structural components that may signify construction errors and/or ageing related deterioration.

***Visual inspections***

The purpose of the visual inspections is to assess the status of completion and to detect the material and structures' defects (ageing effects, cracking, honeycombing, spalling, *etc*). Once the visual inspection of an element/structure is completed, the need for a testing program can be confirmed and finalized. The entire surface of the important to safety related structures were visually inspected for example containment walls, ring beam, base slab, dome etc. Figure 2 shows the scaffolding arrangement was used around exterior surface of the rector building.

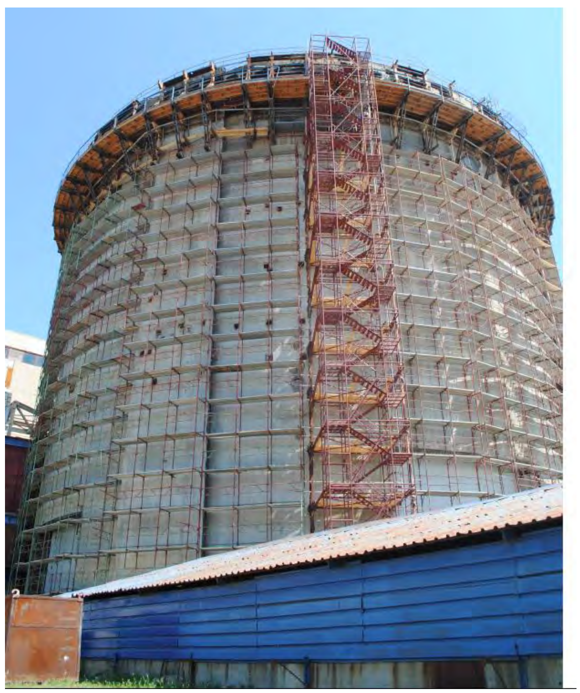

Figure 2: Scaffolding Arrangement Around Containment Wall

***Tests***

The purpose of testing is to obtain useful quantitative and qualitative data for the determination and verification of chemical and physical properties, and the physical conditions of the structural elements. Test methods used can be divided into 2 groups: Non- Destructive Examinations (NDE) and Destructive Testing. Non-destructive methods, while useful in determination of physical properties of structural elements, are generally used to establish physical conditions and extent of deterioration of structural members and systems. Depending upon equipment, results for determination of elastic properties are usually more accurate than those for determining other physical properties. Most nondestructive methods require highly qualified and skilled personnel, specialized equipment and considerable analysis and interpretation of data to develop qualitative and quantitative information. It was very fortunate that during the construction of the containment structure a number of temporary structures were built using the same concrete mix and curing as of the concrete of the containment structure so core sample taken from these temporary structures could give exact characteristics of the concrete of the containment structure.

Although destructive tests require the removal of test specimens without cutting rebar, careful selection and handling can ensure that the usefulness of the member is not impaired and that the damaged areas can be satisfactorily repaired. Tests on specimens provide specific, quantitative information without the requirement of questionable analyses and interpretation of results. Wherever and whenever possible, precedence should be given to physical testing of specimens over nondestructive testing methods to determine similar information. It is also advantageous to use the results of tests in specimens from members as base data to correlate nondestructive testing programs.

#### *Interviews with site staff*

The objective of personnel interviews is to ensure that the information already obtained is complete and to obtain any additional information that will assist the structural assessment of the civil structures, and will aid in evaluating aging degradations. The interview also provides any special construction process details that may have bearing on the suitability of the structures.

### *Concrete Core Test Results*

Both CSA A23.1 (2009) and BS EN 13791 (2007) specify the acceptance criteria for concrete compressive strengths obtained from the core samples. Figure 2 shows the requirements for minimum and average accepted concrete strength with respect to the design strength. Figure 3 shows the results from the core samples taken from two different structures, Unit 3 RB Internal structures and Unit 4 turbine building. The concrete class of internal structure was C32/40 with the specified design concrete cylindrical compressive strength of 32 MPa while the concrete of the turbine building has a concrete class of C18/22.5 with the specified concrete cube compressive strength of 22.5 MPa. As can be seen from these figures both internal walls and turbine building have significantly higher concrete strength than the CSA and Eurocode requirements.

## *Test Beam*

The test beams were prepared during the construction of the reactor building containment structures. The purpose of the test beams is to monitor the behaviour of pre-stressing systems of containment structures. The cracking and collapse test were performed on the test beams. In addition, core samples were taken for laboratory testing.

The test results show that the concrete characteristics, reinforcement bars, pre-stressed wires, injection grout and the adherence are in good condition and acceptable.

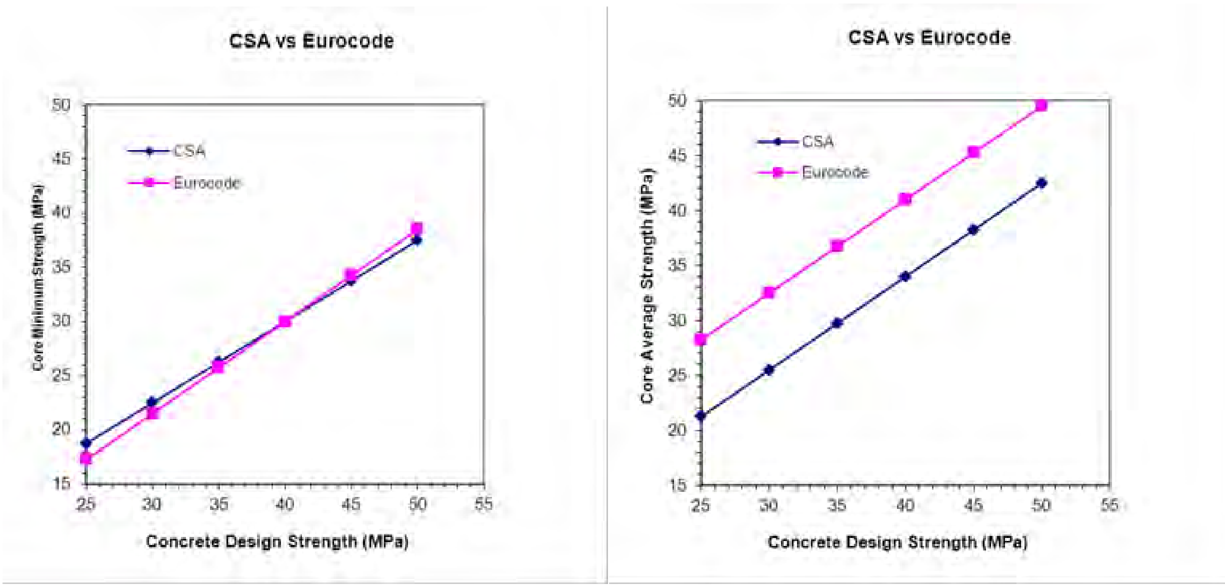


Figure 2. Acceptance criteria for minimum and average concrete core sample tests

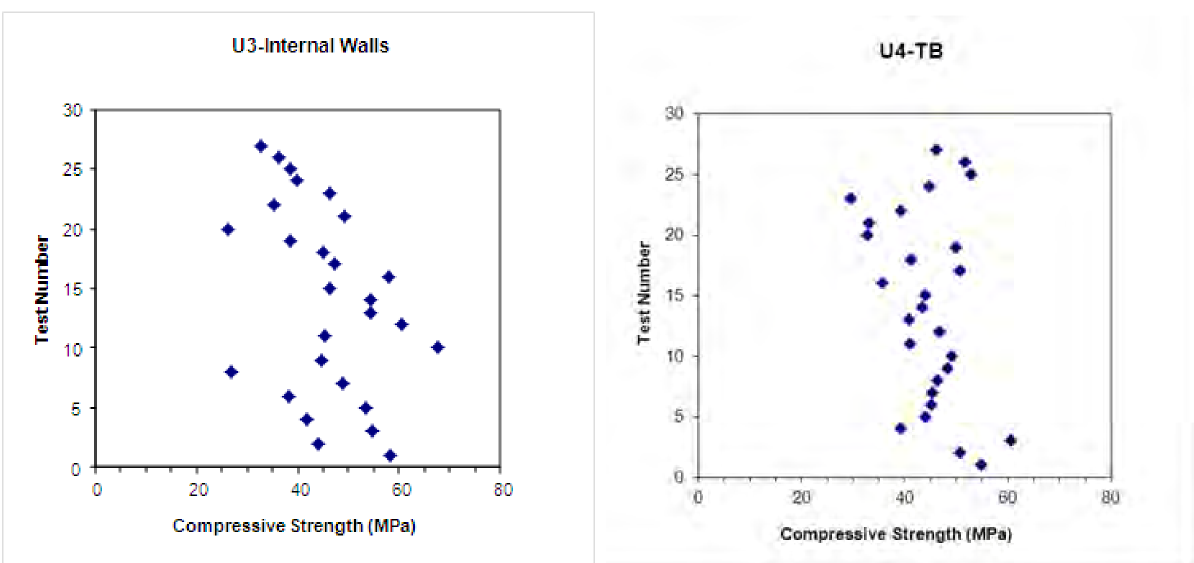


Figure 3. Concrete core sample test results from Unit 3 internal walls and Unit 4 turbine building

***Concluding Remarks***

The inspection and testing includes visual inspection, geometric surveying, and testing of various material parameters. The inspection and testing results reveal that the material properties of the investigated structures are in accordance with or exceed the design specifications.

The main conclusions are as follows:

- Based on the visual inspection and testing of concrete and steel structures of Reactor Building, the quality of the concrete in the sub-base, base slab, tendon gallery, perimeter wall, lower dome, calandria vault, spent fuel transfer bay and internal structure is normal and acceptable.
- The concrete tests for Units 3 and 4 R/B containment structures were carried out based on NDE test and are satisfactory. All the destructive tests completed for all other structures are satisfactory.
- The existing civil assets of the Units 3 and 4 are sound with a very minor sign of deterioration which does not pose concerns on building safety function. It should be noted that the existing concrete assets have been tested after almost 24 years of environmental exposure and the nonconformities found are normal and in acceptable limits provided implementing the recommendations stated in the Rehabilitation reports. These nonconformities found during the testing and inspection program are similar to Units 1 & 2 where they were successfully dispositioned and resolved.
- The existing embedded parts, reinforcing bars and dowels that are exposed to atmospheric elements are slightly rusted.
- The calandria vault steel liner and embedded parts of Units 3 and 4 are slightly rusted.
- The calandria steel liner meets its design requirements and can be used as intended by design in the future assuming the repairs will follow the quality and the recommendations provided in Rehabilitation report.
- The existing non-conformance in the Unit 3 R/B ring beam has been confirmed during the current geometric surveys and visual inspection. Five possible remedial solutions have been investigated and a recommendation has been made to remove the ring beam in its entirety.

## GAP ANALYSIS AND DESIGN SPOT CHECK

The purpose of the gap analysis and design spot check is to present the assessment of the structural suitability of the existing Cernavoda Unit 3 and 4 civil structures under the new design criteria. The civil structures include:

***Reactor Building:***

- Containment Structure
- Internal Structure

***Other buildings:***

- Service building (SB);
- High Pressure Emergency Core Cooling (HP-ECC) building;
- Emergency Water Supply (EWS) pumphouse.

The following BOP buildings are also included in this assessment:

- Chiller building;

- Standby diesel generator (SDG) building.
- Turbine building (please check?)

Additionally, a qualitative structural assessment of the integrated building is performed.

As indicated earlier, the gap analysis and design spot check was carried out under the new design criteria. These new design criteria include:

- New design codes and standards. These are the applicable Canadian and Romanian codes and standards as of October 31, 2009;
- New construction schedule. The original construction schedule needs to be updated because of halting the construction of the partially completed reactor buildings for more than 20 years;
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The purpose of the assessment is:

a) To evaluate the capability of the existing Units 3 and 4 civil structures (stated above) to withstand their functional and performance requirements based on the applicability of the latest codes and standards;

b) To evaluate the gap between the applicable code editions used in the reference plant design (i.e., Cernavoda Unit 2) and the editions of the same codes as of October 31, 2009.

The assessment describes the applicable design criteria, procedures and main findings of the conducted analyses and design spot checks. Recommendations are made in order to provide remedies in the needed areas. The gap analysis and design spot checks for the present assessment have been performed for the critical load cases and using the critical load combinations.

***Concluding Remarks***

The results from the Units 3 and 4 civil structural analysis are, in generally, in agreement with the analysis of the reference plant. As an assessment strategy, it should be noted that the increased concrete strength that has been measured during the site inspection activities and the higher strength of the substitution reinforcement steel used in the construction of Cernavoda Units 3 and 4 were used during the analysis.

In particular, the main conclusions from the present assessment of the RB containment structure and internal structures are the following:

- For the majority of the checked structural sections, the code requirements for section capacity and serviceability are met under the new design basis.
- The RB stability with respect to overturning meets the code requirement in all cases with acceptable level of confident.
- The soil bearing pressure under the RB sub-base for the higher seismic load of the new design basis is below the allowable bearing pressure.

It is expected that a more detailed analysis with respect to RB geometry, modelling techniques, soil-structure interaction, magnitude of time-dependent and temperature-dependent loads, etc. will result in forces within the strength capacity for all containment sections.

## CONCLUSIONS

The inspection and testing results confirmed that the material properties of the investigated structures were in accordance with or exceed the design specifications. The gap analysis and design of the structures indicate that they have the required capacity against the major failure modes under the new design basis. Strengthening of some structural steel members, however, may be needed.

The assessment showed that the functional and performance requirements of the structures will be met in full even if the latest codes and standards are applied.

In summary assuming that these structures would be subjected to design operation conditions, they are suitable for their intended purpose (as defined in the technical specifications) and should be able to have further 50+ years life, without any serious deterioration, provided recommended remedial works are implemented.

## REFERENCES

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