Transactions, **SMiRT-26**
Berlin/Potsdam, Germany, July 10-15, 2022
Division VI

AFCEN RCC-CW CODE: 40 YEARS OF NUCLEAR INDUSTRIAL EXPERIENCE IN THE DESIGN AND CONSTRUCTION OF SAFETY CLASS CIVIL STRUCTURES

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ABSTRACT

Since 1980, AFCEN (the French Association for Design, Construction and In-Service Inspection Rules of NPP Components and Structures, www.afcen.com) has been developing and publishing design codes for the French nuclear industry. The paper provides an overall presentation of the AFCEN code dedicated to civil structures design and construction, the RCC-CW code. It shows some highlights on the recent developments on anchors, deep foundations, and ageing management. It also addresses the ongoing assessment of this nuclear building code by the European Committee for Standardization (CEN).

INTRODUCTION

Since 1980, AFCEN (the French Association for Design, Construction and In-Service Inspection Rules of NPP Components and Structures, www.afcen.com) has been developing and publishing design codes for the French nuclear industry. AFCEN provides codes in different nuclear fields (mechanical and electrical components, civil engineering, nuclear fuel, fire protection). Beyond the scope of PWR, it can be noted that AFCEN RCC-MRx code encompasses high temperature reactors, experimental facilities, and fusion power plants. Today, more than 100 nuclear power plants (NPP) in the world have been designed and built using AFCEN codes, including projects in France, Korea, China, South Africa and in the UK.

Each code is developed, updated, and published by a dedicated sub-committee, composed of members of major companies and organizations in the nuclear energy sector. The 55 members of the AFCEN sub-committee dedicated to Civil Engineering oversee the approval of new proposals and modifications put forward by 8 working groups, each of them responsible for improving a different part of the code. More than 200 active members are working within these working groups.

Concerning civil structures, successive editions of AFCEN codes have been developed (Figure 1). The knowledge and operational experience gained during the construction of the EDF fleet in the 70' and the 80' was captured in the RCC-G code (RCC-G, (1980)).

Release	Description	Key applications
1988	AFCEN document including French PWR fleet experience (RCC-G 1988)	French 1300, 1450 MWe
2010 2012	Prepared for UK GDA process in 2010 Revised in 2012	HPC, SZW
2015 2016 2017 2018 2019 2020 2021	Renewed edition : -post-Fukushima level & methods -improvements & updates -extensions of scope	Updated editions to be used as reference for New Build Projects.

Figure 1. Overview of AFCEN RCC-CW Series for civil structures.

The EPR Technical Code for Civil works (ETC-C, (2012)), published by AFCEN, contains rules for the design, construction and testing of the EPR civil engineering structures, focusing on safety class 1 structures. It describes the principles and requirements for safety, serviceability and durability conditions for concrete and steelwork structures on the basis of Eurocode design principles (European standards for structures) together with specific provisions for safety-class buildings. The ETC-C may be used as a basis for contractual relations between clients and contractors, and in relations with nuclear safety authorities. ETC-C incorporates all relevant proposals coming from the experience gained on several projects: technical discussions along the Generic Design Acceptance project of UK EPR Project, experience gained by members through their involvement in Olkiluoto, Flamanville and Taishan Projects and first lessons learnt from 2011 Fukushima Daichi accident as presented in Gallitre et al., (2013).

In 2015, the development of a new update of the AFCEN code, known as RCC-CW, has been launched. The reasons for drafting this new version were as follows:

- It was necessary for new NPP Projects to comply with requirements from international regulations and practices. A specific care has been applied to better address Design Extension Conditions and Hazards (DEC and DEH) in terms of load cases and design criteria,
- The RCC-CW is not limited to EPR design and this code can be used for the design of other PWR civil structures,
- New design situations and loads were required (for more severe hazard conditions),
- Updated operational experience feedback from operating nuclear power plants as well as current updated safety analysis requirements had to be considered.

The present paper provides an overall presentation of the RCC CW code shedding light on:

- The completeness and the consistency of the code,
- The anchors systems for which an extensive set of requirements covers a wide variety of technologies,

- A first set of consistent requirements FOR Deep foundations design,
- Some recommendations for managing ageing of civil structures, which is a recent enhancement dedicated to recommendation for Long Term Operation,
- The ongoing assessment of the RCC-CW by the European Committee for Standardization (CEN) developed through a Workshop Agreement (CWA) since 2014.

RCC CW OBJECTIVES AND CONTENT

RCC-CW contains rules for the design, construction and testing of the NPP safety-classified civil engineering structures. It describes the principles and requirements for safety, serviceability and durability conditions for elements considered as a part of civil works such as soil, prestressed and reinforced concrete works, steelworks, liners, anchorages and containment testing and monitoring. Table 1 gives an overview of RCC-CW content.

Table 1: Content of the RCC-CW code

Part	Chapter acronym	Chapter scope
PART G General	GUSER	Note to the user
	GTABL	Table of content of RCC-CW
	GREFD	Reference Documents
	GDEFN	Definitions, notations, abbreviations
	GGENP	General Provisions
	GA	Appendix
PART D Design	DGENR	General requirements
	DGEOT	Geotechnical
	DCONC	Concrete Structures
	DCLIN	Containment liner
	DPLIN	Pool and tank liner
	DSTLW	Structural steelwork
	DANCH	Anchor systems
	DA to DM	Part D Appendices
PART C Construction	CGEOT	Geotechnical
	CCONC	Concrete
	CFNSH	Surface Finishes
	CREIN	Reinforcement for RC
	CPTSS	Post tensioning systems
	CPREF	Prefabricated concrete elements
	CCLIN	Containment liner
	CPLIN	Pools and tanks liner
	CSTLW	Structural Steelwork
	CANCH	Anchor systems

	CBURP	Buried RC Pipelines
	CJOIN	Joint sealing
	CCOAT	Coating and paints
	CGEOM	Geomembrane lining system
	CTOLR	Tolerances, survey and monitoring
	CCONT	Containment tests (ISIT and ILRT) and monitoring
	CA to CI	Part C Appendices
PART AM Ageing management	AMGENR	General considerations
	AMGEOT	Structures in interaction with the ground
	AMCONC	Reinforced concrete structures
	AMCONT	Containment structures

All the main aspects of design and construction of civil structures of a standard PWR power plant are addressed in the RCC-CW. One can see in Table 1 that special attention is drawn to the consistency between the different chapters of Part D, C and AM, even if the latest in not completed yet. Regarding the design, most of the rationale of RCC-CW relies on the generic approach proposed by the Eurocodes. More specifically, Eurocodes 0, 1, 2, 3 and 7 are considered for dealing with the following topics:

- Definitions of actions,
- Development of loads combinations,
- Rules relative to reinforced and prestressed concrete structures, anchorages, and steel frameworks,
- Rules relatives to geotechnics and soils conditions.

It should be noted that RCC-CW requirements for seismic design do not use the European standard Eurocode 8. In particular, the notions of behaviour coefficient and ductility class are not involved in the Appendix devoted to seismic analysis.

Moreover, RCC-CW provides specific rules and requirements for the technologies and activities which are not addressed by the Eurocodes: steel liner for pools and containment, some anchorage systems, specific hazards and actions, or containment monitoring (Courtois, (2015)).

The part dedicated to construction is mostly based on European and French standards for current building, enhanced and adapted to the nuclear context.

The 2020 and 2021 editions of the RCC-CW (RCC-CW, (2021)) encompasses several new developments regarding anchorages, deep foundations, and ageing management, which are introduced in the following sections.

REQUIREMENTS FOR ANCHORS SYSTEMS

RCC-CW contains a dedicated chapter for the design of anchor systems (DANCH) and a dedicated chapter for the construction of anchor systems (CANCH). These two chapters aim to design and build anchorages for safety classified non-structural components and systems (NCS).

Anchorages are a complex interface between the NCS, their supports and the concrete structures. The design of each part is made in different codes and standards without link between each other. In

addition, some anchor technologies are supplied according to European technical specifications, e.g., the European Assessment Document 330232 “Mechanical fasteners for use in concrete” and the European Assessment Document 160004 – “Post-tensioning kits for prestressing of structures”. RCC-CW makes the connection between these different documents, to help the engineers perform a proper design. Construction requirements are given to ensure that the anchorages fulfil their intended use on site.

RCC-CW continually evolves to clarify the requirements for anchorages and include more anchor technologies. In 2021, the most important modifications were the following:

- New rules for the design shear connectors (shear lugs),
- New rules for the design and construction of anchorages with T-head bolts (see Fig. 2).

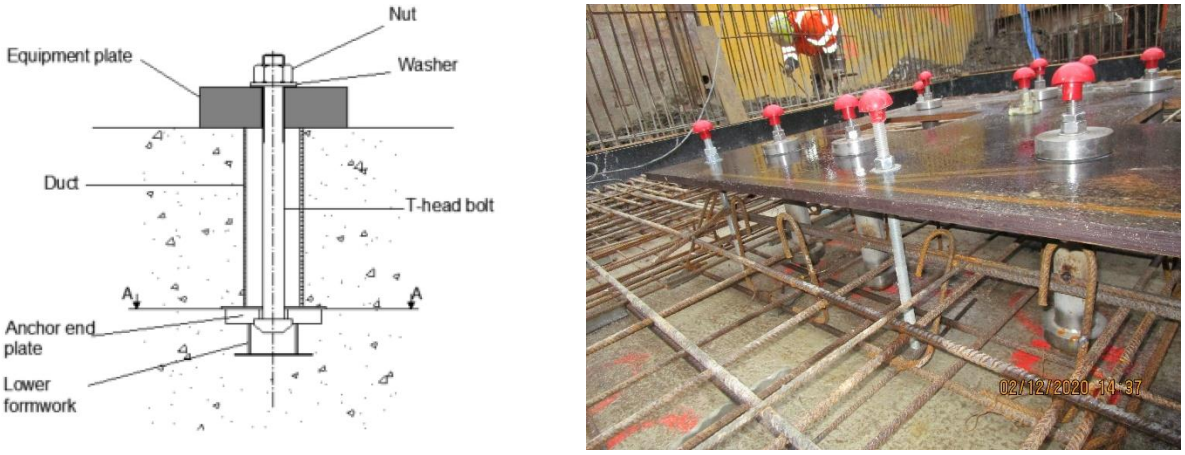

Figure 2. Illustration of anchorages with T-head bolts

Shear connectors and T-head bolts are not covered by current standards. Thus, there was a need to describe their specific failure modes and give the requirements associated to these technologies for safety classified NCS anchorages. In addition to shear connectors and anchorages with T-head bolts, RCC-CW now includes anchorages with headed studs, cast-in headed anchors specifically manufactured, post-installed anchors (torque-controlled, undercut), anchor channels and prestressed anchors.

These improvements make RCC-CW one of the most complete existing code for the design and construction of anchorages.

REQUIREMENTS FOR DEEP FOUNDATIONS

The purpose of the new section DGEOT 7000 related to the design of deep foundations, is to offer the designer another option for founding safety-related buildings on lesser quality grounds or grounds with underground networks.

Whereas the design of the deep foundations under permanent loads is well standardized (Eurocode 7, completed by European and French norms), there are few references or normative documents for their design in seismic situation. Moreover, few nuclear buildings are based on piles. Therefore, there was the need to define a framework for the design of piles under seismic loading, specific to the nuclear industry.

The redaction took place within the Working Group 2 in charge of the sections regarding the geotechnical design (DGEOT) and construction (CGEOT). In support to the text, a benchmark on the direct method has been carried out within the working group, gathering eight teams using six different numerical softwares.

Piles are generally not inspectable nor repairable during the plant operational lifetime. Therefore, the durability of their performances must be insured from the beginning, by the design and the quality control of the construction.

On top of the design rules of the Eurocode 7, the RCC-CW add some requirements to insure the robustness of the design:

- The exclusion of some type of piles like, for instance: inclined piles, prefabricated concrete piles, piles whose construction requires that the reinforcement cage be driven into the fresh concrete previously poured in the borehole (hollow auger type...),
- Special warnings are expressed for specific situations: piles in tension or horizontally loaded by the ground in quasi-permanent situations,
- A design such as the behaviour of the piles remains in the elastic domain, including under seismic loading (non-linearities in the ground are allowed). Other requirements aiming at ensuring the durability of the piles, relate to the concrete quality, the stress threshold in the rebars and concrete, etc,
- The mandatory implementation of static load tests.

The different aspects of the design of the piles in permanent, transient, accidental, and seismic situations are addressed in the RCC-CW; for example, the material properties of both the ground and the piles, the methods of justification of the limit states, the way to account for the group effect… In seismic situations, both the direct method and the sub-structuring method are described, and for the direct method, linear and non-linear ground can be considered. Figure 3 summarizes the sections in the code which are specific to the design under seismic loading.

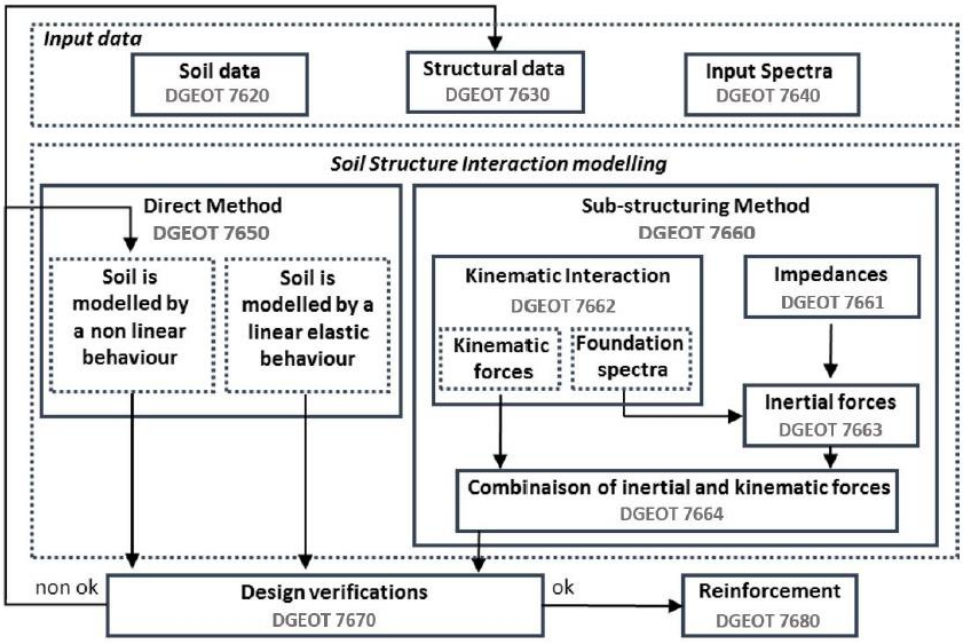

Figure 3. Organization of the different sections of DGEOT regarding the seismic design of deep foundations.

The DGEOT 7000 chapter ends by a section dedicated to the verification of the piles in the Design Extension Domain. It authorises to consider some realistic behaviours such as:

- The passive thrust of the soil against the buried vertical faces of the pile-cap, which may be accounted for under certain conditions,

- Inelastic deformations of the piles, which may be tolerated within strain limits provided in the code.

Finally, in the construction part of the RCC-CW, the CGEOT chapter has been completed by requirements based on the European standard EN 1536 regarding execution, tolerances, type and number of controls to be carried out on the piles.

A NEW PART DEDICATED TO AGEING MANAGEMENT

Before 2020, AFCEN codes for civil works did not address Ageing Management requirements in operation, except for concrete containment (part 3 or part M of the code releases before 2020). For about a decade, Long Term Operation (LTO) has become a concern for nuclear operators with the publication of international guidelines for LTO, such as IAEA NS-G-2.12 or SRS n°82 (IGALL report). In Europe, a part of these recommendations is covered by technical specifications used for in-service inspection (ISI).

AFCEN decided to make a bridge between IAEA standards and operational technical specifications to enhance the design quality and to enable or to facilitate the substantiation regarding LTO, by creating a new section in the code for Ageing Management (AM). This part is composed of a general chapter AMGENR, complemented by other chapters which describe requirements for different civil work topics:

The chapters currently proposed in the RCC-CW 2021 are the following:
- AMGENR: general requirements,
- AMGEOT: application to geotechnical structures,
- AMCONC: application to reinforced concrete structures,
- AMCONT: application to prestressed containment structures.

Currently, a new chapter about coatings and paints is under preparation (AMCOAT). This chapter should be published in the 2022 edition. The content of this future chapter has already been considered for the design of spent fuel long term storage facility in France.

The general chapter AMGENR sets out the general methodology to be implemented to manage the ageing of civil engineering structures. The main requirement of this general chapter is related to the organizational structure that shall be set up by the operator. The main items covered by this general chapter are the following:
- Description of the objectives of ageing management,
- Description of functional requirements for civil engineering,
- Description of systems, structures and components concerned,
- Description of the structure of the documentation and its content, based on several levels of documents:
    - General documents to set the strategy,
    - Ageing management programmes,
    - Operational documents for implementation of the programmes,
    - Documents allowing the global demonstration of the control of ageing,
- Classification of defects,
- Data collection and record keeping.

The Ageing Management chapter dealing with concrete structures, AMCONC, has been added to the RCC-CW in 2021. The main items covered by this chapter on concrete structures are the following:
- Description of ageing mechanisms for concrete and reinforcement,
- Inspection and verification methods for concrete structures, with a table that links ageing mechanism to inspection methods,

- Period of Inspection,
- Evaluation of inspection results,
- Handling of deviations and observations,
- Treatment-repair of defects.

The different ageing mechanisms that are being considered, linked to their identification method are presented in Table 2.

Table 2: Ageing mechanisms of concrete and reinforcement

Ageing mechanism	**Identification methods**	
	Visual inspection	**Monitoring and trending**
Cracking of concrete	X	(X)
Shrinkage / Creep	X	
Alkali-silica reaction	X	X
Delayed Ettringite Formation	X	X
Leaching	X	
Chemical attack	X	X
External erosion	X	
Freeze-Thaw	X	
Thermal exposure	X	
Corrosion caused by carbonation or chloride attack	X	X

CODE ASSESSMENT BY THE CEN WORKSHOP 64

In January 2019, AFCEN kicked off Phase 3 of the CEN workshop on "design and construction codes for mechanical equipment of innovative nuclear installations" (CEN/WS 64). Through this 3-year partnership with the European Committee for Standardization, AFCEN intends to bring stakeholders up to speed on the standardization process in the European nuclear industry through AFCEN's codes while learning how to adapt their local regulatory framework to simplify the use of reactors modelled on AFCEN's codes, or how to gear the codes towards their specific needs and requirements. The participation of certain safety authorities and technical safety organizations (TSOs) in the workshop is conducive to improving mutual understanding of the technical foundations that underlie the design and construction rules for nuclear power plants and adapting them to suit the different national regulations.

RCC-CW is part of the codes being assessed in WS64 Phase 3. This assessment is made by the Prospective Group 3 (PG3), under the lead of the Finnish regulator (STUK). Germany, Switzerland, The UK, Sweden, Finland and France have joined this expert's group and are working on different topics such as seismic analysis (reinforced concrete shear walls, raft uplift), aircraft impact (induced vibrations, concrete punching, simplified methods), robustness of nuclear structures, spent fuel and containment liner design, anchor systems design and ageing management.

Currently, formal code evolution recommendations and R&D actions proposals are being prepared by the different PG and will be send to AFCEN before the end of 2022. AFCEN will examine them and will provide a feedback to the CEN/WS 64 on their possible consideration in the concerned codes.

CONCLUSION

RCC-CW provides, in a single standard, an up-to-date and consistent set of relevant requirements and guidelines for civil structures design and construction to carry out a nuclear power plant project. The about

two hundred RCC-CW subcommittee members are seeking to improve this code, in an ongoing effort to update the content, by incorporating operation experience gained by previous projects in France and overseas. Moreover, an overall assessment is currently undertaken by the European Committee for Standardization (CEN), which is also a beneficial source of evolution for the code.

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