



U.S. NUCLEAR REGULATORY COMMISSION
STANDARD REVIEW PLAN
OFFICE OF NUCLEAR REACTOR REGULATION

3.8.5 FOUNDATIONS

REVIEW RESPONSIBILITIES

Primary - Structural Engineering Branch (SEB)

Secondary - None

I. AREAS OF REVIEW

The following areas related to the foundations of all seismic Category I structures are reviewed.

1. Description of the Foundations

The descriptive information, including plans and sections of each foundation, is reviewed to establish that sufficient information is provided to define the primary structural aspects and elements relied upon to perform the foundation function. Also reviewed is the relationship between adjacent foundations, including the methods of separation provided where such separation is used to minimize seismic interaction between the buildings. In particular, the type of foundation is identified and its structural characteristics are examined. Among the various types of foundations reviewed are mat-foundations and footings, including individual column footings, combined footings supporting more than one column, and wall footings supporting bearing walls.

Other types of foundations that may also be used are pile foundations, drilled caissons, caissons for water front structures, such as a pumphouse, and rock anchor systems. These types of foundation are reviewed on a case-by-case basis.

The major plant Category I foundations that are reviewed, together with the descriptive information, are listed below:

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USNRC STANDARD REVIEW PLAN

Standard review plans are prepared for the guidance of the Office of Nuclear Reactor Regulation staff responsible for the review of applications to construct and operate nuclear power plants. These documents are made available to the public as part of the Commission's policy to inform the nuclear industry and the general public of regulatory procedures and policies. Standard review plans are not substitutes for regulatory guides or the Commission's regulations and compliance with them is not required. The standard review plan sections are keyed to the Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants. Not all sections of the Standard Format have a corresponding review plan.

Published standard review plans will be revised periodically, as appropriate, to accommodate comments and to reflect new information and experience.

Comments and suggestions for improvement will be considered and should be sent to the U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation, Washington, D.C. 20555.

a. Containment Structure Foundation

The most commonly used type of foundation for both concrete and steel containments is a mat foundation, which is a flat thick slab supporting the containment, its interior structures, and a shield building surrounding the containment, if any. For some PWR containments the base mat has a central depression forming the reactor cavity. The general arrangement of the containment base slab is reviewed as described in subsection I.1 of Standard Review Plan (SRP) Section 3.8.1, with particular emphasis on methods of transferring horizontal shears, such as those caused by earthquakes, to the foundation media. Where shear keys are used for such purposes, the general arrangement of the keys is reviewed. Where waterproofing membranes are used, their effect on the shear resistance of the foundation is reviewed. In prestressed concrete containments, where a tendon inspection gallery is used, arrangement of the gallery and means of either isolating it from the remainder of the base slab or of relying upon it for some function such as resisting shears, are reviewed.

b. Containment Enclosure Building Foundation

Where the containment enclosure building is constructed of reinforced concrete, it is usually supported on the same mat foundation which supports the containment.

Where the containment enclosure building is constructed of structural steel and metal siding, it may surround only the exposed portion of the containment. In such a situation, the enclosure building columns are founded on individual or combined footings at grade level, on the roof of the buildings adjacent to or surrounding the containment, on the dome of the containment, or possibly on brackets anchored to the exterior face of the cylindrical wall of the containment. General arrangement of such foundations is reviewed with particular emphasis on methods of isolating the enclosure building from other buildings in a lateral direction, where this is preferable to minimize seismic interaction.

c. Auxiliary Building Foundation

The auxiliary building foundation is typically of a mat type, particularly where the supporting medium is soil.

The general arrangement of the foundation is reviewed, with particular emphasis on methods of transferring loads from the structure to the foundation media.

d. Other Category I Foundations

The foundations for other seismic Category I structures, which may be one or a combination of several foundation types, are reviewed to an extent similar to that of the containment foundation. Among seismic Category I structures the foundations of which are so reviewed, are: fuel storage buildings, control buildings, diesel generator buildings, intake structures, and cooling towers. Also reviewed are foundations of safety-related structures which, because of other design provisions, are not classified as seismic Category I.

2. Applicable Codes, Standards, and Specifications

Information pertaining to design codes, standards, specifications, regulatory guides, and other industry standards that are applied in the design, fabrication, construction, testing, and surveillance of seismic Category I foundations is reviewed.

3. Loads and Load Combinations

Information pertaining to the applicable design loads and their various combinations is reviewed. The loads normally applicable to seismic Category I foundations are the same as those applicable to the structures which the foundations support. These loads are described in subsection I.3 of SRP Section 3.8.4.

4. Design and Analysis Procedures

The design procedures used for seismic Category I foundations are reviewed with emphasis on the extent of compliance with the ACI 349 Code* (Ref. 1) for concrete structures, and with the AISC Specifications (Ref. 2) for steel structures. The analysis procedures used for seismic Category I foundations are reviewed with respect to the applicability of the theories on which these procedures are based.

Among the areas reviewed are the following:

- a. The assumptions made on boundary conditions and the expected behavior of each foundation when subjected to the various design loads.
- b. The methods by which lateral loads and forces and overturning moments thereof are transmitted from the structure to the foundation media. Such forces are mainly generated by the environmental and abnormal plant conditions such as wind, tornadoes, earthquakes, and pipe ruptures. Methods of determining overturning moments due to the three components of the earthquake are also reviewed.
- c. The computer programs that are used in the design and analysis of seismic Category I foundations.
- d. A Category I structures design report is reviewed (Appendix C, SRP Section 3.8.4).
- e. A structural audit is conducted (Appendix B, SRP Section 3.8.4).

5. Structural Acceptance Criteria

The foundation, as a connecting line between the structure and soil media, is reviewed for its capability of receiving and transmitting loads with appropriate safety margins.

The design limits imposed on the various parameters that serve to quantify the structural behavior of each foundation are reviewed with emphasis on the extent of compliance with the ACI-349 Code for concrete structures,

*As augmented by Regulatory Guide 1.142 (Ref. 6)

specifically with respect to stresses, strains, and deformations. Factors of safety against overturning and sliding are reviewed for their appropriate safety margins.

Materials, Quality Control, and Special Construction Techniques

Information on the materials used in the construction of seismic Category I foundations is reviewed. Among the major materials of construction reviewed are the following:

- a. The concrete ingredients.
- b. The reinforcing bars and mechanical splices.
- c. The structural steel.
- d. Rock anchors, including any prestressing system.

The quality control program proposed for the fabrication and construction of seismic Category I foundations is reviewed, including the following: nondestructive examination of the materials to determine physical properties, placement of concrete, and erection tolerances.

Special construction techniques, if proposed, are reviewed on a case-by-case basis.

In addition, the information contained in items a, c and d of subsection I.6 of SRP Section 3.8.3, is also reviewed.

7. Testing and Inservice Surveillance Programs

If applicable, any post-construction testing and inservice surveillance programs for foundations, such as monitoring potential settlements and displacements, are reviewed on a case-by-case basis.

SEB coordinates other branches evaluations that interface with structural engineering aspects of the review as follows: Determination of structures which are subject to a quality assurance program in accordance with the requirements of Appendix B to 10 CFR Part 50 is performed by the Mechanical Engineering Branch (MEB) as part of its primary review responsibility for SRP Sections 3.2.1 and 3.2.2. SEB will perform its review of safety-related structures on that basis. Determination of pressure loads from high energy lines located in safety-related structures other than containment is performed by the Auxiliary Systems Branch (ASB) as part of its primary review responsibility for SRP Section 3.6.1. SEB accepts the loads thus generated as approved by the ASB, to be included in the load combination equations of this SRP section. Determination of loads generated due to pressure under accident conditions is performed by the Containment Systems Branch (CSB) as part of its primary review responsibility for SRP Section 6.2.1. SEB accepts the loads thus generated, as approved by the (CSB), to be included in the load combinations in this SRP section. The review of geological and seismological information to establish the free field ground motion is performed by the Geosciences Branch as described in Section 2.5.1 and 2.5.2. Hydrologic and Geotechnical Engineering Branch reviews the geotechnical parameters and methods employed in the analysis of free field soil media and soil properties as described in Section 2.5.4 and 2.5.5. SEB accepts the results of the reviews performed by these branches including the maximum seismic ground accelerations for the Operating Basis

Earthquake (OBE) and the Safe Shutdown Earthquake (SSE), site dependent free field ground motion records, soil properties, etc., as an integral part of the seismic analysis review of Category I structures. The review for Quality Assurance is coordinated and performed by the Quality Assurance Branch as part of its primary review responsibility for SRP Section 17.0.

For those areas of review identified above as being reviewed as part of the primary review responsibility of other branches, the acceptance criteria necessary for the review and their methods of application are contained in the referenced SRP section of the corresponding primary branch.

II. ACCEPTANCE CRITERIA

SEB acceptance criteria for the design of seismic Category I foundations are based on meeting the relevant requirements of the following regulations:

- A. 10 CFR Part 50, K50.55a and General Design Criterion 1 as they relate to safety-related structures being designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety function to be performed.
- B. General Design Criterion 2 (Ref. 3) as it relates to appropriate considerations being given to the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated, and to the combinations of the effects of normal and accident conditions with the effects of the natural phenomena.
- C. General Design Criterion 4 (Ref. 4) as it relates to structures, systems, and components important to safety being appropriately protected against dynamic effects, including the effects of missiles, pipe whipping, and discharging fluids, that may result from equipment failures and from events and conditions outside the nuclear power unit.
- D. General Design Criterion 5 (Ref. 5) as it relates to structures, systems, and components important to safety not being shared among nuclear power units unless it can be shown that such sharing will not significantly impair their ability to perform their safety functions.

The Regulatory Guides and industry standards identified in item 2 of this subsection provides information, recommendations and guidance and in general describes a basis acceptable to the staff that may be used to implement the requirement of 10 CFR Part 50, K50.55a, and GDC 1, 2, 4, and 5. Also, specific acceptance criteria necessary to meet these relevant requirements of these regulations for the areas of review, described in subsection I of this SRP Section are as follows:

1. Description of the Foundation

The descriptive information in the SAR is considered acceptable if it meets the minimum requirements set forth in Section 3.8.5.1 of Regulatory Guide 1.70, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants."

Deficient areas of descriptive information are identified by the reviewer and a request for additional information is initiated. New or unique design features that are not specifically covered in the "Standard Format...", require a more detailed review. The reviewer determines the additional information required for a meaningful review of such new or unique design features.

2. Applicable Codes, Standards, and Specifications

The design, materials, fabrication, erection, inspection, testing, and surveillance, if any, of seismic Category I foundations are covered by codes, standards, and guides that are either applicable in their entirety or in portions thereof. A list of such documents is contained in subsection I.2 of the SRP Section 3.8.3. In addition the documents listed in subsection II.2 of SRP Section 3.8.1 are acceptable for the containment foundation.

3. Loads and Load Combinations

The specified loads and load combinations used in the design of seismic Category I foundations are acceptable if found to be in accordance with those combinations referenced in subsection II.3 of SRP Section 3.8.1 for the containment foundation, and with those combinations listed in subsection II.3 of SRP Section 3.8.4 for all other seismic Category I foundations.

In addition to the load combinations referenced above, the combinations used to check against sliding and overturning due to earthquakes, winds, and tornados, and against floatation due to floods, are found acceptable if in accordance with the following:

- a. $D + H + E$
- b. $D + H + W$
- c. $D + H + E'$
- d. $D + H + W_t$
- e. $D + F'$

where D, E, W, E', W_t are as defined in SRP Section 3.8.4, H is the lateral earth pressure, and F' is the bouyant force of the design basis flood. Justification should be provided for including live loads or portions thereof in these combinations.

4. Design and Analysis Procedures

The design and analysis procedures used for seismic Category I foundations are acceptable if found in accordance with the following:

- a. The design should consider the soil-structure interaction, hydrodynamic effect, and dynamic soil pressure.
- b. For seismic Category I concrete foundations other than the containment foundations, the procedures are in accordance with the ACI-349 Code, as augmented by Regulatory Guide 1.142.
- c. For Category I steel foundations, the procedures are in accordance with the AISC "Specifications...".

- d. For the containment foundation, the design and analysis procedures referenced in subsection II.4 of SRP Section 3.8.1 are acceptable.
- e. The design report is found acceptable if it satisfies the guidelines contained in Appendix C to SRP Section 3.8.4.
- f. The structural audit is conducted as described in Appendix B to SRP Section 3.8.4.

For determining the overturning moment due to an earthquake, the three components of the earthquake should be combined in accordance with methods described in SRP Section 3.7.2. Computer programs are acceptable if the validation provided is found in accordance with procedures delineated in subsection II.4.e of SRP Section 3.8.1.

5. Structural Acceptance Criteria

For each of the loading combinations referenced in subsection II.3 of this SRP Section, the allowable limits which constitute the acceptance criteria are referenced in subsection II.5 of SRP Section 3.8.1 for the containment foundation, and are listed in subsection II.5 of SRP Section 3.8.4 for all other foundations. In addition, for the five additional load combinations delineated in subsection II.3 of this SRP section, the factors of safety against overturning, sliding and floatation are acceptable if found in accordance with the following:

<u>For Combination</u>	<u>Minimum Factors of Safety</u>		
	<u>Overturning</u>	<u>Sliding</u>	<u>Floatation</u>
a. -----	1.5	1.5	--
b. -----	1.5	1.5	--
c. -----	1.1	1.1	--
d. -----	1.1	1.1	--
e. -----	--	--	1.1

6. Materials, Quality Control, and Special Construction Techniques

For the containment foundation, the acceptance criteria for materials, quality control, and any special construction techniques are referenced in subsection II.6 of SRP Section 3.8.1. For all other seismic Category I foundations, the acceptance criteria are similar to those referenced in subsection II.6 of SRP Section 3.8.4.

7. Testing and Inservice Surveillance Requirements

At present there are no special testing or in-service surveillance requirements for seismic Category I foundations other than those required for the containment foundation, which are covered in subsection II.7 of SRP Section 3.8.1. However, should some requirements become necessary for special foundations, they will be reviewed on a case-by-case basis.

III. REVIEW PROCEDURES

The reviewer selects and emphasizes material from the review procedures described below, as may be appropriate for a particular case.

1. Description of the Foundations

After the type of foundation and its structural characteristics are identified, information on similar and previously licensed plants is obtained for reference. Such information, which is available in safety analysis reports and amendments of license applications enables identification of differences for the case under review. These differences require additional scrutiny and evaluation. New and unique features that have not been used in the past are examined in greater detail. The information furnished in the SAR is reviewed for sufficiency in accordance with the "Standard Format...". A decision is then made with regard to the sufficiency of the descriptive information provided. Any additional required information is requested from the applicant at an early stage of the review process.

2. Applicable Codes, Standards, and Specifications

The list of codes, standards, guides, and specifications is compared with the list referenced in subsection II.2 of this SRP section. The reviewer assures himself that the appropriate code or guide is used and that the applicable edition and stated effective addenda are acceptable.

3. Loads and Load Combinations

The reviewer verifies that the loads and load combinations are as conservative as those referenced and specified in subsection II.3 of this SRP section. Any deviations from the acceptance criteria for loads and load combinations that have not been adequately justified are identified as unacceptable and transmitted to the applicant.

4. Design and Analysis Procedures

The reviewer assures himself that for the design and analysis procedures, the applicant has used the procedures in the applicable code as delineated in subsection II.4 of this SRP section.

Any computer programs that are used in the design and analysis of the foundation are reviewed to verify their validity in accordance with the acceptance criteria delineated in subsection II.4.e of SRP Section 3.8.1.

The reviewer assures himself that the provisions of subsection II.4 of this SRP section are met.

5. Structural Acceptance Criteria

The limits on allowable stresses and strains in the concrete, reinforcement, and structural steel, and on factors of safety for overturning, sliding, and floatation are compared with the corresponding allowable values specified in subsection II.5 of this SRP section. If the applicant proposes to deviate from these limits, justification should be submitted and evaluated. If such justification is determined to be inadequate, a request for additional justification is made.

6. Materials, Quality Control, and Special Construction Techniques

The materials, quality control procedures, and any special construction techniques are compared with those referenced in subsection II.6 of this SRP section. If a new material not used in prior licensed cases is used, the applicant is requested to provide sufficient test and user data to establish the acceptability of such a material. Similarly, any new quality control procedures or construction techniques are evaluated in detail to assure that there will be no degradation of quality that might affect the structural integrity of the foundation.

7. Testing and Inservice Surveillance Programs

For the containment foundation, testing and in-service surveillance programs are reviewed in accordance with subsection II.7 of SRP Section 3.8.1 for concrete containments. Any testing and in-service surveillance programs for other seismic Category I foundations are reviewed on a case-by-case basis.

IV. EVALUATION FINDINGS

The reviewer verifies that sufficient information has been provided to satisfy the requirements of this SRP section, and concludes that his evaluation is sufficiently complete and adequate to support the following type of conclusive statement to be included in the staff's Safety Evaluation Report:

The staff concludes that the design of the seismic Category I foundations are acceptable and meets the relevant requirements of 10 CFR Part 50, §50.55a, and General Design Criteria 1, 2, 4, and 5. This conclusion is based on the following:

1. The applicant has met the requirements of Section 50.55a and GDC 1 with respect to assuming that the seismic Category I foundations are designed, fabricated, erected, constructed, tested and inspected to quality standards commensurate with its safety function to be performed by meeting the guidelines of Regulatory Guides and industry standards indicated below.
2. The applicant has met the requirements of GDC 2 by designing the seismic Category I foundation to withstand the most severe earthquake that has been established for the site with sufficient margin and the combinations of the effects of normal and accident conditions with the effects of environmental loadings such as earthquakes and other natural phenomena.
3. The applicant has met the requirements of GDC 4 by assuring that the design of seismic Category I foundations are capable of withstanding the dynamic effects associated with missiles, pipe whipping and discharging fluids.
4. The applicant has met the requirements of GDC 5 by demonstrating that structure systems and components either are not shared between units or that if shared they have demonstrated that sharing will not impair their ability to perform their intended safety function.

The Criteria used in the analysis, design, and construction of all the plant seismic Category I foundations to account for anticipated loadings and postulated conditions that may be imposed upon each foundation during its service lifetime are in conformance with

established criteria, codes, standards, and specifications acceptable to the Regulatory staff. These include meeting the positions of Regulatory Guide 1.142 and industry standards ACI-349 and AISC, "Specification for Design, Fabrication and Erection of Structural Steel for Building.

The use of these criteria as defined by applicable codes, standards, and specifications; the loads and loading combinations; the design and analysis procedures; the structural acceptance criteria; the materials, quality control, and special construction techniques; and the testing and in-service surveillance requirements provide reasonable assurance that, in the event of winds, tornadoes, earthquakes, and various postulated events, seismic Category I foundations will withstand the specified design conditions without impairment of structural integrity and stability or the performance of required safety functions.

V. IMPLEMENTATION

The following is intended to provide guidance to applicants and licensees regarding the NRC staff's plans for using this SRP section.

Except in those cases in which the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the method described herein will be used by the staff in its evaluation of conformance with Commission regulations.

Implementation schedules for conformance to parts of the method discussed herein are contained in the referenced regulatory guides.

VI. REFERENCES

1. ACI-349, "Code Requirements for Nuclear Safety-Related Concrete Structures," American Concrete Institute.
2. AISC, "Specification for Design, Fabrication and Erection of Structural Steel for Building," American Institute of Steel Construction.
3. 10 CFR Part 50, §50.55(a), "Codes and Standards."
4. 10 CFR Part 50, Appendix A, General Design Criterion 1, "Quality Standards and Records."
5. 10 CFR Part 50, Appendix A, General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena."
6. 10 CFR Part 50, Appendix A, General Design Criterion 4, "Environmental and Missile Design Bases."
7. 10 CFR Part 50, Appendix A, General Design Criterion 5, "Sharing of Structures."
8. Regulatory Guide 1.142, "Safety-Related Concrete Structures for Nuclear Power Plants."