Fitness for purpose: the perspective of two California licensed SEs

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Chair, ASCE DANS Committee
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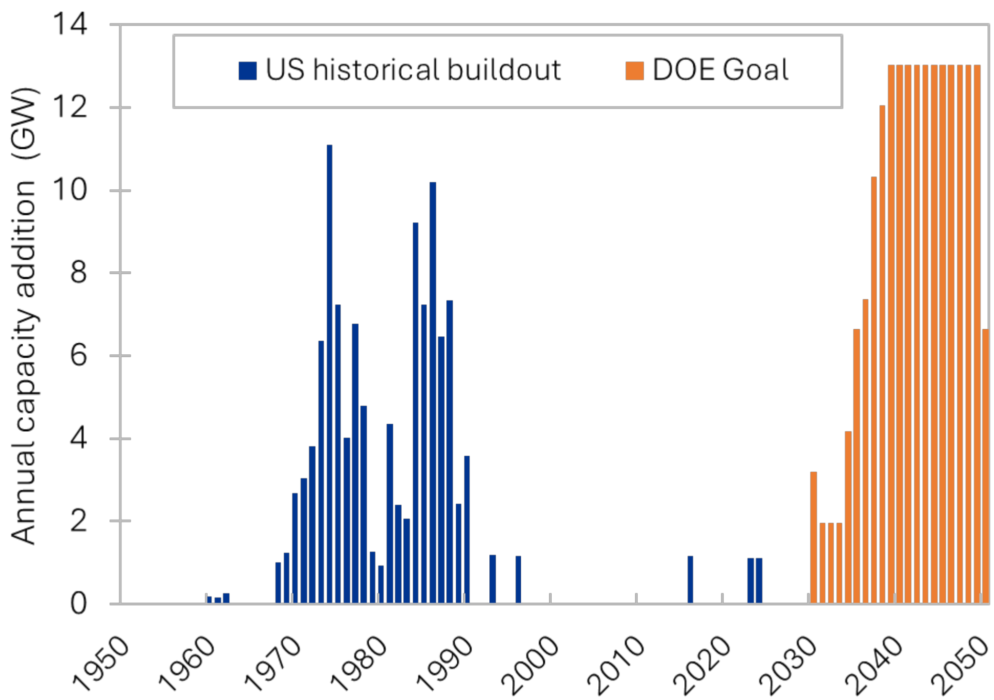
Chair, ASCE Nuclear Standards Committee

NRIC, Washington, DC, December 2024

W. Robb Stewart (Alva) and DOE LPO



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Fitness for purpose: high quality civil structures*

- Non-nuclear civil standards?
  - ASCE/SEI 7 and 41
  - ACI 318
  - AISC 360 and 341
  - Standards referenced therein, including ASTM
- Non-nuclear standards deliver what?
  - Limit State A through Limit State D
  - Performance-based seismic design, since mid 1990s
- Domain experts
  - Ron Hamburger, P.E., S.E., NAE; Fred Grant, P.E.; SGH
  - Jim Malley, P.E., S.E., NAE; Degenkolb

Ferrari, electric, $500K

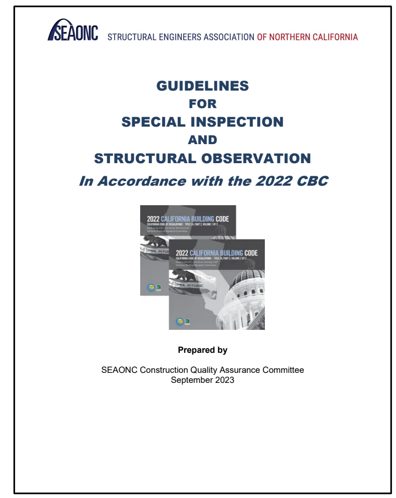
Porsche, electric, $200K

❖ Both fast enough to break the speed limit, three times over

Fitness for purpose: high quality civil structures

Porsche, 2024

- **Proven** ingredients for **sufficient** quality
  - Experienced design team, with construction experience
  - Contractor engagement
  - Peer review
  - Materials
  - Analysis, design, and detailing
  - Construction documents, including drawings and specifications
  - Construction supervision by EoR and licensed engineers
  - Special inspection
- Nuclear is **not** special, just another building



SEAONC STRUCTURAL ENGINEERS ASSOCIATION OF NORTHERN CALIFORNIA

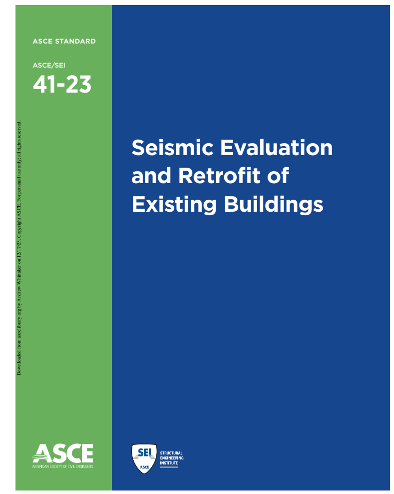
GUIDELINES
FOR
SPECIAL INSPECTION
AND
STRUCTURAL OBSERVATION
In Accordance with the 2022 CBC

Prepared by

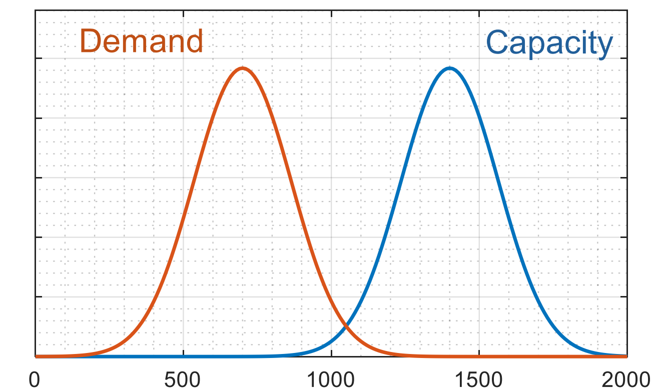
SEAONC Construction Quality Assurance Committee
September 2023

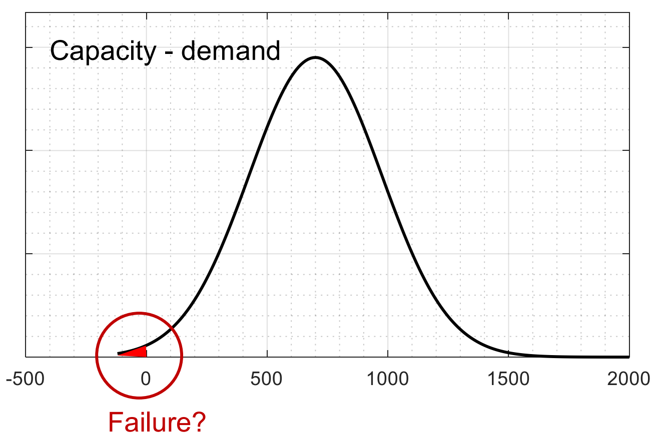
Analysis, design, and detailing for civil structures

- Analysis and design
  - US nuclear lags non-nuclear sectors by decades
  - Adopt innovations in non-nuclear: buildings, infrastructure, oil, gas
    - Sufficient safety is delivered at lowest cost, in shortest time
  - BIM, digital twins, nonlinear analysis, PBD, and *advanced* materials **more mature** in non-nuclear sectors
  - Merging and update of ASCE 4 and 43
    - To adopt best practice in non-nuclear sectors, wherever possible



An inconvenient truth





Hypotheses

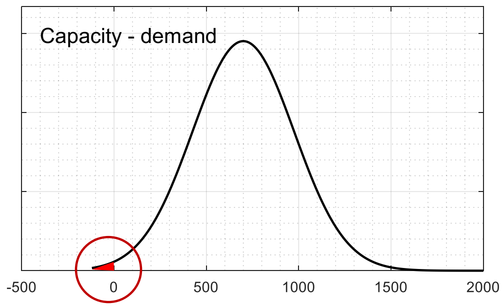
- Modern standards treat loads and strengths as random variables that can be fit to statistical distributions
- Component failure is postulated to occur when the randomly low strength falls below a randomly high load
- Bell curves, and thus failure rates, can be calculated from standards and QA/QC measures, as shown in the graph
- These graphs suggest that imposing ever more onerous QA/QC to *skinny-up* the bell curves will make failure much less likely

And wrong

- Nowak* and others show actual failure rates to be much higher than calculated (2+ orders of magnitude)
- Why? Almost all structural failures are due to **human error** in design and construction not contemplated in these curves
- How do we prevent these mistakes?
  - Independent design peer reviews
  - Special inspections by knowledgeable professionals
  - Simplifying (but not weakening) standards and regulations

* *Reliability of Structures*, Nowak and Collins, 2000

An inconvenient truth



Load and resistance factors for components (not including earthquakes) are derived such that the calculated failure probability (red area under failure function) is consistent with the nature of the failure and potential consequences.

Systems are different, and performance-based design of *lateral force resisting systems* for earthquake resistance requires additional consideration.

Table 1.3-1. Target Reliability (Annual Probability of Failure, P_F) and Associated Reliability Indices (β) for Load Conditions That Do Not Include Earthquake, Tsunami, or Extraordinary Events.

Basis	Risk Category I	Risk Category II	Risk Category III	Risk Category IV
Failure that is not sudden and does not lead to widespread progression of damage	$P_F = 1.25 \times 10^{-4}$ per year $\beta = 2.5$	$P_F = 3.0 \times 10^{-5}$ per year $\beta = 3.0$	$P_F = 1.25 \times 10^{-5}$ per year $\beta = 3.25$	$P_F = 5.0 \times 10^{-6}$ per year $\beta = 3.5$
Failure that is either sudden or leads to widespread progression of damage	$P_F = 3.0 \times 10^{-5}$ per year $\beta = 3.0$	$P_F = 5.0 \times 10^{-6}$ per year $\beta = 3.5$	$P_F = 2.0 \times 10^{-6}$ per year $\beta = 3.75$	$P_F = 7.0 \times 10^{-7}$ per year $\beta = 4.0$
Failure that is sudden and results in widespread progression of damage	$P_F = 5.0 \times 10^{-6}$ per year $\beta = 3.5$	$P_F = 7.0 \times 10^{-7}$ per year $\beta = 4.0$	$P_F = 2.5 \times 10^{-7}$ per year $\beta = 4.25$	$P_F = 1.0 \times 10^{-7}$ per year $\beta = 4.5$

More people at risk

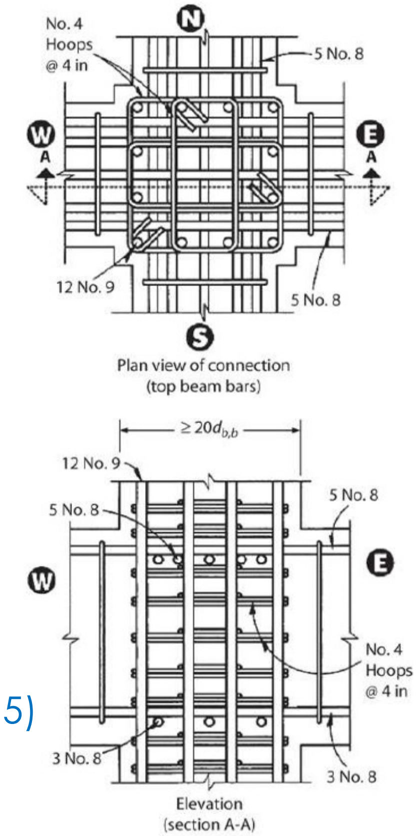
More sudden and/or devastating

Delivering quality in non-nuclear, mission-critical structures

- CA structural engineers recognized decades ago that mission-critical structures needed additional (over the then baseline) quality measures to assure sufficient performance. **Three** aspects of enhanced QA/QC have been codified :
  - **Design peer review**: independent evaluation by domain experts to determine whether the design meets specified performance objectives by reviewing design assumptions, simplifications, analysis methods, and calculated responses: see next slide
  - **Special inspections**: monitoring of materials and workmanship that are critical to the integrity of the building structure to provide assurance that a project complies with the design and regulations
  - **Structural observations**: visual observation by a licensed engineer of the structural system for general conformance with the design

Peer review of civil structures

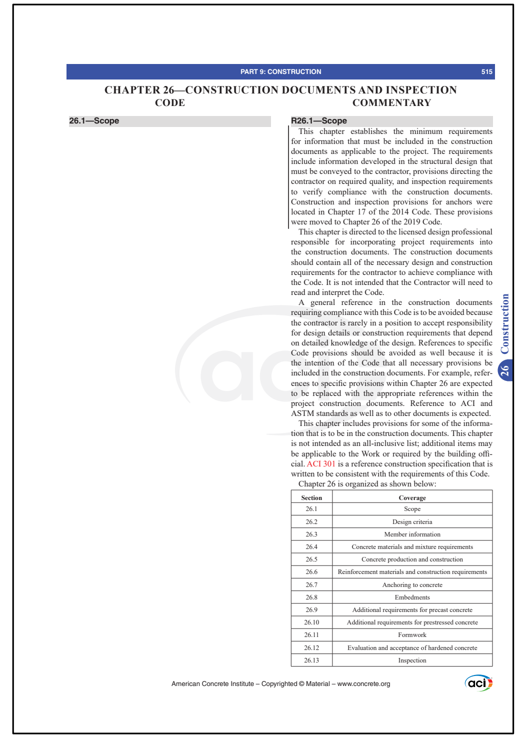
- Scope
  - High-level, and **not** to replace regulator plan check
  - Design criteria
  - **Engineered** hazard analysis (e.g., seismic, flood, wind)
  - Geotechnical engineering, including foundations
  - Structural engineering
  - Nonlinear dynamic analysis, including ISRS
  - Seismic isolation, if used
  - Specifications, if non-typical
  - Construction details (e.g., main components and connections)



Moehle (2015)

Materials for civil structures

- Concrete
  - Addressed in Chapters 19 and 26 of 318-19
  - Cylinder test is primarily for quality control
  - On-site testing
  - 28-day compressive strength, f_c, including Section 26.12.3.1,
    - ACI 214R-11, 1% probability less than f_c
  - Long-term, in-service strength between 130% and 150% of f_c
  - **Conclusion**: in-service strength will virtually always exceed f_c
- Is a 25% change in f_c important for reinforced concrete?
  - Flexural strength: insignificant, why?
  - Shear strength of beams, columns, walls: insignificant, why?
  - Axial strength: insignificant, why? 0.85 per Richart at UIUC (1930)
  - Even less important for deformation capacity (Limit States A, B, and C)


PART 9: CONSTRUCTION 515

CHAPTER 26—CONSTRUCTION DOCUMENTS AND INSPECTION

CODE

26.1—Scope

COMMENTARY

R26.1—Scope

This chapter establishes the minimum requirements for information that must be included in the construction documents as applicable to the project. The requirements include information developed in the structural design that must be conveyed to the contractor, provisions directing the contractor on required quality, and inspection requirements to verify compliance with the construction documents. Construction and inspection provisions for anchors were located in Chapter 17 of the 2014 Code. These provisions were moved to Chapter 26 of the 2019 Code.

This chapter is directed to the licensed design professional responsible for incorporating project requirements into the construction documents. The construction documents should contain all of the necessary design and construction requirements for the contractor to achieve compliance with the Code. It is not intended that the Contractor will need to read and interpret the Code.

A general reference in the construction documents requiring compliance with this Code is to be avoided because the contractor is rarely in a position to accept responsibility for design details or construction requirements that depend on detailed knowledge of the design. References to specific Code provisions should be avoided as well because it is the intention of the Code that all necessary provisions be included in the construction documents. For example, references to specific provisions within Chapter 26 are expected to be replaced with the appropriate references within the project construction documents. Reference to ACI and ASTM standards as well as to other documents is expected.

This chapter includes provisions for some of the information that is to be in the construction documents. This chapter is not intended as an all-inclusive list; additional items may be applicable to the Work or required by the building official. ACI 301 is a reference construction specification that is written to be consistent with the requirements of this Code.

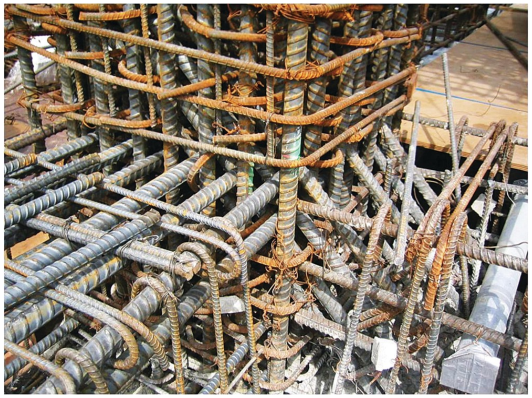
Chapter 26 is organized as shown below:

Section	Coverage
26.1	Scope
26.2	Design criteria
26.3	Member information
26.4	Concrete materials and mixture requirements
26.5	Concrete production and construction
26.6	Reinforcement materials and construction requirements
26.7	Anchoring to concrete
26.8	Embedments
26.9	Additional requirements for precast concrete
26.10	Additional requirements for prestressed concrete
26.11	Formwork
26.12	Evaluation and acceptance of hardened concrete
26.13	Inspection

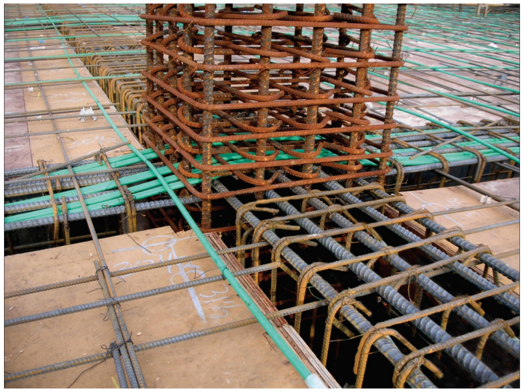
26 Construction

Analysis, design, and detailing for civil structures

- Detailing
  - Key to performance, irrespective of limit state
    - Quality and construction experience of the design team
  - Tolerances, spacing requirements, etc., per ACI 318, AISC 360, AISC 341 appropriate for nuclear structures



Take your pick



F. Grant, SGH, 2024

Fitness for purpose, the perspective of two CA licensed SEs

- Non-nuclear US civil standards?
  - More than sufficient for **high quality** US nuclear facilities
    - 10s of 1000s of examples
    - **No additional work is needed**
  - Innovation in the non-nuclear sectors, often decades before
    - Codes, standards, guidance
    - Performance-based seismic design since mid 1990s
  - Evidence of poorly performing, code-compliant buildings?
    - None, failures due to poor quality engineering and not materials
- Need to work with the USNRC to right size requirements for delivering high quality civil structures

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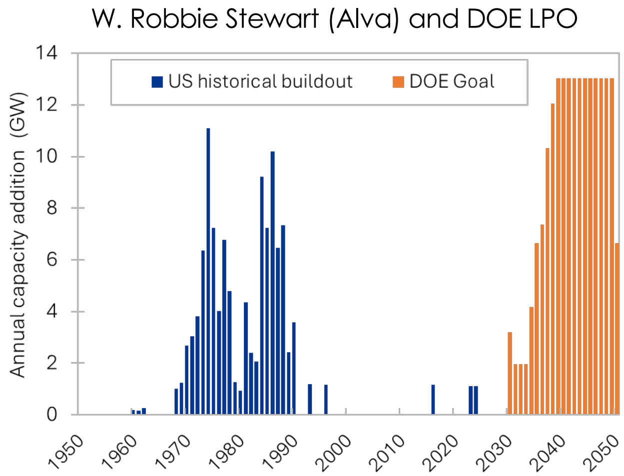

NRIC, Washington, DC, December 2024