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RECORD OF REVISIONS

Rev	Date	Description	POC	OIC
0	6/28/99	Initial issue in Facility Eng Manual.	Doug Volkman, *PM-2*	Dennis McLain, *FWO-FE*
1	2/09/04	Incorporated IBC & ASCE 7 in place of UBC 97; incorporated DOE-STD-1020-2002 versus 1994 and concepts from DOE O 420.1A; FEM became ESM, an OST.	Mike Salmon, *FWO-DECS*	Gurinder Grewal, *FWO-DO*
2	5/17/06	Major revision: Reduced commentary in favor of IBC 2003 amendments only; clarification of PC-0 applicability; OST became ISD.	Mike Salmon, *D-5*	Mitch Harris, *ENG-DO*
3	10/27/06	Administrative changes only. Organization and contract reference updates from LANS transition; 420.1A became 420.1B. IMP and ISD number changes based on new Conduct of Engineering IMP 341. Master Spec number/title updates. Other administrative changes.	Mike Salmon, *D-5*	Kirk Christensen, *CENG*
4	6/19/07	Incorporated new seismic hazard analysis results into the seismic design parameters (1.7.1); supersedes Salmon interim guidance of 1/22/07 (D5:07-021). Added Appendix A on concrete anchor design.	Mike Salmon, *D-5*	Kirk Christensen, *CENG*
5	6/16/08	Incorporated IBC 2006 & ASCE 7-05 in place of IBC 2003 & ASCE 7-02; minor App A changes.	Mike Salmon, *D-5*	Kirk Christensen, *CENG*

Contact the Structural Standards POC
for upkeep, interpretation, and variance issues

Ch. 5, Section II	**Structural POC/Committee**

This Chapter is online at http://engstandards.lanl.gov

II PC-0, PC-1, & PC-2 DESIGN & ANALYSIS REQUIREMENTS

A. This Section provides the minimum requirements for the structural design and analysis of PC-0, PC-1, and PC-2 building structures, nonstructural components, and non-building structures at LANL, including programmatic equipment. Structural design procedure generally consists of the following:

- Establish structural arrangement/geometry
- Establish loads and load combinations
- Establish a complete load path for vertical and horizontal loads
- Evaluate the structural response to the loads
- Specification of structural capacity and drift limits (acceptance criteria)
- Special design considerations, such as ductile detailing requirements

B. Following the graded approach philosophy outlined in DOE Order 420.1B, "Facility Safety," and implemented in guidance document DOE G 420.1-2 and design/evaluation standard DOE-STD-1020, PC-1 and PC-2 Structures, Systems, and Components (SSC) design, tests, inspections, observations, quality, and construction shall follow the provisions of the International Building Code (IBC; edition and amendments per ESM Chapter 16, IBC Program) and IBC Chapters 16 through 23, as further amended below (citations based on IBC 2006). PC-0 recognizes that for certain lightweight equipment items, furniture, etc, and for other special circumstances where there is little or no potential impact on safety, mission, or cost, design or evaluation for natural phenomena hazards may not be needed. Assignment of an SSC to PC-0 is intended to be consistent with, and not take exception to, model building code NPH provisions.

C. Note that Chapter 6 – Mechanical, and Chapter 7 – Electrical, and others of this ESM also contain design requirements for many nonstructural components, and non-building structures.

D. Loads listed in this Section shall be used in the design of PC-0, PC-1, and PC-2 SSC. Criteria for assessment and mitigation for other natural phenomena loads listed in Appendix C of DOE G 420.1-2 are documented in "Design-Load Basis for LANL Structures, Systems, and Components," LANL Report No. LA-14165 [6]. This report [6] provides the basis for the loads, analysis procedures, and codes to be used in this Chapter.

E. **Nuclear Facilities**: Per ESM Chapter 1 Section Z10 (Codes and Standards subsection), significant nuclear facility projects require compliance with DOE-STD-1189, *Integration of Safety into the Design Process.* Appendix A of DOE-STD-1189 requires new methodology for seismic design, and ESM Chapters 5 and 12 have not yet been revised to reflect this; however, the structural designer remains responsible for following DOE-STD-1189 and should seek clarification from the ESM Chapter 5 POC when doing so.

1.0 IBC CHAPTER 16 STRUCTURAL DESIGN

1.1 SECTION 1604 GENERAL DESIGN REQUIREMENTS

A. **1604.5 Occupancy category.** Add the following text:

PC-0 SSC shall be Occupancy Category I. PC-1 SSC shall be Occupancy Category II. PC-2 SSC shall be Occupancy Category IV.

1.2 SECTION 1605 LOAD COMBINATIONS

1.2.1 1605.2 Load combinations using strength design or load and resistance factor design

A. **1605.2.2 Other loads.** Add the following text:

Ice loads shall be considered in accordance with Section 2.3.4 of ASCE 7.

1.2.2 1605.3 Load combinations using allowable stress design.

A. **1605.3.1 Basic load combinations.**

- **1605.3.1.2 Other loads.** Add the following text:

  Ice loads shall be considered in accordance with Section 2.4.3 of ASCE 7.

B. **1605.3.2 Alternative basic load combinations.** Add the following text:

The alternative basic load combinations shall not be used for anchorage design of SSCs.

1.3 SECTION 1606 DEAD LOADS

1.3.1 Add **1606.3 Future floor dead load.**

An allowance for a 10-psf future dead load in addition to project dead loads shall be included for the floors (not roofs) of new PC-1 and PC-2 buildings.[1] However, this allowance shall not be used with equations 16-6, -7, -14, -15, -21, and -23.

1.4 SECTION 1607 LIVE LOADS

1.4.1 1607.8 Impact loads.

A. Add **1607.8.3 Experimental explosion loads.**

1. Reactions from experimental explosion containment structures, due to explosions, shall be considered live loads.
2. External loads from experimental explosions shall be calculated in accordance with DOD TM 5-1300 and shall be considered live loads.

1.4.2 1607.11 Roof loads

A. **1607.11.2 Reduction in roof live loads.**

- **1607.11.2.1 Flat, pitched and curved roofs.** Substitute the following text:
  The minimum roof live load shall be taken as 30 psf for PC-1 and PC-2 buildings.[2] The minimum roof live load shall not be reduced.

[1] Not required for PC-0 since these tend to be pre-engineered structures for which this would be cost prohibitive.
[2] Same as footnote 1.

1.5 SECTION 1608 SNOW LOADS

A. **1608.2 Ground snow loads.** Substitute the following text:

The ground snow load shall be taken as 16 psf.

1.6 SECTION 1609 WIND LOADS

A. **1609.3 Basic wind speed.** Substitute the following text:

The basic wind speed shall be taken as 90 mph (i.e., 3-second gust).[3]

B. **1609.4 Exposure category.** Substitute the following text:

The wind exposure category shall be taken as Exposure C.

1.7 SECTION 1613 EARTHQUAKE LOADS

1.7.1 1613.5 Seismic ground motion values.

A. **1613.5.4 Design spectral response acceleration parameters.** Substitute the following text: Five-percent damped design spectral response acceleration at short periods, S_{DS}, = 0.75 g, and at 1-second period, S_{D1}, = 0.64 g.

Replace in Sections 11.3 and 11.4.5 of ASCE 7, the definition for T_o from $T_o = 0.2\ S_{D1}/S_{DS}$ to T_o = 0.1 sec.

B. **1613.5.6 Determination of seismic design category.** Substitute the following text: The seismic design category shall be taken as Seismic Design Category D.

1.7.2 Add **1613.7 Foundations.**

A. Foundations shall not be designed in locations that are within 50 feet of known active faults. Hazardous waste treatment, storage and disposal facilities must not be located within 200 feet of a fault that has had displacement in Holocene time (the most recent time of Quaternary period, 11,000 years) regardless of their performance category per 40 CFR 264.

B. To mitigate potential differential movements associated with surface faulting during the design-level earthquake, the design shall provide for a minimum horizontal and vertical differential movement between footings of ½ inch for PC-2 structures unless greater movement is indicated by geotechnical investigation.

C. The perimeter basement walls, and other subterranean structural walls, shall be designed for soil pressures, including potential seismic loads, as recommended by a licensed geotechnical engineer knowledgeable of LANL soil conditions. An alternative for obtaining potential seismic loads is use of the Elastic Solution in ASCE 4 (para. 3.5.3.2).

[3] Note that DOE-STD-1020 states that the basic wind load, V, for PC-2 SSCs at LANL is 96 mph, and the importance factor, I is 1.0. Nevertheless, the velocity pressure due to wind loads in ASCE 7 Eq. 6-15 is the same if V = 90 mph and I = 1.15 (ASCE 7 Table 6-1 for Category IV) are used instead.

1.7.3 Add **1613.8 Additional requirements for architectural, mechanical, and electrical components, and their supports and attachments.**

A. Replace the following text in ASCE 7, Section 13.4.2, "The anchor is designed in accordance with Section 14.2.2.14," with the following text:

The design strength of anchors in concrete shall be determined in accordance with the provisions of IBC Section 1912 as amended below in this Section.

1.8 Add **SECTION 1614 ICE LOADS.**

Ice-sensitive structures, such as trussed towers, cable-supported structures, etc., shall consider the additional effects of ice loads in accordance with ASCE 7 Chapter 10.

1.9 Add **SECTION 1615 ACCIDENTAL BLAST LOADS.**

1. Permanent explosive facilities shall comply with DOD TM 5-1300 and, as applicable, DOD UFC 3-340-01.

2. The design of all new facilities, or those with major modifications, shall conform to DOE M 440.1-1A Explosives Safety Manual requirements for either accidental explosions of explosives or vapor cloud explosions. Protective construction design features are provided in DOD TM 5-1300 and DOD UFC 3-340-01. When evaluating for accidental blast load, A_B, the loading A_B shall replace E (earthquake) loads in the load combination equations. All potential blast effects shall be considered including blast overpressure, gas pressure, fragments, and ground shock.

1.10 Add **SECTION 1616 MINIMUM ANTITERRORISM STRUCTURAL DESIGN MEASURES.**

Structural design measures on progressive-collapse avoidance and window protection, presented in DOD UFC 4-010-01, shall be considered for those buildings where there is a credible terrorist threat. LANL shall specify whether these minimum antiterrorism measures are to be implemented; see also ESM Chapter 9, Facility Protection and Security.

2.0 IBC CHAPTER 17 STRUCTURAL TESTS AND SPECIAL INSPECTIONS

Refer to LANL ESM Chapter 16, IBC Program for LANL amendments to this and other IBC chapters.

3.0 IBC CHAPTER 18 SOILS AND FOUNDATIONS

3.1 SECTION 1805 FOOTINGS AND FOUNDATIONS.

3.1.1 1805.1 General.

Add the following text: Permanent buildings and similar structures shall have a permanent foundation (e.g., full perimeter support, rodent-excluding, no trailer skirting, etc.). Permanent is defined in ESM Chapter 1, Section Z10[4].

[4] LANL experience is that permanent foundations reduce O&M costs by minimizing settling that causes roof and structure cracks, excluding rodents and other pests, and improving energy efficiency by virtue of their superior insulation.

3.1.2 1805.4 Footings.

A. **1805.4.2.2 Footing Seismic ties.** Substitute the following text:

Interconnect all spread-footing-type foundations using tie beams. The tie beam shall be capable of resisting, in tension or compression, a minimum horizontal force equal to 10% of the larger column vertical load. The tie beams shall also be capable of resisting bending due to prescribed differential settlements of the interconnected footings, as stipulated by the project geotechnical engineer.[5]

4.0 IBC CHAPTER 19 CONCRETE

4.1 SECTION 1912 ANCHORAGE TO CONCRETE – STRENGTH DESIGN

A. Anchorage to concrete shall follow Section II, Appendix A

5.0 IBC CHAPTER 20 ALUMINUM

No change.

6.0 IBC CHAPTER 21 MASONRY

No change.

7.0 IBC CHAPTER 22 STEEL

No change.

8.0 IBC CHAPTER 23 WOOD

No change.

[5] LANL-specific requirement for conservatism.

APPENDIX A – DESIGN OF ANCHORS IN CONCRETE

A.1 DESCRIPTION

A. This appendix establishes the technical design requirements for designing concrete anchors for PC-0, PC-1, and PC-2 Structures Systems, and Components (SSCs) at Los Alamos National Laboratory (LANL). There are different design criteria for PC-3 and PC-4 concrete anchors. An anchor acceptable for a higher safety classification (PC-3 and PC-4) may be used for a lower PC application.
B. Cast-in anchors: This appendix covers the design of the following cast-in anchors: Headed bolts, bolts with embedded nuts, or headed studs. Cast-in anchors are generally ASTM A36, A307, A354, A449, A193, or F1554 material. ASTM F1554 is the preferred material due to its excellent ductile properties, as well as its being manufactured in longer lengths (i.e., relative to other material types) that could be required by some anchorage designs. Welding and mechanical properties of headed studs shall comply with AWS D1.1 and ESM Chapter 13, Welding and Joining.
C. Post-installed (PI) concrete anchors: This appendix covers the design of the following types of PI anchors: expansion, adhesive, undercut, and powder actuated fasteners. Grouted rebar is also covered. Purchase, installation, and testing requirements for PI anchors are given in the LANL Master Specification Sections listed below
D. Not Included: Design of concrete anchors for PC-3 and PC-4 SSC.
E. Definitions: Definitions of anchors per ACI 355.1R and ACI 355.2 apply.

A.2 APPLICABLE CODES

IBC	International Building Code by International Code Council (ICC), edition per ESM Ch 16

A.3 APPLICABLE INDUSTRY STANDARDS AND REPORTS[6]

ACI 355.2	Qualification of Post-Installed Mechanical Anchors in Concrete and Commentary
ACI 355.1R	State-of-the-Art Report on Anchorage to Concrete
ACI 318	Building Code Requirements for Structural Concrete and Commentary
ICC ES Reports	ICC Evaluation Services Reports (http://www.icc-es.org/)

A.4 LANL DOCUMENTS

Master Spec Section 03 1512	Post-installed concrete anchors purchase – High Confidence
Master Spec Section 03 1534	Post-installed concrete anchors purchase – Normal Confidence
Master Spec Section 03 1550	Post-installed concrete anchors – Installation and Testing
ESM Chapter 13	Welding and Joining
ESM Chapter 16	IBC Program, Section IBC-GEN

A.5 PERFORMANCE CATEGORY CLASSIFICATION

A. The Engineer of Record shall determine if an attachment is PC-1, PC-2, PC-3, or PC-4. For example, anchorage for a PC-1 or -2 pump being installed on a PC-3 or -4 concrete slab is considered PC-1 or -2. Documentation of whether a system is PC-1, -2, -3 or -4 may be obtained from the LANL FIMS database or contact the ESM Structural POC for guidance.
B. Anchors for PC-1 and PC-2 systems for which failure could compromise a PC-3 or PC-4 system shall be designated as PC-3 or PC-4 to account for seismic ‘II over I’ or ‘III over I’ design basis

[6] As a minimum, use standard edition referenced by required IBC edition; more recent also acceptable.

issues. Engineering drawings shall indicate the designated Performance Category. A higher safety class design (PC-3 or PC-4) can be used in lower safety class applications (PC-1 or PC-2).

A.6 Environmental Conditions

A. Anchors for indoor use in non-aggressive chemical environments may be carbon steel with zinc electroplating. Anchors for use outdoors or in aggressive environments should be galvanized or made of stainless steel.

A.7 Non-Structural Anchors

A. Non-structural anchors support very light loads and subsequently are exempt from being "designed anchors." PI anchors for use in non-structural applications shall be chosen from qualified anchors in compliance with the IBC and ESM Chapter 16, IBC Program.
B. A non-structural application must meet the following criteria:
   1. Are PC-1 mechanical and electrical components with flexible connections between the components and associated ductwork, piping, and conduit and
   2. Also meet any of the following conditions:
      a. Components are mounted at 4 ft or less above a floor level and weigh 400 lb or less, or
      b. Components weighing 20 lb or less, or
      c. Distribution systems weighing 5 lb/ft or less.

A.8 Powder-Actuated Fasteners

A. Powder-actuated fasteners may be used for attachment to concrete. Structural applications must be designed to resist applied forces and displacements. Powder-actuated fasteners shall not be used for seismic tension loading unless approved for such loading in their ICC ES report and in compliance with the IBC. Design shall comply with all requirements of the ICC ES report (including minimum spacing, edge distance, allowable loads, etc.).

A.9 Grouted Rebar

A. Rebar may be post-installed into hardened concrete by using an epoxy, acrylic, or cementitious grout. The allowable load and embedment depth for epoxy and acrylic grouted rebar shall be determined per the ICC ES Report. In cases where the ICC report does not give an embedment depth sufficient to develop the full design strength of the bar, use an embedment depth equal to the development length of the bar being post-installed.
B. Embedment length of grouted rebar or threaded rod shall be determined per manufacturer design guides, subject to the ESM Structural POC approval.

A.10 General Design Requirements

A. PI anchors and surface mounted plates are limited to applications where support requirements are added or modified after concrete placement, except for lightly loaded items where an embedded plate is not economical. For heavy loads, cast-in-place embeds should be used in lieu of PI anchors where possible.
B. Anchors for vibrating and rotating machineries: only cast-in place (CIP) or PI undercut anchors shall be used.
C. Use of PI anchors shall comply with the following:
   1. PI anchors shall not be installed through liner plate.
   2. To minimize rebar damage during anchor installation, the PI anchor design shall provide for limited anchor relocation (at least ± 1 inch) to facilitate anchor installation. Due

consideration shall be given to the location tolerances of the anchors to avoid interferences with reinforcement.

3. Welding base plates to high-strength or non-weldable PI anchors is not permitted.
4. PI anchors shall not be used in masonry walls. Through-bolting may be an acceptable alternative.
5. PI anchors shall not be located in the bottom of precast and pre/post-tensioned T-beams stems. PI anchors in the sides of the T-beam stems shall be designed and approved by the Engineer of Record.
6. Adhesive anchors shall not be used where they are subjected to sustained tension load (e.g., overhead applications)[7].
7. Adhesive anchors shall not be used in high temperature service or in high radiation environments. See manufacturer's data and ICC ES reports for reduced allowable strength at elevated temperatures and limitations on aggressive exposure conditions including fire. At elevated temperatures where strength reduction is significant for epoxy and adhesive anchors, consider the use of cementitious grout.

A.11 DESIGN REQUIREMENTS

A. Anchors approved for use at LANL for PC-0, PC-1, and PC-2 SSCs must be in compliance with the IBC as amended below (sections based on IBC 2006).

B. **Section 1704.13 Special Cases.** Add the following text: Special case components such as anchors are subject to LANL Building Official approval per ESM Chapter 16, IBC Program (Section IBC-GEN Subsection 6.2).

C. **Section 1908.1.16 ACI 318, Section D.3.3.**

Delete IBC modification D.3.3.5

D. **Section 1912.1 Scope.** Add the following text after first paragraph:

PI anchors may be used in lieu of CIP anchors provided either 1912.2 or 1912.3 are met.

E. Add **Section 1912.2 Ductile PI anchors.** The strength of ductile PI anchors is governed by ductile yielding of a steel element.

- **1912.2.1 Ductile PI anchor applicability.** Either ductile PI anchors or CIP anchors shall be used for the following circumstances:
  1. Column anchorage for vertical bracing with a height greater than 12 feet.
  2. Fixed-base column anchorage for moment-resisting frames which are part of the seismic-force-resisting system.
  3. Any component, greater than 12-feet high, which transfers lateral seismic loads to the foundation.

  Ductile anchors may be used for any structure, system or component.

- **1912.2.2 Ductile PI anchor criteria.** Ductile PI anchors shall be designed and evaluated in accordance with Appendix D of ACI 318 as modified by Section 1908.1.16.

F. Add **1912.3 Brittle PI anchors[8].** The strength of brittle PI anchors is governed by brittle behavior (i.e., tension or shear on a brittle steel element; concrete breakout, side-face blowout,

[7] Adhesive creep issue; ref. Bechtel Corporation Engineering Data Letter, Post Installed Adhesive Anchors, 3DL-C13-00001 Rev. 000 March 17, 2008

pullout, or pryout). All anchors shall be assumed to have brittle behavior unless ductile behavior has been demonstrated by meeting Appendix D, paragraphs D.3.3.1 through D.3.3.5, of ACI 318.

- **1913.3.1 Brittle PI anchor applicability.** Brittle PI anchors shall not be used where ductile PI anchors are required.

- **1913.3.2 Brittle PI anchor criteria.** The capacity of brittle PI anchors shall be developed from either 1 (strength design) or 2 (ASD):

1. $\text{Capacity} = \begin{cases} \dfrac{0.6}{R_p} \times \phi N_n \\ \dfrac{0.6}{R_p} \times \phi V_n \end{cases}$ 2. $\text{Capacity} = \begin{cases} \dfrac{0.6\lambda}{R_p} \times N_{allowable} \\ \dfrac{0.6\lambda}{R_p} \times V_{allowable} \end{cases}$

in which: ϕN_n and ϕV_n are calculated in accordance with Appendix D of ACI 318, excluding paragraph D.3.3 and $0.6/R_p \leq 0.4$.
$N_{allowable}$ and $V_{allowable}$ are manufacturer's allowable working capacities, per an International Code Council Evaluation Service report (ICC-ES ER/ESR), based on the manufacturer's recommended factor of safety (FS). If FS < 4, then multiply allowable capacity by the ratio FS/4.
$\lambda = 0.75$, unless (1) the manufacturer's allowable capacity includes the effects of cracked concrete, or (2) it can be demonstrated by calculation that the concrete will not crack for all applied loading combinations. If (1) or (2) apply, λ may be taken as 1.0.
R_p is the Response Modification Coefficient used to develop the seismic loads, given as R in ASCE 7 Tables 12.2–1 and 12.4–1, or as R_p in ASCE 7 Tables 13.5–1 and 13.6–1.

- Allowable loads, minimum embedment, spacing, edge distance, increase factors for short term loading, etc., for PC-1 and PC-2 anchors shall be determined per the most current ICC Evaluation Service report (www.icc-es.org).
- Use allowable load tables for "with special inspection." Capacity of the anchor bolts shall be determined in accordance with this Appendix.
- Combined shear and tension interaction shall be determined per the ICC ES report.
- Allowable loads may not be increased for short term (wind or seismic) loading unless specifically allowed by the ICC ES report.

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[8] Ductile anchors are currently required by ACI 318 for structural members because seismic loads are assumed to be reduced for inelastic energy absorption. The requirement for ductile anchors is retained in these criteria for structural elements that are part of the seismic lateral load resisting system. While it is conservative to design equipment anchorage, component anchorage, etc. using ductile anchors, it is not always cost effective. The brittle anchor criteria are developed to provide a safe, conservative, alternative design approach. The brittle anchor criteria are not applicable to components that are part of the structure's lateral seismic load path. The brittle anchor modifications to ACI 318 code capacities, 0.6/Rp, is intended to (1) remove the effects of the inelastic response modification factor, Rp; and (2) provide a capacity similar to the brittle anchor criteria in ACI 349. The net effects of these criteria are that the brittle anchor will not fail below 167% of the design seismic load. Brittle anchor criteria are also provided for anchors using vendor catalog allowable capacities. Vendor catalog allowable capacities are usually based on the average (mean) ultimate capacity, determined by testing, divided by a factor-of-safety (FS). Use of 60% of the allowable capacity results in less than a 1% probability of failure for an FS = 3 and coefficients-of-variation (COV) less than 0.67. It is judged that anchors with a COV greater than 0.67 will have a larger FS. Thus, it is judged that the brittle anchor criteria are sufficiently conservative. ACI 318 considers cracked concrete in anchor design, while previous codes wee often silent on the effects of cracked concrete on anchor strength. Vendor allowable capacities which do not consider cracking are multiplied by the factor $\lambda = 0.75$, which is based on the guidance of DOE-EH-0545 for expansion anchors.

- Threaded rod used for epoxy and acrylic anchors shall be of the steel grades listed in the ICC ES report unless otherwise approved by the ESM Structural POC.