Transactions, SMiRT-22
San Francisco, California, USA - August 18-23, 2013
Division X (Challenges of New Reactors)

LESSONS LEARNED DURING U.S. CONSTRUCTION OF NEW REACTORS: A STRUCTURAL ENGINEERING PERSPECTIVE[1]

Mohamed Shams[1], Bret Tegeler[2]

[1] Chief, Structural Engineering Branch, Office of New Reactors, Division of Engineering, U.S. Nuclear Regulatory Commission, USA
[2]Senior Structural Engineer, Office of New Reactors, Division of Engineering, U.S. Nuclear Regulatory Commission, USA

ABSTRACT

The objective of this paper is to discuss recent lessons learned from the U.S. Nuclear Regulatory Commission's (NRC's) review of applications for license amendments in the structural engineering area from a regulatory perspective. The paper describes the Title 10 of the *Code of Federal Regulations* (10 CFR) Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants," design-change process and makes recommendations for improving the quality of technical justifications supporting design changes. For a proposed design change, the paper discusses the need to adequately justify the proposal to ensure the safety of the revised design.

The paper also emphasizes the importance of maintaining compliance with the standard design and the cited codes and standards during detailed design development and construction of Seismic Category I reinforced concrete and steel-concrete (SC) structures. The paper focuses on the role of critical sections, significance of Tier 2* information (the asterisk is part of the expression) in design control documents (DCD), and implementation of the detailed design.

Additionally, the paper makes recommendations for consideration by current and future new-reactor license applicants. This paper recommends the level of information needed to describe the methods of design for each structural element (wall, floor, frame, etc.) and to describe the design of the critical sections. The paper also discusses the prudence of a design certification (DC) applicant in considering a level of flexibility to account for construction realities such as materials availability and fabrication constraints.

INTRODUCTION

The AP1000 DC Amendment final rule was published in the *Federal Register* on December 30, 2011 and combined operating licenses (COLs) were issued for the Vogtle Electric Generating Plant (Units 3 and 4) and the V.C. Summer Nuclear Station (Units 2 and 3) on February 10, 2012 and March 30, 2012, respectively. Construction activities at both sites have commenced in many areas, including fabrication of steel-plated modules, installation of nuclear-island

---

1 This speech, paper, or journal article was prepared (in part) by employees of the U.S. Nuclear Regulatory Commission. It presents information that does not represent an agreed-upon staff position. The NRC has neither approved nor disapproved its technical content.

basemat reinforcement, and construction of adjacent structures' foundation elements. In March 2013, both sites completed placing concrete in the basemat, representing the first nuclear concrete poured in several decades.

The AP1000 standard plant, licensed under 10 CFR Part 52 regulations and included in the regulations as Appendix D, "Design Certification Rule for the AP1000 Design," to Part 52, was reviewed by the NRC staff and found to be acceptable. However, certain site-specific construction considerations, such as the feasibility of fabrication or installation of structural components, have resulted in the need by licensees to make design changes to the standard plant. Performing a change to the licensed design requires an understanding of the licensing basis and of the procedures required to be used in implementing the change. The 10 CFR Part 52 framework provides the licensing mechanism to make changes to the three categories of information in the final safety analysis report (FSAR): Tier 1, Tier 2, and Tier 2* information. Tier 1 information is the portion of the generic DCD that is approved and certified and contains design descriptions, significant site parameters, significant interface requirements, and inspections, tests, analyses, and acceptance criteria (ITAAC). Tier 2 information constitutes the great majority of the FSAR and is the portion of the generic DCD that is approved but not certified. Tier 2* information is a portion of Tier 2 information that is of such special importance to the design that it requires special change control. The AP1000 change process is outlined in Section VIII of Appendix D to Part 52. Changes to Tier 1 and Tier 2* information require prior NRC approval. A licensee may depart from Tier 2 information without prior NRC approval. Section VIII.B.5.a, b and c describes exceptions where departures from Tier 2 information would require prior regulatory approval.

The staff reviews and approves design changes in accordance with the regulations. Implementing guidance such as the Standard Review Plan (SRP), Regulatory guides, and interim staff guidance, along with cited codes and standards, informs the staff review and represents an acceptable technical approach for demonstrating compliance with the regulations. Successful and timely staff approval of change requests relies on the licensee's adherence to the appropriate regulatory-change process and the licensee's ability to provide high-quality technical justification. The next section of this paper makes recommendations on how to provide high-quality technical justifications for design changes.

LICENSE-AMENDMENT REQUESTS

Construction realities, such as limited access to reinforcement and material availability, have resulted in several license-amendment requests (LARs) in the first year of new reactor construction at the V.C. Summer and Vogtle sites. At both sites, notable changes in the civil structures area included design changes to the basemat, containment internal structures, and nuclear island walls. In reviewing and approving the requested changes, the staff performed safety evaluations of the applications to conclude, with reasonable assurance, that the revised design was safe. The staff's approach in performing safety evaluations for LARs is to focus the review on the areas impacted by the proposed change and to assess the extent to which the proposed change impacts the conclusions made by the staff during the design-certification review. In particular, the staff focuses on the extent to which the proposed changes impact the design-basis analysis inputs, the design-methodology commitments, and the related ITAAC. The staff also considers the extent to which the proposed change conforms to generally accepted industry methods (e.g., standard practice) and to those methods that were reviewed and approved during the design certification and combined licensing reviews. Conformance to approved methods is particularly relevant for those design aspects that are not directly addressed by current industry codes and standards, such as the design of SC composite structures.

In performing the safety review of a proposed licensing-basis change, the staff relies on the technical justification provided by the licensee to demonstrate that the facility's design remains safe and satisfies the NRC regulatory requirements. A technically sound and complete justification of the proposed change is essential for the staff to conduct its review efficiently and effectively. The level of detail provided in the LAR technical justification should be commensurate with the extent to which the proposed change impacts the aforementioned focus areas. For example, changes impacting the seismic analysis, such as changes in wall thickness or floor elevations, should be addressed in detail. Qualitative assessments which describe the impact of the change on the design in terms of "minimal" or "insignificant" are generally insufficient and should be substantiated quantitatively. Simplified engineering approaches can be used to effectively quantify the outcome of a minor change on the stresses and strains in the structure. More significant changes in the mass and stiffness of nuclear-island segments might have a more measurable impact on stresses and strains and should be justified in greater detail. An acceptable approach for such justification is to compare in-structure response spectra at key locations to clearly quantify and disposition the impact of the proposed change.

Submitting a high-quality application will result in an efficient, and timely, review. In addition to LAR requests, lessons learned from new-reactor construction activities have yielded valuable insights about the challenges associated with performing detailed design, interpreting licensing basis, and adherence to the Part 52 change process. These insights are discussed in the next section.

CONSTRUCTION TO THE LICENSING BASIS

Following the issuance of a COL, a licensee can commence construction of safety-related structures, such as the basemat and foundation walls. The construction process will typically involve developing the certified design into a detailed design and procuring safety-related components. In carrying out these construction activities, licensees have the responsibility to recognize the advantages and obligations inherent in the 10 CFR Part 52 licensing process. Part 52 provides design finality by allowing the NRC to issue combined construction and operating licenses. This design finality brings with it the responsibility to comply with the licensing basis at all times. To this end, licensees have instituted quality-assurance programs during construction with a focus on ensuring the consistency of the constructed design with the licensing basis. The role that quality-assurance programs have in avoiding construction errors and non-conformances is paramount. With regard to construction and adherence to the licensing basis, it should also be recognized that the certified design offers the first order of licensing commitments. That is to say, the certified design identifies design parameters, approved design and analysis methods, codes and standards, and, in the case of civil structures, descriptions of critical sections. These commitments must be satisfied at all stages of the design and construction process. In particular, as the detailed design of structures is carried forward beyond the level of detail in the certified design, both the detailed and the as-built designs must comply with both the certified design and the licensing-basis codes and standard commitments.

Code compliance should be carried out using a methodical yet pragmatic approach. In the case of AP1000 and other new reactor designs, the American Concrete Institute (ACI) code ACI 349 has been identified as the code of record for certain reinforced concrete structures and must be complied with. Compliance with the code does not mean satisfying every provision in the code. Rather, it means compliance with every provision that is relevant to the element under consideration. For example, a beam will have different code provisions than a column, a wall is different than a mat foundation, a mechanical anchor is different than an adhesive anchor, and so forth. In assessing the applicability of code provisions to structural elements, definitions and functions matter. How the element functions and how it was idealized in the seismic analysis model dictates how it should be designed and detailed. An element that is part of the lateral-force-resisting system is designed and detailed differently than an element that is not part of the system. Similarly, a basemat idealized as a diaphragm in resisting lateral forces should comply with the relevant code provisions for diaphragms. It should be noted that ACI 349 Chapter 21 provides acceptable detailing requirements for structural components designed to resist seismic demands. These provisions provide assurance that the component will be detailed to have adequate strength, stiffness, and ductility under beyond-design-basis seismic events.

An important element to compliance with the licensing basis is the consideration of critical sections during construction. Critical sections of a safety-related structure are those sections selected by an applicant to be representative of the design. Many factors contribute to the selection of critical sections, including high stress ratios, repetition in the design, unique detailing aspects, the need to comply with particular code provisions, the use of novel design approaches, etc. To be consistent with maintaining the finality of the certified design, critical-section designs and their respective descriptions are usually designated as Tier 2* information. Plant designers and constructors should have a clear understanding of the licensing basis for the critical sections. Detailed engineering calculations and drawings should be prepared sufficiently early in the construction phase for early identification of required changes. Carrying out any changes to the design of these locations in a way consistent with the appropriate regulatory framework is essential.

Design codes such as ACI 349 are typically cited for the design of critical sections. ACI 349 code provisions are clear and prescriptive. These provisions represent an extensive body of research and experience with the design, analysis, and behavior of reinforced concrete structures. The ACI code is versatile, providing a framework to be used for the design of many types of concrete structures with few restrictions. The code even provides guidance for the design of novel construction approaches for which the code provisions are not directly transferable, such as SC construction. The code provisions also include an inherent level of conservatism to account for complex phenomena, compensate for uncertainties, allow the use of reasonable approximations, and avoid undesirable structural behavior (such as brittle failure modes). Conservatism notwithstanding, the versatility of the code does require the design engineer to have the appropriate level of knowledge, experience, and engineering judgment to appropriately apply the code for design purposes. In developing the detailed design, the design engineer should be cognizant of the licensing-basis commitments associated with the design and of the extent to which the code is committed in the licensing basis. Most importantly, the designer should justify and document all aspects of the design using relevant code provisions. If the design contains complex structural configurations or uses novel construction techniques that might not fall directly within a certain code provision, the designer should address the behavior through equivalent code provision(s) or provide an alternative, sound technical basis to achieve a safe design.

NEW REACTOR APPLICATIONS

The lessons learned from new-reactor construction activities offer valuable insights that are relevant to current and future DC applicants. During the DC stage, the staff's review is focused on the description of the structural design, including critical sections, analysis and design methods, and cited codes and standards. Construction experience indicates that providing clarity in these DC review areas and striking a balance between the level of specificity and degree of flexibility benefits the later phases of detailed design development and construction. A certain level of specificity in DCD Tier 2* information is necessary for providing regulatory control of key aspects of the design of a Seismic Category I structure. In addition, it might be prudent for the DC applicant to maintain a level of flexibility to account for construction realities such as materials availability and fabrication constraints. For structural elements not explicitly addressed in code provisions (e.g., SC modules), specific dimensions such as stud spacing should be provided with acceptable construction tolerances. For conventional reinforced-concrete structural elements, specific rebar size and spacing may be replaced with the nominal rebar area to be installed. Important seismic detailing features such as the use of hoops, stirrups, hook configurations, rebar anchorage methods, etc., should be clearly identified and designated as Tier 2* information.

DC applications should contain explicit descriptions of the methods of design for each structure element (wall, floor, frame, etc.) and provide the design of the critical sections in a way consistent with the relevant design code provisions. That is, the design description should be clear enough to include terms such as one-way slab, braced-frame, moment-frame, diaphragm, etc., as applicable. These terms determine the applicable code provisions for the design and detailing, and are relevant in assessing the adequacy of the design during the licensing and construction inspection phases. The description should include the relevant aspects of the design and detailing, including (for example) the number and orientation of flexural rebar layers, the location and configuration of shear reinforcement, and the approach for ensuring development in reinforced-concrete sections. The DCD should be clear on whether a critical section design is applicable to a specific location or is intended to be used at similar configurations (i.e., is typical). Such clarification will benefit construction inspection by describing the extent and applicably of the critical section details.

CONCLUSION

In terms of construction and adherence to licensing basis, Part 52 provides design finality by allowing the NRC to issue combined construction and operating licenses. This design finality brings with it the responsibility to comply with the licensing basis at all times. The certified design offers the first order of commitments; that is to say, approved design and analysis methods, codes and standards, and description of critical sections. These commitments must be satisfied at all stages of design and construction. In particular, as the detailed design of structures is carried forward beyond the level of detail in the certified design, codes and standards commitments also have to be complied with, as appropriate.

In proposing design changes during construction, a licensee's technical evaluation should be based on quantitative assessments and should address the impact of the change on other areas of the design-basis analysis and design such as seismic response. General statements such as the terms "minimal" and "insignificant" should be avoided. The use of simplified models based on engineering fundamentals is acceptable so far as it adequately justifies a proposed change.

New reactor DC applications should make use of the construction lessons learned by providing clear descriptions of critical sections (text and figures) and carefully considering the use of Tier 2* information to balance the description of essential information with the flexibility to address construction realities.

REFERENCES

1. *U.S. Code of Federal Regulations*, "Domestic Licensing of Production and Utilization Facilities," Part 50, Chapter I, Title 10, "Energy."

2. U.S. Nuclear Regulatory Commission (NRC), "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," NUREG-0800, March 2007.

3. American Concrete Institute (ACI), "Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary," ACI-349-01.