NRIC NQA-1 WORKSHOP

SESSION 2A – NUCLEAR CONSTRUCTION QUALITY REQUIREMENTS FOR RC, SC, AND STEEL STRUCTURES

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Acknowledgements

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Outline

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Role of QA/QC in Ensuring Structural Reliability

The difference between Quality Assurance and Quality Control

https://www.planradar.com/au/quality -assurance-vs-quality-control/

What is Quality Assurance (QA)?

Quality Assurance (QA) is a systematic approach to ensuring that all processes and activities involved in a construction project meet established standards and requirements. The primary purpose of QA is to prevent defects and issues by focusing on the processes used to manage and complete projects. Unlike Quality Control (QC), which aims to identify and correct defects in the finished product, QA is concerned with improving and managing the processes to build quality into the project from the outset.

Key principles of QA include, but are not limited to:

- **Process orientation**: QA emphasizes the importance of well-defined and documented processes. By following established procedures, construction activities can achieve consistency and reliability, reducing the likelihood of defects.
- **Continuous improvement**: One of the core principles of QA is the ongoing effort to improve processes. This involves regularly reviewing and analyzing performance data, feedback, and outcomes to identify areas for enhancement and implement changes accordingly.
- **Documentation:** Maintaining comprehensive records of procedures, standards, and outcomes is crucial in QA. Proper documentation helps track progress, identify issues, and ensure accountability throughout the project.
- **Stakeholder involvement**: QA requires the active participation and collaboration of all parties involved in the project, including architects, engineers, contractors, and clients. Engaging stakeholders ensures that everyone understands their role in achieving quality objectives.
- **Preventive measures:** Implementing preventive measures is a key aspect of QA. This includes risk assessments, regular audits, and thorough planning to anticipate and mitigate potential issues before they occur.
- **Training and competence**: Ensuring that all team members are adequately trained and competent in their roles is essential. QA focuses on providing the necessary training and resources to maintain high standards of work.
- **Customer focus:** QA emphasizes understanding and meeting the needs and expectations of the client. By focusing on customer satisfaction, QA ensures that the final product aligns with the client's requirements and standards.

QA measures consist of proactive planning and organizing steps to be undertaken prior to the execution of design and construction activities.

Role of QA/QC in Ensuring Structural Reliability

The difference between Quality Assurance and Quality Control

https://www.planradar.com/au/quality -assurance-vs-quality-control/

Benefits of implementing QA in construction projects typically include:

- **Reduction of defects and rework:** By emphasizing quality from the outset and focusing on preventive measures, QA helps minimize the occurrence of errors and defects. This proactive approach not only saves time and money but also enhances the overall efficiency of the project.
- **Improved compliance with regulatory requirements:** QA ensures that all construction activities align with relevant codes, standards, and regulations. This reduces the risk of legal issues and enhances the project's credibility and reliability.
- **Enhanced project efficiency:** With well-defined processes and continuous improvement, QA helps streamline construction activities, leading to smoother project execution and timely completion.
- **Increased team accountability:** QA promotes adherence to established processes and standards, creating a disciplined and responsible work environment. Every team member understands their rol in delivering a high-quality outcome, leading to better team cohesion and performance.
- **Long-term cost savings:** By preventing defects and reducing the need for rework, QA contributes t significant cost savings over the lifespan of the project. Investing in quality processes upfront can result in fewer costly issues down the line.

Quality Assurance is a crucial component of quality management in construction. It focuses on preventing defects by establishing and maintaining robust processes, continuously improving them, and ensuring compliance with standards and regulations. Implementing QA leads to higher efficiency, reduced costs, enhanced compliance and improved team accountability.

QA measures help realize the desired reliability for the structure

Role of QA/QC in Ensuring Structural Reliability

The difference between Quality Assurance and Quality Control

The underlined text refers to “final product”; however, it typically relates to each executed task that warrants QC inspection/observation or testing.

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What is Quality Control (QC)?

Research from the US National Institute of Standards and Technology indicates that poor quality control results in an average cost of $12.7 billion annually in rework costs for the construction industry.

Quality Control (QC) is a reactive process focused on identifying and correcting defects in the final product of a construction project. Unlike Quality Assurance (QA), which aims to prevent defects through the management of processes, QC is concerned with the verification of quality after construction activities have been completed. The primary purpose of QC is to ensure that the final output meets the specified standards and requirements, thereby ensuring the safety, reliability, and durability of the construction.

Some of the key principles of QC include:

- **Inspection and testing:** QC involves systematic inspections and tests of materials, components, and systems to detect any defects or deviations from standards. This includes visual inspections, mechanical testing, and non-destructive testing methods.
- **Compliance verification:** Ensuring that all aspects of the construction project comply with the relevant standards, codes, and specifications is a core principle of QC. This involves checking that the work adheres to the agreed-upon quality benchmarks.
- **Defect identification and correction:** QC focuses on identifying defects or non-conformities in the finished product and taking corrective actions to fix them. This may involve repairing, reworking, or replacing defective elements.
- **Documentation and reporting:** Detailed documentation and reporting are crucial in QC. Records of inspections, test results, and corrective actions provide a traceable history of quality control activities and support accountability.
- **Measurement and analysis:** QC relies on precise measurement and analysis of construction elements to ensure they meet specified criteria. This includes the use of calibrated instruments and tools to gather accurate data.
- **Standardized procedures:** Adhering to standardized procedures for inspections and testing ensures consistency and reliability in QC activities. This helps in maintaining uniform quality across different projects.

QC measures consist of in-process inspection, testing, and observation steps that are intended to identify (and rectify) potential deficiencies. These measures help assure that the as-constructed structure will meet its quality and long-term reliability goals.

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Role of QA/QC in Ensuring Structural Reliability

Some Structural Reliability Basics

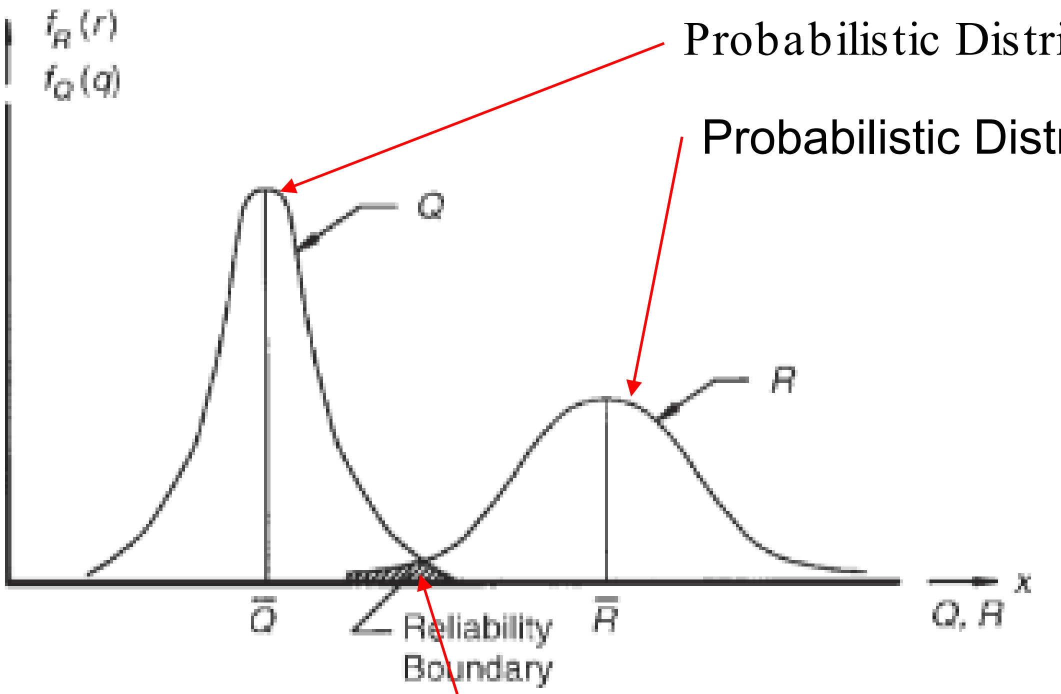


Fig. 6.4 Probability density functions for load and resistance.

Probabilistic Distribution of **Demand**

Probabilistic Distribution of **Capacity**

Overlapping Area represents the Probability of Failure

Role of QA/QC in Ensuring Structural Reliability

Some Structural Reliability Basics

V_Q = coefficient of variation of the load effect, Q
V_R = coefficient of variation of the resistance, R
β = reliability index

For structural elements and the usual loading, R_m, Q_m, and the coefficients of variation, V_R and V_Q, can be estimated, so a calculation of

$$\beta = \frac{\ln(R_m/Q_m)}{\sqrt{V_R^2 + V_Q^2}} \quad \text{(C-B3-2)}$$

$$\varphi = (\mu_R/R_n)\exp[-\alpha_R \beta V_R] \quad \text{(C2.3-2)}$$

where
μ_R = Mean strength,
R_n = Code-specified strength,
V_R = Coefficient of variation in strength, and
α_R = Sensitivity coefficient equal to approximately 0.7.

$$\gamma_Q = (\mu_Q/Q_n)(1 + \alpha_Q \beta V_Q) \quad \text{(C2.3-1)}$$

Structural Reliability is expressed as β, (the "Reliability Index"), which governs probability of failure for the structure.

ϕ, the "Resistance Factor", can be determined for a target β value.

α_R and α_Q represent the sensitivity coefficients that depend on the relative variabilities of Resistance and Demand.

γ_Q, the load factor, is determined for each load case based on whether it represents the primary load or companion load action.

Role of QA/QC in Ensuring Structural Reliability

- The demand distribution curve mostly accounts for random/aleatory uncertainties. It may account for some modeling related uncertainties (especially those related to extreme load characterization)–
  - However, it does not account for potential analysis/modeling errors or software issues and validity of any applicable heuristics

- Similarly, the capacity distribution curve mostly accounts for random / aleatory uncertainties, but not construction / inspection errors or defects

- QA/QC requirements are necessary to mitigate the impact of various epistemic uncertainties (especially potential human errors); however, there is no definitive correlation between target reliability and extent of QA/QC

Role of QA/QC in Ensuring Structural Reliability

However, a majority of structural failures and damage costs, in ordinary construction, at least, occur as a consequence of errors in planning, design, construction, and utilization (26). Unforeseen circumstances and conceptual, analytical, or executional errors can occur even when competent organizations and qualified personnel are involved in design and construction and when accepted methods of quality assurance and control are employed. Errors are difficult to quantify, inasmuch as their source is human imperfection. The involvement of the human element removes the solution to the error problem (at least partially) from the realm of statistics, probability, and reliability theory.

DESIGN AND CONSTRUCTION ERROR EFFECTS
ON STRUCTURAL RELIABILITY

By Bruce Ellingwood,[1] M. ASCE

J. Struct. Eng., 1987, 113(2): 409-422

Role of QA/QC in Ensuring Structural Reliability

Source	Nature	Example
Design concept	- Possible failure mode unrecognised - Incorrect nature of use assumed	. . . neglect of lateral torsional buckling . . . room used for storage of heavy equipment in office premises
Design and analysis	- Omission of a load or load combination - Misinterpretation of geotechnical data - Computational error in analysis - Misinterpretation of units - Error in detailing	. . . effect of ground-water pressure overlooked . . . soft stratum not detected . . . error in computer program . . . kilogrammes interpreted as Newtons . . . 20 mm bars used instead of 40 mm
Construction	- Misinterpretation of drawings - Use of incorrect material - Incorrect fabrication - Incorrect construction	. . . 100 mm slab instead of 150 mm . . . grade 43 steel used instead of grade 50 . . . omission of heat treatment . . . error in position of reinforcement
Inspection	- Gross defect not detected	. . . crack in weld
Use	- Accidental loading - Change of use without structural assessment - Need for specialist maintenance overlooked	. . . severe impact or explosion . . . domestic premises used for public library . . . cathodic protection system becomes inoperative

Table 13.1. General classification of the nature and sources of gross errors.

Impact of Design, Construction, and Inspection Errors

Palle Thoft-Christensen
Michael J. Baker

Structural Reliability Theory and Its Applications

Role of QA/QC in Ensuring Structural Reliability

Impact of Design, Construction, and Inspection Errors

Figure 19 Total detection rate vs. years of inspection experience.

The average detection rate for all 30 inspectors of all 70 cracks located on the painted specimens was 65%. Detection rates ranged from 31% to 86%. Univariate analysis between detection rates and other factors, like inspection time or the day's weather, revealed slight, but statistically significant, correlations. Detection rate

For the total population of cracks for this set of inspectors, a 1-inch-long crack had a 50% chance of being detected and a 5-1/2-inch-long crack had a 90% chance of being detected. The data was too scattered to assign a 95% confidence bound.

Probability of Detection Study for Visual Inspection of Steel Bridges: Volume I—Executive Summary

Leslie E. Campbell, Luke R. Snyder, Julie M. Whitehead, Robert J. Connor, Jason B. Lloyd

SPR-3820 • Report Number: FHWA/IN/JTRP-2019/21 • DOI: 10.5703/1288284317103

Even QC inspections are not immune to human errors!

Role of QA/QC in Ensuring Structural Reliability

Uncertainties owing to Use of Heuristics

- A heuristic refers to a problem-solving approach that relies on a pragmatic method or simpler proxy/thumb rule that is based on (plausible) intuitive judgment and experience that however could turn out to be *unjustified or potentially fallible in the final analysis*

- Structural engineering, and by extension structural reliability theory, is based on use of many design and construction related heuristics (e.g., turn-of-the-nut method, T-beam tributary width, treatment of live load as being uniform, use of drift or plastic rotation capacity as a measure of acceptable damage, etc.)

- Heuristics represent additional sources of epistemic uncertainties, along with modeling uncertainties and potential human errors during design and construction phases.

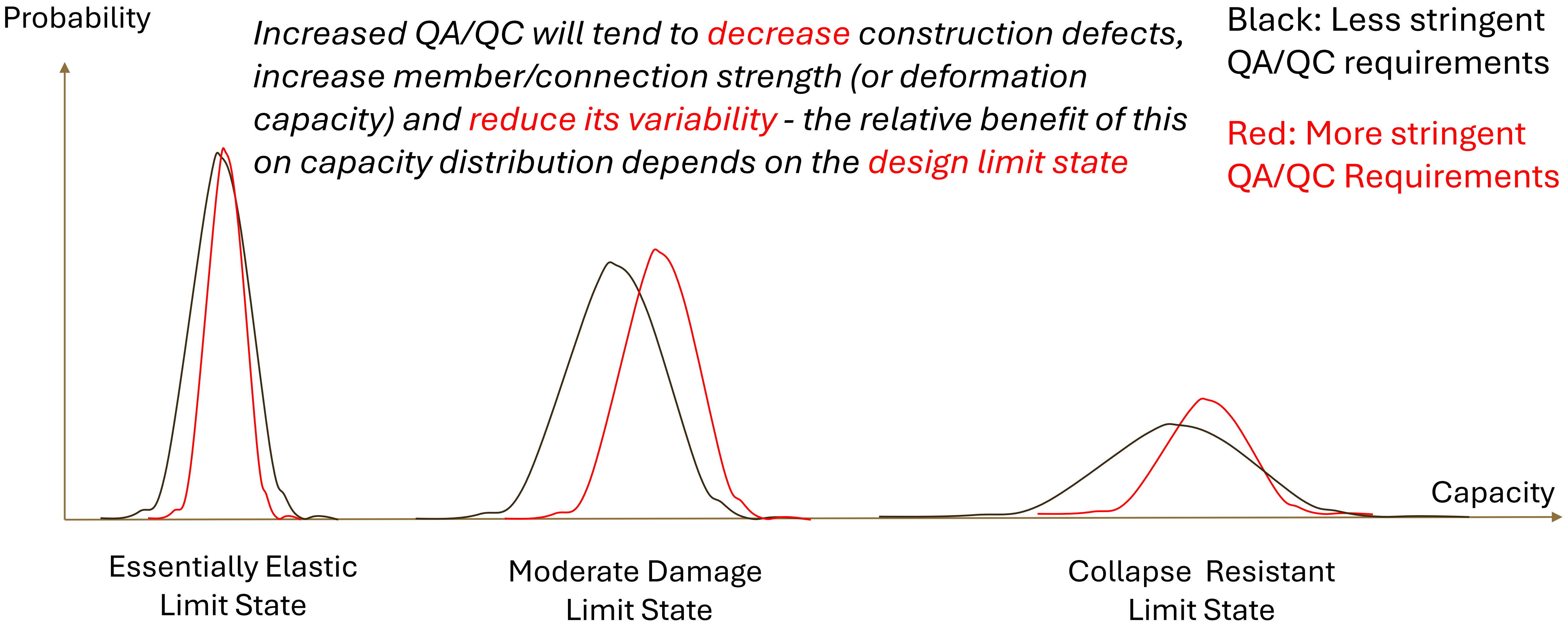
- The individual and collective impact of these types of uncertainties is unknown and not captured in the structural reliability framework.

Role of QA/QC in Ensuring Structural Reliability

Increased QA/QC will tend to decrease construction defects, increase member/connection strength (or deformation capacity) and reduce its variability - the relative benefit of this on capacity distribution depends on the design limit state

Black: Less stringent QA/QC requirements

Red: More stringent QA/QC Requirements



Note: A design or construction error may change the member/structure behavior in unexpected ways such that the resistance characteristic is significantly altered

Role of QA/QC in Ensuring Structural Reliability

Assessment of Seismic Fragility of Structures with Consideration of the Quality of Construction

Article in Earthquake Spectra · November 2006
DOI: 10.1193/1.2360671

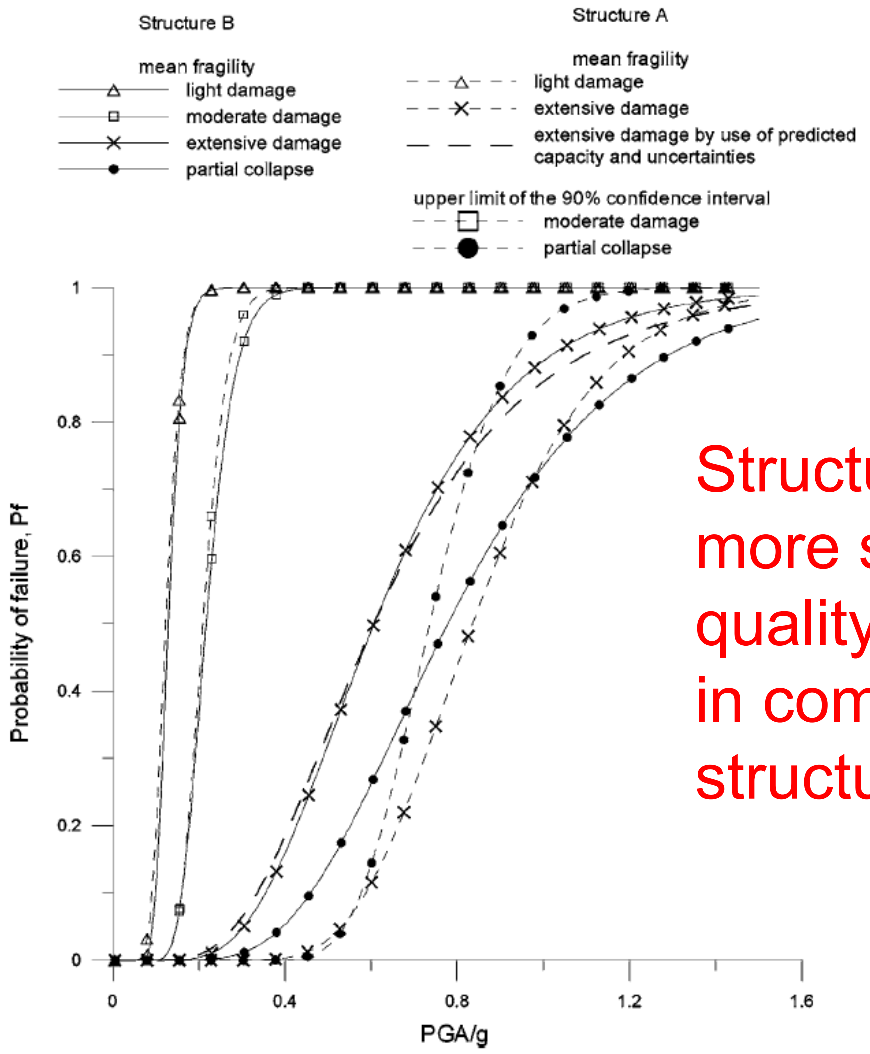


Figure 10. Estimation of the fragility of a structure with deficiencies based on the design data.

Structure A had more stringent quality requirements in comparison to structure B

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Historical Evolution of Nuclear QA Requirements

WWII — 1940s — 1950s — 1960s

1940s

Atomic Energy Act (1946)
Establishment of AEC

1950s

Military QA Requirements
- MIL-Q-5932 (1950)
- MIL-Q-9858 (1959)
- MIL-Q-21549 (1959)

Establishment of NASA (1958)
- Initial QA Practices and Standards

AEC's Nuclear Safety Guide
- TID-7016 (1957)

1960s

Early QA Requirements by AEC
- 10 CFR Part 50 Appendix A (1965)
- RDT F2-2 (1969)

AEC's Hearing for Zion Nuclear Plant
- 10 CFR Part 50 Appendix B (1969)

ASME BPVC Scope Expansion to Quality Control and Non-Destructive Examination (1967)

Historical Evolution of Nuclear QA Requirements

1970s

AEC's Safety Guide 26 (1972)

AEC's Regulatory Guide 1.28 (1973)

Energy Reorganization Act (1974)
- Establishment of NRC

10 CFR 50 Amendment (1975)
- Expansion on Criterion 1 Quality Standards and Records

Development of Industry Standards by ASME BPVC and ANSI N45

- ASME BPVC Expansion to Reflect 10 CFR 50 Appx. B Criteria (1971)
- ANSI N45.2 (1973) - Endorsed by AEC in Reg Guide 1.28
- NA-4000 of ASME BPVC Section III (1974)
- ASME NQA-1 (1979)

Three Mile Island Accident (1979)

Historical Evolution of Nuclear QA Requirements

1980s

US DOE Order 5700.6 (1981)

Congressional Directive (1983)

- Publication of NUREG-1055 (1984)

Withdrawal of AEC RDT F2-2 (1982)

Rev.3 of Reg Guide 1.28 (1983)

- First Endorsement of NQA-1 by NRC

ASME NQA-2 (1983)
ASME NAQ-3 (1989)

1990s

US DOE Order 5700.6C (1991)

Consolidation of NQA Standards

- NQA-1(1994)

2000s

Rev.4 of Reg Guide 1.28 (2010)

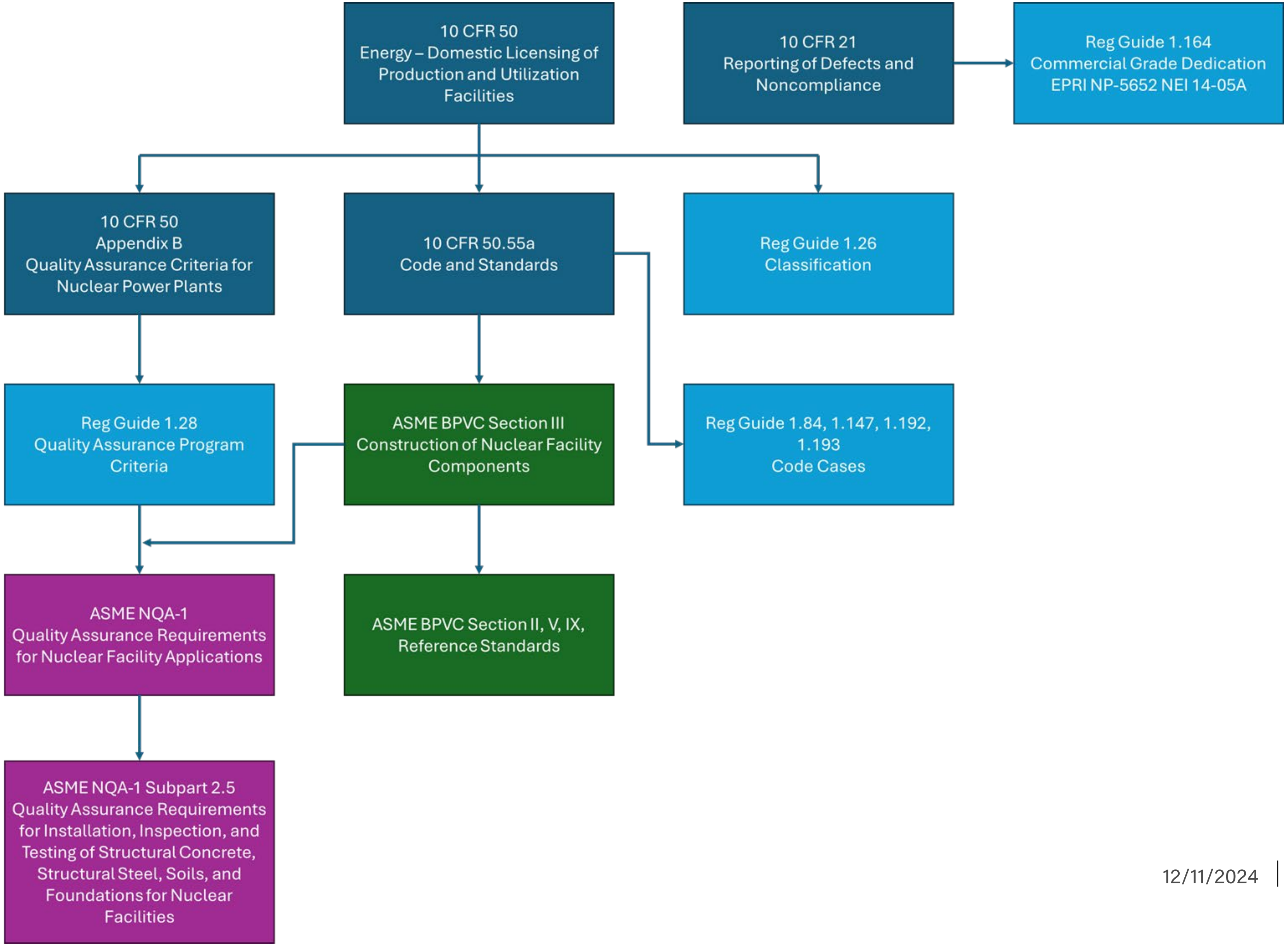
- Endorsement of NQA-1-1994

NQA-1 (2008)

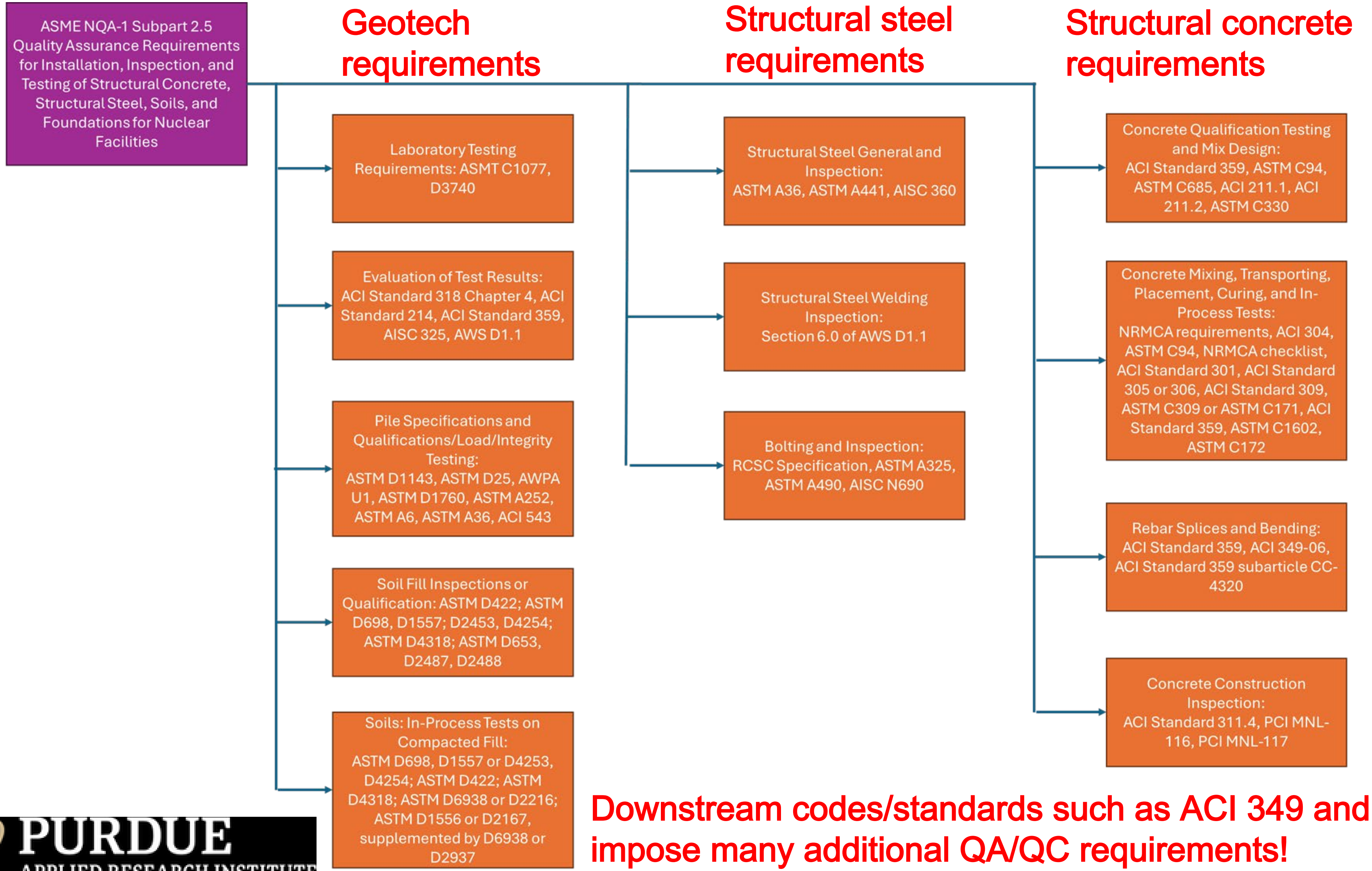
Rev.5 of Reg Guide 1.28 (2017)

- Endorsement of NQA-1-2008

Flowchart of Relevant Nuclear QA/QC Requirements



Flowchart of Relevant Nuclear QA/QC Requirements



Downstream codes/standards such as ACI 349 and AISC N690 impose many additional QA/QC requirements!

Relevant 10CFR50 Appendix B Requirements

III. Design Control

Measures shall be established to assure that applicable regulatory requirements and the design basis, as defined in §50.2 and as specified in the license application, for those structures, systems, and components to which this appendix applies are correctly translated into specifications, drawings, procedures, and instructions. These measures shall include provisions to assure that appropriate quality standards are specified and included in design documents and that deviations from such standards are controlled. Measures shall also be established for the selection and review for suitability of application of materials, parts, equipment, and processes that are essential to the safety-related functions of the structures, systems and components.

Specifications/quality standards must be developed to ensure that construction of the structure will meet its design intent – this is a QA measure

V. Instructions, Procedures, and Drawings

Activities affecting quality shall be prescribed by documented instructions, procedures, or drawings, of a type appropriate to the circumstances and shall be accomplished in accordance with these instructions, procedures, or drawings. Instructions, procedures, or drawings shall include appropriate quantitative or qualitative acceptance criteria for determining that important activities have been satisfactorily accomplished.

Acceptance criteria for inspections must be defined – this is a QA measure

VII. Control of Purchased Material, Equipment, and Services

Measures shall be established to assure that purchased material, equipment, and services, whether purchased directly or through contractors and subcontractors, conform to the procurement documents. These measures shall include provisions, as appropriate, for source evaluation and selection, objective evidence of quality furnished by the contractor or subcontractor, inspection at the contractor or subcontractor source, and examination of products upon delivery. Documentary evidence that material and equipment conform to the procurement requirements shall be available at the nuclear power plant or fuel reprocessing plant site prior to installation or use of such material and equipment. This documentary evidence shall be retained at the nuclear power plant or fuel reprocessing plant site and shall be sufficient to identify the specific requirements, such as codes, standards, or specifications, met by the purchased material and equipment. The effectiveness of the control of quality by contractors and subcontractors shall be assessed by the applicant or designee at intervals consistent with the importance, complexity, and quantity of the product or services.

Must have material documentation prior to arrival, at installation, and maintained on record on-site – this is a QA measure

VIII. Identification and Control of Materials, Parts, and Components

Measures shall be established for the identification and control of materials, parts, and components, including partially fabricated assemblies. These measures shall assure that identification of the item is maintained by heat number, part number, serial number, or other appropriate means, either on the item or on records traceable to the item, as required throughout fabrication, erection, installation, and use of the item. These identification and control measures shall be designed to prevent the use of incorrect or defective material, parts, and components.

Material identification must be maintained – this is a QC measure

Relevant 10CFR50 Appendix B Requirements

IX. CONTROL OF SPECIAL PROCESSES

Measures shall be established to assure that special processes, including welding, heat treating, and nondestructive testing, are controlled and accomplished by qualified personnel using qualified procedures in accordance with applicable codes, standards, specifications, criteria, and other special requirements.

Demonstrate that workers are qualified to perform the work and that they follow qualified procedures – this is a QA measure

X. INSPECTION

A program for inspection of activities affecting quality shall be established and executed by or for the organization performing the activity to verify conformance with the documented instructions, procedures, and drawings for accomplishing the activity. Such inspection shall be performed by individuals other than those who performed the activity being inspected. Examinations, measurements, or tests of material or products processed shall be performed for each work operation where necessary to assure quality. If inspection of processed material or products is impossible or disadvantageous, indirect control by monitoring processing methods, equipment, and personnel shall be provided. Both inspection and process monitoring shall be provided when control is inadequate without both. If mandatory inspection hold points, which require witnessing or inspecting by the applicant's designated representative and beyond which work shall not proceed without the consent of its designated representative are required, the specific hold points shall be indicated in appropriate documents.

Verification of work quality must be performed by independent inspection – this is a QC measure

10CFR50.55a recognizes the ASME NQA-1 standard as one of the ways in which the 10CFR50 Appendix B requirements can be met - the 10CFR Appendix B requirements are further explained and amplified in Part 1 of ASME NQA-1

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NQA-1 Concrete Construction Requirements at a glance

Requirements related to Concrete Construction		
NQA-1 Provision No.	**Referenced Standard**	**Description**
303 Laboratory Testing	ASTM C1077, D3740	Laboratory testing requirements
402 Materials Suitability	ASME Boiler and Pressure Vessel Code, Section III, Division 2 (ACI Standard 359)	Qualification testing for materials
	ASTM C94, ASTM C685	Concrete mix design and batching
	ACI 211.1	Normal, heavyweight and mass concrete mix design
	ACI 211.2	Lightweight concrete mix designs
	ASTM C330	Material qualification tests for lightweight concrete
701 General	ACI Standard 311.4	Concrete construction inspection
	PCI MNL-116, MNL-117	Concrete construction inspection
703 Measuring, Mixing, and Transporting Equipment	Requirements of National Ready-Mix Concrete Association (NRMCA)	Concrete batching and mixing facility requirements
	ACI 304, ASTM C94, NRMCA checklist	Inspection requirements prior to and during concrete production
	ACI Standard 301	Inspection of method of adding water when batching lightweight aggregates
705 Concrete Placement	ACI Standard 305 or 306	Hot or cold weather concrete practice
	ACI Standard 309	Adequate concrete consolidation equipment and technique of operation
707 Curing	ASTM C309, or ASTM C171	Qualification tests on liquid membrane forming curing compounds and sheet materials for concrete curing
711 In-Process Tests on Concrete	ACI Standard 359	In-process tests during construction for control of structural, prestressed, and precast concrete
	ASTM C1602	Requirements for mixing water and ice, if not potable
	ASTM C172	Samples for in-process tests of concrete
712 Mechanical Splice Testing	ACI Standard 359, ACI 349-06	Mechanical splice testing
713 Welded Reinforcing Bar Splices	ACI Standard 359	Welded splice requirements
714 Bending of Reinforcement	ACI Standard 359, subarticle CC-4320	Provisions for bending rebar
902.1 Evaluation of Concrete Test Results	ACI Standard 318, Chapter 4	Concrete quality and acceptance criteria
	ACI Standard 214	Standard deviation data
902.2 Evaluation of Mechanical Splice Test Results	ACI Standard 359	Evaluation of mechanical splice test results

QA Measures

QC Measures

ASME NQA-1 CONCRETE-RELATED REQUIREMENTS

Sample comparisons with ACI 318, ACI 349, and ACI 359 (ASME BPVC Section III Div. 2) requirements

Outline

- Introduction
- Summary of ASME NQA-1 Concrete-related requirements
- Sample comparisons with ACI 349, ACI 318, and ACI 359 requirements

Introduction

- ASME NQA-1 establishes a comprehensive framework for **Quality Assurance (QA)** programs applicable to design, construction, operation, and decommissioning of **nuclear facilities**.

- This module focuses on ASME NQA-1 requirements pertaining to **reinforced concrete construction**

- The ASME NQA-1 requirements are summarized and sample comparisons of these requirements with similar requirements in **ACI 349, ACI 318, and ACI 359** are made

ASME NQA-1 Concrete Requirements

- Part II Subpart 2.5 of ASME NQA-1 provides quality assurance requirements for installation, inspection, and testing of structural concrete

- The NQA-1 requirements for reinforced concrete construction can be classified as follows:
  - Documentation Requirements (applicable to all types of construction, but covered here)
  - Material Requirements
  - Construction Requirements
  - Inspection and Evaluation Requirements (not covered in this presentation)

ASME NQA-1 Subpart 2.5 Requirements

Documentation Requirements

- Requires detailed records of design analyses, including final drawings and specifications (with revisions), and **important steps in the design process** (e.g., sources of design inputs)

- Detailed procurement documentation that include test, inspection, and acceptance criteria, nonconformances. These need be reviewed prior to purchases.

- Material specifications, test results, inspection reports, nonconformance reports, and corrective actions for traceability

- Specific procedure for document control

ASME NQA-1 Requirements: Sample Comparison with ACI Codes

Documentation Requirements

ACI 318-2019	ACI 349-2023	ACI 359-2015
No specific requirements for QA program	A QA program needs to be developed based on requirements of USNRC 10CFR50:2015; which may lead to adoption of all requirements of ASME-NQA-1	Majority of the processes need to be done per a QA program approved by the constructor, which may lead to adoption of all requirements of ASME NQA-1
Calculations pertinent to design need to provided only if required by building official. No verification/validation of numerical models is needed	Calculations pertinent to design need to provided only if required by AHJ. Verification and validation of software needs to be documented.	Significantly detailed requirements, e.g., concrete average strength documentation procedure, steel CMTR documentation requirements
Pertinent documentation required for special cases (e.g., if recycled aggregates are being used, for concrete being exposed to water))	Same as ACI 318	
Concrete mix characteristics need to be documented, reviewed, and approved. Previous project results using the same mix-design may be used as evidence that the mix design meets the construction specifications.	Same as ACI 318	

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ASME NQA-1 Concrete Requirements

Material Requirements

- Strict protocols for storage and handling of materials
- Mandatory preconstruction qualification tests and in-process tests
- Batching and mixing of concrete per ASTM C94/C685
- Proportioning of mix-design per ACI 211.1/ACI 211.2
- In-process tests for concrete required per ACI 349 and ACI 359
- Requires traceability, material testing, and certification for all reinforcing steel, including welding procedures

ASME NQA-1 Requirements: Sample Comparison with ACI Codes

Material Requirements

ACI 318-2019 (Ch 26)	ACI 349-2023 (Ch 26)	ACI 359-2015
Cementitious materials, aggregates, water, admixtures, need to conform to specific ASTM specifications		**CMTRs and Certificates of compliance required for all materials. Requirements for CMTRs provided. Very specific requirements for permitted types of cement, aggregates, mixing water, admixtures**
Detailed design information for concrete mixture based on assigned exposure class or member design (17 items)		Strenuous/extensive requirements, e.g., for chloride content, resisting ASR, tests for reactivity, thermal property tests
Compliance requirements for concrete mixture, e.g., requirements for members subjected to freeze/thaw, deicing chemicals		
Concrete mix characteristics need to be documented, reviewed, and approved. Previous project results using the same mix-design may be used as evidence that the mix design meets the construction specifications	Same as ACI 318	Very specific proportioning and testing requirements for concrete mix designs

CC-2231.3.1 Testing for Reactivity. Materials and proportions selected for concrete mixtures shall be tested

CC-2233 Proportioning on the Basis of Field Experience and/or Trial Mixtures

CC-2233.1 Standard Deviation. Standard deviation shall be calculated using the methods of ACI 214R.

CC-2233.1.1 Test Record Requirements. Where a concrete production facility has test records not more than 12 months old, a standard deviation shall be established. Test records from which a standard deviation is calculated shall

(a) represent materials, quality control procedures, and conditions similar to those expected, and changes in materials and proportions within the test records shall not have been more restricted than those for proposed work

(b) represent concrete produced to meet a specified strength or strengths f'_c within 1,000 psi (7 MPa) of that specified for proposed work

(c) consist of at least 30 consecutive tests or two groups of consecutive tests totaling at least 30 tests as defined in CC-5232.3.2(a), except as provided in CC-2233.1.2

ASME NQA-1 Concrete Requirements

Construction Requirements

Requirement	ASME-NQA-1
Construction processes	Section 403: Inspections required to ensure process qualification, control, etc.
Inspection of concrete construction	Section 700 • Includes inspection of concreting preparations, and in-process inspections of concrete measuring, mixing, transporting, placing, curing and protection. • Should comply with ACI 311.4, PCI MNL-116/117
Preplacement preparations	Section 704 • Extensive list of inspection requirements (a through l); e.g., formwork inspection, mechanical reinforcing bar splicing • Documentation of inspection needs to be verified for completion and satisfaction
Concrete placement	Section 705: For example, inspection regarding • performance of specified concrete tests, • adherence to requirements for concrete class, time of placement, etc. (ACI 305 or 306) • Concrete consolidation equipment and technique (ACI 309)

ASME NQA-1 Concrete Requirements

Construction Requirements (Contd.)

Requirement	ASME-NQA-1
Finishing and repairs	Section 706 • Inspection to ensure specified finishes are obtained • Indication of honeycomb, voids, contamination needs to be explored by physical removal of concrete • Non-cosmetic repairs shall be directed by design organization
Curing	Section 707 • Qualification tests for curing compounds/membranes per ASTM C309/C171 • Continuous inspections during the curing period to verify compliance, for example, use of correct curing method, continuous curing if wet curing used, curing temperature is maintained within limits
Stress transfer of pretensioned members	Section 708: For example, if applicable • Ensure concrete strength is specified strength before prestressing load is transferred • Stress transfer uses approved stressing procedure and sequence

ASME NQA-1 Concrete Requirements

Construction Requirements (Contd.)

Requirement	ASME-NQA-1
Post-tensioning	Section 709: For example, if applicable, • Concrete strength in accordance with specified strength for post-tensioning • Tendons and ducts are lubricated with specified lubricant, prior to installation
Shipping and handling of pre-cast concrete members	Section 710: inspections prior to and during installation. For example, • Handling by approved devices at designated pick-up points • Cracking, spalling, and other defects due to shipping and handling do not exceed specified limits
In-process tests on concrete	Section 711 • Minimum tests and frequency per ACI 359 and 349 • Higher frequency if erratic tests • Special requirements for distance between delivery and placement points to be more than 5min
Mechanical splice testing	Section 712 • Per ACI 359 and 349
Welded reinforcing bar splices	Section 713 • AWS D1.1 requirements (covered in steel section) and ACI 359
Bending of reinforcement	Section 714 • Per ACI 359 • Field bending of bars partially embedded in concrete not permitted

ASME NQA-1 Requirements: Sample Comparison with ACI Codes

Construction Requirements: Curing

ACI 318-2019 (Ch 26)	ACI 349-2023 (Ch 26)	ACI 359-2015
Supplementary testing of field-cured specimens on a need-basis	Same as ACI 318	**Construction specification needs to specify curing requirements. Additional requirements, for example, requirements for cold weather curing.**
Concrete needs to be maintained at temperature of at least 50°F and moist for at least 7 days (3 days for high-strength concrete)		
Criteria for accelerated curing provided		
Curing procedures considered adequate if: (a) Average strength of field-cured specimen at age designated for determination of $f`_c$ is equal to or at least 85% of companion standard cured-cylinders (b) Average strength of field cured cylinders at test age exceeds $f`_c$ by more than 500 psi		

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ASME NQA-1 Requirements: Sample Comparison with ACI Codes

Construction Requirements: Finishing and repair

ACI 318-2019 (Ch 26)	ACI 349-2023 (Ch 26)	ACI 359-2015
No explicit requirements	No explicit requirements. However, an approved QA program may invoke ASME NQA-1.	**Specific requirements for inspection of finished concrete and repair of regions with honeycombing.**

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STEEL-PLATE COMPOSITE (SC) RELATED QA/QC REQUIREMENTS

Composite/SC Construction QA/QC Inspections

- Nothing specified in ASME NQA-1 – this is a relatively new territory!
- IBC 2024, AISC 360, AISC 303
  - Do not address quality requirements specific to composite or SC construction
- AISC 341
  - Covers composites, does not address SC or Speedcore specifically
  - QA/QC inspection requirements geared towards composite floor systems
- AISC N690
  - Provides detailed QA/QC inspection requirements for SC construction
    - Chapter NM provides inspection and tolerance requirements for fabrication and erection
    - Chapter NN provides QA/QC requirements

Composite/SC Construction QA/QC Inspections

Chapter NM SC -specific requirements

- Dimensional tolerance, fabrication and erection requirements of Chapter NM ensure constructability and applicability of SC design equations
- Chapter NM SC-specific requirements include tolerance limits
  - (a) at fabrication shop for empty steel modules
  - (b) fit-up tolerances for ensuring connections between adjacent panels/sub-modules/modules (additional references to AWS standards and Code of Standard Practice)
  - (c) steel faceplate tolerances after concrete hardening (in addition to ACI 349 and ACI 117 requirements)
- Steel-specific requirements of Chapter NM apply to steel elements of the SC element

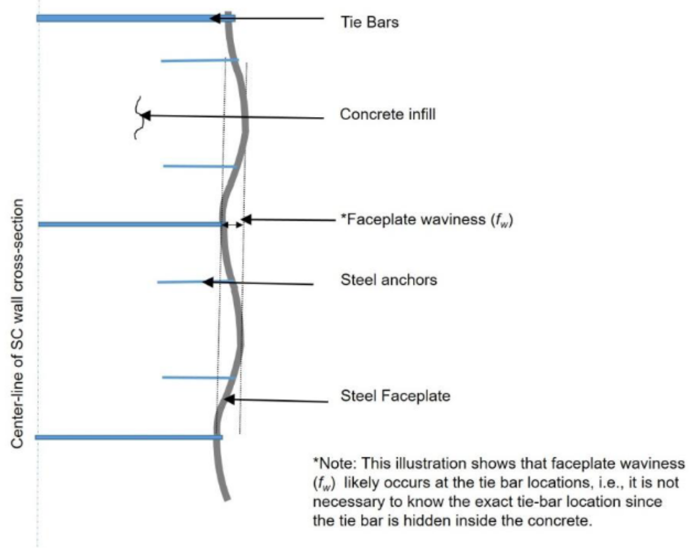

Fig. C-NM2.1. Faceplate waviness. (The faceplate waviness and the variation in tie-bar dimensions has been exaggerated for illustration purposes.)

Additionally, after concrete curing, the faceplate waviness, f_w, shall be limited to the following:

$$f_w \le \left(\frac{t_p}{2}\right)\left(\frac{s_{t,min}}{s}\right) \quad \text{(NM2-1)}$$

where

s = spacing of the steel anchors, in. (mm)
$s_{t,min}$ = minimum tie spacing, in. (mm)
t_p = thickness of faceplate, in. (mm)

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Composite/SC Construction QA/QC Inspections

Chapter NN SC -specific requirements

- Inspection requirements for SC empty steel structural element and its component steel elements before concrete placement
- Inspection requirements for SC structural element after concrete placement
- All inspection points for SC structural elements are **Perform (P)** , which is a more stringent QC activity

TABLE NN6.1
Inspection of Steel Elements of Composite Construction Prior to Concrete Placement

Inspection of Steel Elements of Composite Construction Prior to Concrete Placement	QC	QA
Verify placement and installation of steel deck and all deck accessories with construction documents	P	P
Verify size and location of welds, including support, sidelap, and perimeter welds	P	P
Verify welds meet visual acceptance criteria	P	P
Verify repair activities of decking and accessories, if applicable	P	P
Verify placement and installation of steel headed stud anchors: Check spacing, type, and installation	P	P
Verify repair activities of steel headed stud anchors, if applicable	P	P
Document acceptance or rejection of steel elements	P	P

TABLE NN6.2
Inspection of SC Structural Element Prior to Concrete Placement

Inspection of Steel Elements of Composite Construction Prior to Concrete Placement	QC	QA
Inspection of faceplates	P	P
Placement and installation of ties	P	P
Placement and installation of ~~steel anchors~~shear connectors	P	P
Document acceptance or rejection of steel elements	P	P

TABLE NN6.3
Inspection of SC Structural Element After Concrete Placement

Inspection of Steel Elements of Composite Construction after Concrete Placement	QC	QA
Inspection of faceplates	P	P
Document acceptance or rejection of steel elements	P	P

Observe (O)—The inspector shall observe these items on a random basis. Operations need not be delayed pending these inspections.
Perform (P)—These tasks shall be performed for each welded joint or member.

Composite/SC Construction QA/QC Inspections

Chapter NN SC -specific requirements

- In contrast, AISC 360's QA/QC requirements (e.g., Table J10.1) are less onerous as they are only Observe (O)
- Additionally, AISC 360 requirements do not cover multiple inspection points pertinent to SC wall construction

TABLE NN6.1
Inspection of Steel Elements of Composite Construction Prior to Concrete Placement

Inspection of Steel Elements of Composite Construction Prior to Concrete Placement	QC	QA
Verify placement and installation of steel deck and all deck accessories with construction documents	P	P
Verify size and location of welds, including support, sidelap, and perimeter welds	P	P
Verify welds meet visual acceptance criteria	P	P
Verify repair activities of decking and accessories, if applicable	P	P
Verify placement and installation of steel headed stud anchors: Check spacing, type, and installation	P	P
Verify repair activities of steel headed stud anchors, if applicable	P	P
Document acceptance or rejection of steel elements	P	P

TABLE J10.1
Inspection of Composite Structures Prior to Concrete Placement

Inspection of Composite Structures Prior to Concrete Placement	QC Task	QC Doc.	QA Task	QA Doc.
Material identification of reinforcing steel (type/grade)	O	–	O	–
If welded, determination of carbon equivalent for reinforcing steel other than ASTM A706/A706M	O	–	O	–
Proper reinforcing steel size, spacing, and orientation	O	–	O	–
Reinforcing steel has not been rebent in the field	O	–	O	–
Reinforcing steel has been tied and supported as required	O	–	O	–
Required reinforcing steel clearances have been provided	O	–	O	–
Composite member has required size	O	–	O	–

Note:
Doc. = documentation
– = indicates no documentation is required

TABLE NN6.2
Inspection of SC Structural Element Prior to Concrete Placement

Inspection of Steel Elements of Composite Construction Prior to Concrete Placement	QC	QA
Inspection of faceplates	P	P
Placement and installation of ties	P	P
Placement and installation of ~~steel anchors~~ shear connectors	P	P
Document acceptance or rejection of steel elements	P	P

Observe (O)—The inspector shall observe these items on a random basis. Operations need not be delayed pending these inspections.
Perform (P)—These tasks shall be performed for each welded joint or member.

NQA-1 Steel Construction Requirements at a glance

Requirements related to Steel Construction		
NQA-1 Provision No.	**Referenced Standard**	**Description**
801 General	ASTM A36, ASTM A441	Conformance to steel specifications
	AISC 360	Inspection of steel construction
804 High-Strength Bolting	RCSC specification, ASTM A325, A490, AISC N690	Installation of high strength bolts
	AISC N690	Procedures for verifying tension installation and job inspection torque
804.1 Inspection of Bolting	RCSC Specification, AISC N690	Bolt tension inspection
805 Welding	Section 6.0 of AWS D1.1	Inspection of structural steel welding
903 Stel Construction Test Data Evaluation and Analysis	AISC 325, AWS D1.1	Evaluation of data

ASME NQA-1 contains mostly QC requirements for welding and bolting, except for material qualification requirements in Section 801.

ASME NQA-1 STEEL CONSTRUCTION RELATED QA/QC REQUIREMENTS

Sample comparisons with AISC 3690, AISC N690, and AISC 341 requirements

Introduction

- ASME NQA-1 establishes a comprehensive framework for **Quality Assurance (QA)** programs applicable to design, construction, operation, and decommissioning of **nuclear facilities**.

- This module focuses on ASME NQA-1 requirements pertaining to **structural steel construction**

- The ASME NQA-1 requirements are summarized and sample comparisons of these requirements with similar requirements in **AISC 360, AISC N690, and AISC 341** are made

ASME NQA-1 Structural Steel Requirements

- Part II Subpart 2.5 of ASME NQA-1 provides quality assurance requirements for installation, inspection, and testing of structural steel
- The NQA-1 requirements for structural steel construction can be summarized as follows:
  - (QA) Material CMTRs showing conformance to specifications such as ASTM A36, ASTM A992 need to be documented
  - (QC) Inspection of steel construction per AISC 360 and needs to include assembly and erection operations, fastening or connecting operations (bolting and welding), and related items (e.g., baseplates)
  - (QC) High-strength bolts
    - in accordance with RCSC specification for high strength bolts and AISC N690
    - Visual inspection of bolting
    - Bolt tension inspection per RCSC specification and AISC N690
  - (QC) Welding
    - Inspection per Section 6 of AWS D1.1
    - Includes visual and NDE inspections
    - Weld repairs as necessitated by visual or NDE, and the repairs need to have documented NDE inspections

ASME NQA-1 Requirements: Sample Comparison with AISC Codes

Welding Requirements: AISC 360 vs AISC N690

TABLE N5.4-2
Inspection Tasks During Welding

Inspection Tasks During Welding	QC	QA
Control and handling of welding consumables • Packaging • Exposure control	O	O
No welding over cracked tack welds	O	O
Environmental conditions • Wind speed within limits • Precipitation and temperature	O	O
WPS followed • Settings on welding equipment • Travel speed • Selected welding materials • Shielding gas type/flow rate • Preheat applied • Interpass temperature maintained (min./max.) • Proper position (F, V, H, OH)	O	O
Welding techniques • Interpass and final cleaning • Each pass within profile limitations • Each pass meets quality requirements	O	O
Placement and installation of steel headed stud anchors	P	P

Observe (O)—The inspector shall observe these items on a random basis. Operations need not be delayed pending these inspections.
Perform (P)—These tasks shall be performed for each welded joint or member.

TABLE NN5.4.-2
Inspection Tasks During Welding

Inspection Tasks During Welding	QC	QA
Use of qualified welders	N/A	O
Control and handling of welding consumables • Packaging • Exposure control	P	O
No welding over cracked tack welds	P	O
Environmental conditions • Wind speed within limits • Precipitation and temperature	P	O
WPS followed • Settings on welding equipment • Travel speed • Selected welding materials • Shielding gas type/flow rate • Preheat applied • Interpass temperature maintained (min./max.) • Correct position (F, V, H, OH)	P	O
Welding techniques • Interpass and final cleaning • Each pass within profile limitations • Each pass meets quality requirements	P	O

N/A = not applicable

ASME NQA-1 Requirements:
Sample Comparison with AISC Codes

Bolting Requirements: AISC 360 vs AISC N690

TABLE N5.6-2
Inspection Tasks During Bolting

Inspection Tasks During Bolting	QC	QA
Fastener assemblies placed in all holes, and washers and nuts are positioned as required	O	O
Joint brought to the snug-tight condition prior to the pretensioning operation	O	O
Fastener component not turned by the wrench prevented from rotating	O	O
Fasteners are pretensioned in accordance with the RCSC *Specification*, progressing systematically from the most rigid point toward the free edges	O	O

TABLE N5.6-3
Inspection Tasks After Bolting

Inspection Tasks After Bolting	QC	QA
Document acceptance or rejection of bolted connections	P	P

TABLE NN5.6-2
Inspection Tasks During Bolting

Inspection Tasks During Bolting	QC	QA
Fastener assemblies placed in all holes and washers (if required) are positioned as required	P	O
Joint brought to the snug-tight condition prior to the pretensioning operation	P	O
Fastener component not turned by the wrench prevented from rotating	P	O
Fasteners are pretensioned in accordance with a method approved by the RCSC *Specification* and progressing systematically from the most rigid point toward the free edges	P	O

Table NN5.6-3
Inspection Tasks After Bolting

Inspection Tasks after Bolting	QC	QA
Document acceptance or rejection of bolted connections	P	O

The Conundrum of How Much QA/QC is enough?

- Because of the various unaccounted uncertainties, use of graded (consequence dependent) QA/QC measures during design and construction phases is necessary for reduction of their impact.

- The difficult question is what is enough or how much is too much even after we factor in the consequences?

- The QA/QC practices used for commercial applications, which are graded (e.g., based on ASCE 7/IBC Seismic Design Category) are a good reference point/baseline; however, they have not been validated using a reliability framework.

- On the other hand, many of the current QA/QC practices for nuclear structures are deemed to be rather onerous and possibly out-of-date, and they too have not been validated using a reliability framework.

How to Select Rational Basis for QA/QC Requirements?

- Can we establish a reliability-based framework (and reliability baselines) for assessing the QA/QC practices in nuclear (and commercial) applications?

- How to evaluate/calibrate the various QA/QC measures in a graded manner (e.g., in recognition of the structure's safety significance (consequences of failure), design limit state, and the relative performance impact of specific members and connections)?

- How can we use available and/or yet-to-be-performed testing-based findings to threshold/assess impact of potentially undetected errors or shortcomings?

- How can we bring to bear the benefits of automation, and modern/emergent construction, fabrication, concrete mixing, steel production practices, etc., for reducing QA/QC requirements?

- How can we bring to bear new non-destructive monitoring techniques and digital engineering/digital twin related tools (e.g., photogrammetry, embedded sensors, etc.) to redefine or calibrate some of the QA/QC requirements?

Perhaps a combination of the above approaches (and more) and a vigorous stakeholder engagement is needed for devising rational QA/QC requirements

Suggestions for Path Forward

Need an industry wide effort involving a team of Owner reps, NRC/DOE reps, code/standard committee reps, SMEs, and fabricators/constructors!

1. Explore if and how a reliability-based framework can be developed to evaluate the efficacy of various QA/QC programs, including for specific items that are deemed to be more egregious
2. Explore opportunities to apply QA/QC requirements in a graded manner based on structure's importance (failure consequences), design limit state, and relative importance of specific members and connections within the structure
3. Explore if and how we can use test data and / or numerical models to assess impact of certain types of undetected errors (possibly using a reliability-based framework)
4. Explore if and how improved construction/fabrication and material production practices in the past few decades may lead to improved nuclear QA/QC practices
5. Demonstrate how increasing use of automation and its expanded adoption could further improve some of the QA/QC requirements
6. Demonstrate how emerging trends and tools such as digital engineering, digital twin, and drones, sensors, etc., can alleviate / redefine (and thus improve) some of the QA/QC requirements

To craft a path forward, poll a team of SMEs, Owner Reps, NRC/DOE Reps, and Fabricators /Constructors to help draft a research proposal for the next phase