Draft
SEISMIC DESIGN GUIDELINES
and
DATA SUBMITTAL REQUIREMENTS
FOR LNG FACILITIES

Federal Energy Regulatory Commission
Office of Energy Projects
Washington D.C. 20426
(January 23, 2007)

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SEISMIC DESIGN GUIDELINES
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Executive Summary

These guidelines were developed to assist applicants in addressing the seismic design requirements for proposed liquefied natural gas (LNG) facilities. They apply to all new LNG facilities or proposed significant changes to existing LNG facilities under the jurisdiction of the Federal Energy Regulatory Commission (FERC). This document replaces and supersedes "*Data Requirements for the Seismic Review of LNG Facilities*, NBSIR 84-2833" (18 CFR 380.12(h)(5) and (o)(15)).

Federal regulations applicable to seismic design of LNG facilities are identified and summarized, and guidance is provided in a number of areas that may be subject to interpretation by technical experts.

In general, the guidelines are based on existing rules and procedures found in NFPA 59A, ASCE 7-05, ASCE 4-98, API 650 Appendix E and other current standards documents applicable to LNG facilities. The guidelines also rely on the National Seismic Hazard Maps and the 2006 IBC MCE Ground Motion Maps, which were developed specifically for use in the design of buildings and other structures in the United States by the United States Geological Survey (USGS).

This document also provides guidance on the classification of structures, components and systems and the seismic criteria that applies to each classification (Seismic Categories I, II and III). The guidelines provide minimum limits on the determination of OBE, SSE and MCE site specific ground motions based on the aforementioned USGS National Seismic Hazard Maps and MCE maps. Also provided are minimum limits on the margins of uncertainty of soil properties to be considered when performing site response and soil-structure interaction analysis. Additional guidance is provided for LNG tank minimum freeboard limits and on LNG tank foundation design. Specific additional guidance is also provided for Category I, II and III structures, components and systems, as well as seismic recording instrumentation.

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Part I
Seismic Design Guidelines

1. Introduction

These guidelines apply to all proposed new liquefied natural gas (LNG) facilities or proposed significant changes to existing LNG facilities under the jurisdiction of the Federal Energy Regulatory Commission (FERC). This document replaces and supersedes "*Data Requirements for the Seismic Review of LNG Facilities*, NBSIR 84-2833" (18 CFR 380.12(h)(5) and (o)(15)).

Federal regulations applicable to seismic design of LNG facilities are identified and summarized, and guidance is provided in a number of areas that may be subject to interpretation by technical experts.

This guidance is intended for those facilities to be constructed on land and is not intended for floating or offshore facilities. The scope of the submittals includes all portions of the facility located within the facility security fence including loading docks.

1.1 Regulations and Code Requirements

Title 49 CFR 193 (Ref. 1), requires that LNG facilities built in the United States satisfy the design requirements of National Fire Protection Association (NFPA) 59A-2001 (Ref. 2). In addition, Title 33 CFR 127.103 (Piers and wharves) contains the U.S. Coast Guard's requirements for seismic design of LNG waterfront facilities.

Although NFPA 59A-2001 requirements for seismic design address only the critical safety-related structures and systems of LNG facilities, other structures, systems, and components are typically designed and built in accordance with local building code requirements which may vary between jurisdictions. To ensure a level of consistency for FERC-jurisdictional LNG facilities across the entire United States, these Guidelines recommend use of the seismic design provisions of the 2006 edition of the International Building Code (IBC) (Ref. 3) as a basis for design of all structures, systems, and components of LNG facilities not specifically addressed in NFPA 59A. The 2006 IBC is consistent with and uses the latest material standards (e,g., ACI 318-05 (Ref. 4), AISC 341-05 (Ref. 5), etc.).

NFPA 59A-2001 defines two levels of earthquake motions, the Operating Basis Earthquake (OBE) and the Safe Shutdown Earthquake (SSE). These motions are to be used as the basis for design for a limited specific list of critical safety-related structures and systems. These guidelines identify those structures and systems as Seismic Category I. The remaining structures, systems and components are classified as either Seismic Category II or III and should be designed in accordance with the seismic requirements of the 2006 IBC. The OBE and SSE ground motions are to be determined by site-specific evaluations and are defined in terms of 5 percent damped response spectra.

The OBE ground motions at the site are defined as the lesser of:

1. ground motion with a 10% probability of exceedance within a 50 year period (475 year return period); or

2. two-thirds (2/3) of the Maximum Considered Earthquake (MCE) ground motion

In NFPA 59A-2001 the MCE is defined as future potential ground motion with a 2 percent probability of exceedance within a 50 year period (2475 year return period) with deterministic limits; the same definition used for establishing the MCE specified in the 2006 IBC. Procedures to be used to establish site specific MCE ground motions with deterministic limits are provided in Chapter 21 of ASCE 7-05 (Ref. 6).

The SSE ground motions at the site are defined as the lesser of:

1. 1% probability of exceedance within a 50 year period (4975 year return period); or

2. two times the OBE

1.2 Interpretations and Advice

There are areas where NFPA 59A-2001 does not provide specific requirements and therefore there can be a wide range of opinions by technical experts on how it is to be applied. The seismic design guidelines contained within this document were developed to provide guidance to applicants on the requirements of NFPA 59A-2001 and the 2006 IBC, and provide a basis for uniform reviews of various LNG terminal structures, components and systems under FERC jurisdiction.

In general, the guidelines are based on existing rules and procedures found in ASCE 7-05 (Ref. 6), ASCE 4-98 (Ref. 7), API 650 Appendix E (Ref. 8) and other current standards documents. The guidelines also rely on the National Seismic Hazard Maps (Ref. 16) and the 2006 IBC MCE Ground Motion Maps (Chapter 22 of Ref. 3), which were developed specifically for use in the design of buildings and other structures in the United States by the United States Geological Survey (USGS).

This document also provides guidance on the classification of structures, components and systems and the seismic criteria that applies to each classification (Seismic Categories I, II and III). The guidelines provide minimum limits on the determination of OBE, SSE and MCE site specific ground motions relying on the aforementioned USGS National Seismic Hazard Maps and MCE maps. Also provided are minimum limits on the margins of uncertainty of soil properties to be considered when performing site response and soil-structure interaction analysis. Additional guidance is provided for LNG tank minimum freeboard limits and on LNG tank foundation design. Specific additional guidance is also provided for Category I, II and III structures, components and systems, as well as seismic recording instrumentation.

As noted, NFPA 59A-2001 does not provide specific requirements for Category II and III items, so the guidance provided herein for these items is based on the seismic requirements of 2006 IBC and are defined in terms of the "Design Earthquake" (DE) ground motions which is two-thirds (2/3) of the corresponding MCE considering site amplification effects.

The 2006 IBC references ASCE 7-05 including Supplement No.1 for its seismic requirements (hereafter referred to as ASCE 7-05). Therefore, by meeting the seismic requirements of ASCE 7-05, the seismic requirements of the 2006 IBC are also being satisfied. For simplicity, in this document we generally refer to ASCE 7-05 rather than the 2006 IBC. The referencing of the NFPA 59A-2001 and ASCE 7-05 includes all published errata for these documents at the time of issuance of this document. Additional regulatory guidance may be issued in the future, as necessary.

2. Classification of Structures, Components and Systems

For purposes of design, all structures, components and systems of the LNG facility should be classified into one of the three Seismic Categories that are defined in Section 2.1, 2.2 or 2.3. Guidance on classification of individual LNG facility structures, components and systems is provided in Appendix C.

2.1 Seismic Category I

The following structures, components and systems that are specified in Section 4.1.3.3 of NFPA 59A-2001 should be classified as Seismic Category I:

1) LNG storage containers and their impounding systems

2) System components required to isolate the LNG container and maintain it in a safe shutdown condition

3) Structures and systems, including fire protection systems, the failure of which could affect the integrity of (1) or (2) above.

2.2 Seismic Category II

Structures, components and systems not included in Category I that are required to maintain safe plant operation should be classified as Seismic Category II.

2.3 Seismic Category III

All other structures, components and systems of the LNG facility that are not included in Categories I and II should be classified as Seismic Category III.

3. Seismic Performance Goals by Category

The following are the seismic performance goals for each category:

3.1 Seismic Category I

These structures, components and systems should be designed to remain operable during and after the OBE design ground motion. The design should provide for no loss of containment capability of the primary container and it should be possible to isolate and maintain the LNG container during and after the SSE design ground motion.

As a minimum, the impounding system should be designed to withstand an SSE, while empty and an OBE while holding maximum operating volume of the LNG container. After an OBE or SSE, there should be no loss of containment capability.

3.2 Seismic Category II

These structures, components and systems should be designed to meet the seismic performance goals of the 2006 IBC for "essential" facilities. For essential facilities, it is expected that the damage from the Design Earthquake (DE) ground motion defined in ASCE 7-05 would not be so severe as to preclude continued occupancy and function of the facility.

3.3 Seismic Category III

These structures, components and systems should be designed to meet the seismic performance goals of the 2006 IBC and ASCE 7-05 for normal "non-essential" facilities. For normal facilities, it is expected that structures designed and constructed according to ASCE 7-05, would sustain repairable damage when subjected to DE ground motions although it may not be economical to do so.

4. General Seismic Design Criteria by Category

Structures, systems and components should be designed to satisfy the general seismic criteria provided in this section and the additional guidelines provided in Sections 5 through 10 of this document.

4.1 Seismic Category I

These structures, systems and components should be designed to satisfy the requirements of Section 4.1.3 of NFPA 59A-2001, and should be designed with no inelastic reduction factors permitted with OBE load combinations. Normal code allowable stresses and capacities with normal permitted seismic increases should be used in the design with the OBE. These structures, systems and components should be designed also for SSE motions. Inelastic reduction factors are permitted with SSE motions.

Inelastic reduction factors should be justified and should not exceed the 'R' values found for these structures in Chapter 15 and 'R_p' values for nonstructural systems and components in Chapter 13 of ASCE 7-05. For both OBE and SSE design analyses, damping ratios should not be taken as greater than 5% for all Category I structures and systems unless soil-structure interaction is performed (see Section 6.2 of this document). Because of their higher seismic requirements, all

Category I structures, systems and components whose designs satisfy the requirements of NFPA 59A and these guidelines are deemed to satisfy ASCE 7-05.

4.2 Seismic Category II

Seismic Category II structures, systems and components should satisfy the ASCE 7-05 seismic requirements for Occupancy Category IV structures. Structures should be designed using an 'I' factor equal to 1.5 while systems and components should be designed using an 'I_p' factor of 1.5. Mechanical and electrical equipment assigned to Seismic Category II should be deemed to be active and therefore are required to satisfy Section 13.2.2 of ASCE 7-05.

4.3 Seismic Category III

Seismic Category III structures, systems and components should be designed to satisfy the seismic requirements of ASCE 7-05 for Occupancy Category II structures. Structures should be designed using an 'I' factor of 1.0, and nonstructural components (except for life safety systems identified in Chapter 13 of ASCE 7-05) an 'I_p' factor of 1.0.

5. Seismic Design Ground Motion Determination

Category I structures, systems and components are to be designed for NFPA 59A-2001 OBE and SSE defined ground motions while Seismic Category II and III structures, systems and components are to be designed for ASCE 7-05 DE defined ground motions. Therefore, design ground motions for both standards need to be determined. The specified lower limits on OBE and SSE site-specific design ground motions are supported by similar limits found in ASCE 7-05 when used in conjunction with the USGS MCE Maps. The determination of the ASCE 7-05 design ground motions are discussed first in this section. The NFPA 59A-2001 and ASCE 7-05 design ground motions at a site are defined in terms of 5 percent damped response spectra.

5.1 Design Ground Motions – ASCE 7-05

5.1.1 Maximum Considered Earthquake (MCE)

The site-specific MCE response spectra for ASCE 7-05 design evaluations should be determined in accordance with Chapter 21 of ASCE 7-05. This means that the site specific value should not be taken as less than 80% of the MCE motion determined in accordance with Section 11.4.5 of ASCE 7-05 at any period where the MCE motions have been adjusted for Site Class effects in accordance with Section 11.4.3. Site Class is defined in Section 11.4.2 and Chapter 20 of ASCE 7-05. The design spectral acceleration values for Site Class 'F' should not be taken as less than 80% of S_a determined for Site Class 'E' in accordance with Section 11.4.5. The spectral values determined in accordance with Section 11.4.5 should use the T_L mapped values found in Chapter 22 of ASCE 7-05.

> *Exception: Site Specific MCE response spectra for Site Class B may be taken less than 80% of the current USGS MCE mapped values if the assumptions (e.g., time dependent probabilistic seismic hazard assessment (PSHA), attenuation relationships, earthquake return intervals, etc.) used in the site-specific seismic hazard analysis are different from those used by the USGS in the development*

of their 2006 IBC MCE maps AND if the USGS concurs with the applicant that these different assumptions are appropriate and will likely be utilized in the next edition of the maps.

5.1.2 Design Earthquake (DE)

The site specific DE response spectra and the DE design acceleration parameters S_{DS} and S_{D1} should be determined in accordance with Sections 21.3 and 21.4 of ASCE 7-05.

5.2 Design Ground Motions – NFPA 59A-2001

5.2.1 Operating Basis Earthquake (OBE)

The OBE ground motion at a site is defined in NFPA 59A-2001 as the lesser of:

1. ground motion with a 10% probability of exceedance within a 50 year period (475 year return period); or

2. two-thirds (2/3) of the Maximum Considered Earthquake (MCE) ground motion

In NFPA 59A-2001 the MCE is defined as ground motion having a 2 percent probability of exceedance within a 50 year period (2475 year return period) with deterministic limits. This is the same definition used for establishing the MCE in the 2006 IBC and ASCE 7-05. The MCE response spectra adjusted for site effects should not be taken as less than that determined in Section 5.1.1 above.

The site specific OBE spectral accelerations at any period should not be taken as less than 80% of the 475 year motion considering appropriate site effects determined using the 2002 USGS National Seismic Hazard maps and using the site coefficients of Tables 11.4-1 and 11.4-2 of ASCE 7-05 except the site specific spectral values at 0.2 seconds and 1 second replace S_S and S_1 in the table. In using the aforementioned tables, the Site Class should be as defined in Section 11.4.2 and Chapter 20 of ASCE 7-05. The spectral values for Site Class 'F' should not be taken less than 80% of those determined for the same site assuming site coefficients for Site Class 'E' from the aforementioned Tables. The USGS Seismic Hazard response spectra displacement cutoff period (T_L-OBE) should be determined based upon the predominant deaggregated OBE earthquake modal magnitude (M_d) at a 2 second oscillator period as follows (taken from Page 27 of the commentary to FEMA 450 (Ref.9)).

M_d	T_L-OBE (sec)
6.0 – 6.5	4
6.5 – 7.0	6
7.0 – 7.5	8
7.5 – 8.0	12
8.0 – 8.5	16
8.5 – 9.0+	20

Exception: Site Specific OBE response spectra for Site Class B may be taken less than 80% of the current USGS National Seismic Hazard Map values if the assumptions (e.g., time dependent PSHA, attenuation relationships, earthquake return intervals, etc.) used in site-specific seismic *hazard analysis are different from those used by the USGS in the development of their 2002 National Seismic Hazard maps AND if the USGS concurs with the applicant that these different assumptions are appropriate and will likely be utilized in the next edition of the maps.*

5.2.2 Safe Shutdown Earthquake (SSE)

The SSE ground motion at a site is defined in NFPA 59A-2001 as the lesser of:

1. 1% probability of exceedance within a 50 year period (4975 year return period); or

2. two times the OBE

The SSE response spectra used for design should not be taken as less than the ASCE 7-05 MCE response spectra adjusted for site effects as defined in Section 5.1.1 above.

6. Limits on Site Response Analysis and Soil-Structure Interaction Analysis

6.1 Site Response Analysis

Where site response analysis is performed to determine the site-specific design spectral accelerations in Sections 5.1 or 5.2 above, such analyses should be performed in accordance with Chapter 21 of ASCE 7-05. Base ground motions should be selected and scaled in accordance with Section 21.1.1 of Chapter 21. For site response analyses, site conditions should be modeled as described in Section 21.1.2 of Chapter 21. Uncertainties in soil properties should be considered in accordance with Section 3.3.1.7 of ASCE 4-98 (Ref. 7). Where site-specific motions are used as the input to site response analyses, they should be determined in the same manner as described above in Section 5 except the motions should be determined for the Site Class that is appropriate for the base level where the site motions are input to the site response model.

The soil properties that are used in the site response analysis should reflect the site conditions after all planned soil improvements of the site are considered. If there are several options of improvements, site response analyses should be performed for each option with uncertainties as described above considered in each analysis. The results of each option may be separately provided or they may be enveloped to obtain the design response spectra. The final design response spectra for the project should be based on the final actual soil improvement option selected. Alternatively the envelope of all options may be used to define the final design response spectra.

6.2 Soil Structure Interaction Analysis

If soil structure interaction analysis (SSI) is performed as part of the design, seismic design forces and overturning moments at the base of the structure should not be less than 80% of those determined using the equivalent static force approach using the ground motions of Section 5 above. If they are less, the results should be scaled upward until seismic design forces and overturning moments at the base are at least 80% of those obtained by the equivalent static force approach. Uncertainties in soil properties in SSI analyses should be treated in accordance with 3.3.1.7 of ASCE 4-98. Time histories used in SSI analyses should be selected and scaled in accordance with Section 21.1.1, Chapter 21 of ASCE 7-05 where the design motions have been determined in accordance with Section 5 of this document except the motions should be determined for the Site Class that is appropriate for the base level where the site motions are input to the site response model.

7. Additional Guidance for LNG Tanks

7.1 Seismic Design Liquid Level

For determining seismic forces and minimum freeboards for LNG tanks, the liquid levels should be determined as follows:

The liquid level height (h_{OBE}) to be used in determining seismic forces and freeboards in conjunction with the OBE should be that height that is expected when the facility, in full operation, is to be exceeded only 1 % of the time in a given year but should not be taken as less than 95% of the rated capacity height. Alternatively, the h_{OBE} may be taken as the rated capacity height.

The liquid level height (h_{SSE}) to be used in determining seismic forces and freeboards in conjunction with the SSE should be that height that is expected when the facility, in full operation, is to be exceeded only 5 % of the time in a given year but should be not be taken as less than 90% of the rated capacity height. Alternatively, the h_{SSE} may be taken as the rated capacity height.

7.2 Minimum Design Freeboard for LNG Tanks

The design freeboard for LNG tanks should be equal to or greater that specified below in Table 7.2 depending on the type of inner and outer tanks. The minimum freeboard specified in Table 7.2 is based on the OBE slosh height (δ_{OBE}) and SSE slosh height (δ_{SSE}). The total minimum required tank height for seismic design is the sum of the appropriate seismic design liquid height plus the minimum freeboard height for both OBE and SSE conditions. The OBE and SSE slosh heights are determined by the equation on page 9 and is based on the slosh height equation found in Section E.7.2 of API 650 Appendix E, 10th Edition, Addendum 4, 2005 (Ref. 8).

7.3 Inelastic Reduction Factors for Inner LNG Tanks (LNG Tanks)

The inelastic reduction factors used on the design for the inner LNG containers should not exceed the values specified in API 620 – 2007 (Ref. 10).

7.4 LNG Tank Foundation Design Guidance

7.4.1 Bearing Capacity and Settlement

The foundation design should ensure that a minimum static factor of safety of 3.0 is present against bearing capacity failure and settlements of the tank foundation should not exceed tolerable limits established by the tank designer. Differential settlement around the periphery of the tank should not exceed 1:500 or the arc length under consideration. The differential settlement from the center to the edge of the tank should not exceed 1:300 of the tank radius. The planar tilt angle of the tank foundation should not exceed 0.002 radians.

LNG Slosh Height Determination Equation

$$\delta_{OBE} = 0.5\, D\, a_{f\text{-}OBE}$$

where:

δ_{OBE} = OBE slosh height in feet (including run-up)

D = inner tank diameter in feet

$a_{f\text{-}OBE}$ = 0.5% damped spectral acceleration (in units of g) of the OBE determined in accordance with Section 5.2.1 of this document at the sloshing period of the LNG tank. It is acceptable to determine the 0.5% damped spectral values by multiplying the 5% spectral values at a given period by a factor of 1.5. In determining the convective period the liquid height should be determined using the OBE seismic design liquid level determined in Section 7.1.

and,

$$\delta_{SSE} = 0.5\, D\, a_{f\text{-}SSE}$$

where:

δ_{SSE} = SSE slosh height in feet (including run-up)

D = inner tank diameter in feet

$a_{f\text{-}SSE}$ = 0.5% damped spectral acceleration (in units of g) of the SSE determined in accordance with Section 5.2.2 of this document at the sloshing period of the LNG tank. It is acceptable to determine the 0.5% damped spectral values by multiplying the 5% spectral values at a given period by a factor of 1.5. In determining the convective period, the liquid height should be determined using the SSE seismic design liquid level determined in Section 7.1.

Settlements of the tank should be monitored during the hydrotest. At least eight equally spaced survey points should be established on the tank foundation around the perimeter of the tank. Measurements should be taken for the empty tank, at fill levels of ¼, ½, ¾, and full depth, and after the tank is emptied. Care should be taken to establish a stable reference benchmark for the settlement surveys.

Tank settlement limits should not be exceeded for settlements during hydrotest, or a combination of settlements from the structural loads, seismic loads, liquefaction, seismic compaction, and any other expected differential displacements.

Table 7.2 Minimum LNG Tank Freeboard Requirement

LNG Tank Type	Minimum Freeboard Height
All LNG tank styles – OBE	δ_{OBE}
Full Containment: - SSE	
Suspended deck With venting sized for potential vapor generated	No requirement
Without venting provisions for potential vapor generated Inner tank dome roof	0.7 δ_{SSE}
Inner tank roof and shell designed for sloshing impingement	No requirement
Inner tank roof and shell NOT designed for sloshing impingement With venting sized for potential vapor generated	0.7 δ_{SSE}
Without venting provisions for potential vapor generated	δ_{SSE}
Double or Secondary Containment: - SSE	
With venting sized for potential vapor generated	0.7 δ_{SSE}
Without venting provisions for potential vapor generated	δ_{SSE}
Single Containment: - SSE	δ_{SSE}

7.4.2 Seismic and Geologic Hazards

In addition to ground motions, other seismic hazards which could cause failure of the tanks include displacement due to fault rupture, loss of bearing capacity and settlement due to liquefaction and seismic compaction, tsunamis, flooding, and seiche, slope instability and lateral spreading. As a minimum, the tanks should satisfy the requirements of ASCE 7-05, Section 11.8 regarding these hazards and mitigation of the hazards, where present.

Settlement due to liquefaction should be calculated using Tokimatsu and Seed (Ref. 12) or Ishihara and Yoshimine (Ref. 14) and total and differential settlements from structural loads and liquefaction combined should not exceed the tank settlement criteria discussed in Section 7.4.1. If potential for sand boils and bearing capacity failure or excessive settlement is present, recommendations for mitigation of liquefaction potential should be provided.

The LNG tanks should have a minimum calculated static factor of safety of 1.5 for slope stability with respect to any nearby slopes of berthing slips or other existing or future slopes. Pseudo-static analyses may be used to determine seismic slope stability, provided the soils are not liquefiable or expected to lose shear strength significantly during deformation. Pseudo-static screening analyses should be performed in accordance with the procedure outlined by Blake et al., 2002 (Ref. 29), using the pseudo-static coefficient corresponding to the threshold movement of 2-inches (5 cm). If the calculated pseudo-static factor of safety is equal to or greater than 1.0, the site passes the screen and should be considered to have adequate stability and require no further stability analyses.

Sites with a pseudo-static factor of safety less than 1.0 using the method outlined by Blake et al. 2002, will require dynamic displacement analysis (e.g., Newmark (Ref. 24), Makdisi and Seed, 1978 (Ref. 18), Bartlett & Youd (Ref. 13), Jibson, R.W. et al., 2003 (Ref. 32)). Where significant lateral spreading is anticipated, finite difference analyses with programs such as FLAC (Itasca, 2000 (Ref. 19)) should be performed to define the extent of lateral spreading before and after any proposed remediation. The displacement analysis should determine the magnitude of potential ground movement for use by the structural designer in determining its effect upon the performance of the structure to meet the design performance level.

8. Additional Guidance for Category I Structures, Components and Systems

8.1 Seismic Category I Structures

Seismic Category I structures should be designed using dynamic analysis procedures or when justified equivalent static procedures using both horizontal and vertical input ground motions. For dynamic analyses, either response spectra or time history analyses approaches may be used. Dynamic analysis should be performed in accordance with the procedures of ASCE 4-98 with the exception of the damping limitations noted in Section 4.1 of this document

8.2 Seismic Category I Components and Systems (except piping)

Category I components and systems (except piping) should be designed using either dynamic or equivalent static analysis procedures. The design should be based on in-structure response spectra developed from the Category I analysis. Category I equipment should be seismically qualified. Acceptable procedures for qualification are provided in Section 13.2.2 of ASCE 7-05 except the in-structure spectra should be developed based on the requirements of ASCE 4-98.

8.3 Seismic Category I Piping

Seismic Category I piping should be seismically designed in accordance with Section 6.1.2 of NFPA 59A-2001, except that the OBE ground motion and S_{DS} coefficient should be determined in accordance with Section 5 of this document.

8.3.1 Method of Stress Analysis

In an equivalent static analysis, the seismic input should be 1.5 times the peak spectral acceleration at 5% damping, including in-structure amplification to envelope all pipe support attachment points to the structure.

In a dynamic analysis, the seismic input should be the three-directional in-structure response spectra, at 5% damping, which envelope all pipe support attachment points to the structure.

8.3.2 Qualification of Piping Systems

Stress analysis of piping should be conducted in accordance with the following requirements:

1) The analysis should consider all three directional inputs to be concurrent (plant reference east-west, north-south, and vertical).

2) Seismic input should be based on 5% critical damping.

3) The analysis should consider the relative seismic anchor motions between support attachment structures and end points.

4) The system responses to each directional input should be combined by square-root-sum of the squares.

5) Dynamic response spectra analysis should consider the effects of rigid modes beyond the cut-off frequency.

6) The seismic-induced loads and movements should be combined with concurrent operating loads.

7) Piping stress limits should be as specified in ASME B31.3.

8) The analysis should address the cumulative fatigue effects of an OBE or SSE at end of design life, including expansion-contraction fatigue damage usage factor sustained during operation.

9) Relative movements at mechanical joints should be limited to manufacturer specified limits to assure leak tightness and function.

10) Equipment or component nozzle loads should be limited as specified by the manufacturer to assure operability of the equipment or component.

11) In-line active components (such as valves and instruments that need to perform an active function during or after the OBE or SSE) should be qualified for the accelerations imparted by the piping system.

12) The stiffness of pipe supports in the direction of applied restraint should be included in the pipe stress analysis model unless the supports can be qualified as rigid according to the following criteria:

    a) 12” and larger pipe: minimum support stiffness of 100 Kips/inch in the direction of restraint;

b) 3” to 12” pipe: minimum support stiffness of 10 Kips/inch in the direction of restraint;

c) 2” and smaller pipe: minimum support stiffness established by technical judgment.

13) Seismic supports should be designed to sustain the seismic and concurrent loads imparted by the piping system.

8.4 Seismic Category I Foundations

All Seismic Category I foundations should be designed to meet the requirements of Chapter 18 of the 2006 IBC. In addition Seismic Category I foundations should be designed to meet the requirements specified for LNG tanks in Section 7.4 of this document. Where liquefaction settlements result in foundation movements that exceed the allowable movements for the Seismic Category I structures or systems, the liquefaction hazard should be mitigated so that the foundation movements are within the acceptable limits. In addition, structures where total liquefaction settlement is greater than 3 inches should be:

1) supported on piles and piles designed for down-drag due to settlement; or

2) designed to mitigate the liquefaction hazard by ground improvement; or

3) a combination of both.

9. Additional Guidance for Category II Structures, Components and Systems

9.1 Seismic Category II Structures

Seismic Category II structures, with the exception of docks and piers, should be analyzed and designed using either dynamic analysis or, if the structure is not highly irregular, equivalent static procedures in accordance with the requirements of ASCE 7-05. Docks and piers should be designed in accordance with the MOTEMS (Ref. 15) or per U.S. Coast Guard requirements if more stringent, except the design earthquake motions should be determined in accordance with Section 5.1 of this document.

9.2 Seismic Category II Components and Systems (except piping)

Seismic Category II components and systems (except piping) should be designed using either dynamic or equivalent static analysis procedures in accordance with the requirements of ASCE 7-05 utilizing an $I_p = 1.5$. Category II active equipment should be seismically qualified in accordance with Section 13.2.2 of ASCE 7-05.

9.3 Seismic Category II Piping

Seismic Category II piping shall be seismically designed in accordance with Section 6.1.2 of NFPA 59A-2001, except that the OBE ground motion and S_{DS} coefficient should be determined in accordance with Section 5 of this document. Piping stress analysis should be conducted in accordance with Sections 8.3.1 and 8.3.2 of this Part except as follows:

1) The analysis may be bi-directional (North-South + Vertical and East-West + Vertical) as permitted in ASCE 7-05.

2) The importance factor should be $I_p = 1.5$.

3) The reduction factor R_p should equal 3, with the allowable stress limited to 1.3S as specified in ASME B31.3.

9.4 Seismic Category II Foundations

All Category II foundations should be designed to meet the requirements of Chapter 18 of the 2006 IBC and ASCE 7-05 Section 11.8. Where liquefaction settlements result in foundation movements that exceed the allowable movements for the Seismic Category 2 structures or systems, the liquefaction hazard should be mitigated so that the foundation movements are within the acceptable limits. In addition, structures where total liquefaction settlement is greater than 3 inches should be:

1) supported on piles and piles designed for down-drag due to settlement; or

2) designed to mitigate the liquefaction hazard by ground improvement; or

3) a combination of both.

10. Additional Guidance for Category III Structures, Components and Systems

10.1 Seismic Category III Structures, Components and Systems

Seismic Category III structures should be analyzed and designed in accordance with ASCE 7-05 seismic requirements.

10.2 Seismic Category III Foundations

All Seismic Category III foundations should be designed to meet the requirements of Chapter 18 of the 2006 IBC and ASCE 7-05 Section 11.8.

11. Material Standards

The LNG facility design should satisfy the material standards requirements contained within Chapters 19-24 of the 2006 IBC. This means the basis of design should be ACI 318-05, AISC 341-05 including Supplement 1, etc. and all errata. It also means that any exceptions to these standards that are taken in Chapters 19-24 of the 2006 IBC should also be satisfied in the design.

12. Seismic Recording Instrumentation

Seismic recording instrumentation should be triaxial digital systems that record accelerations versus time accurately for periods between 0 and 10 seconds. Recorders should have rechargeable batteries such that if there is a loss of power, recording will still occur. The instrumentation should be housed in appropriate weather and creature proofed enclosures. At all LNG facilities, as a minimum, one recorder should be located in the free field mounted on rock or competent ground generally representative of the site. In addition, at sites classified as Seismic Design Category D, E, or F in accordance with Chapter 11 of ASCE 7-05 (assuming Occupancy Category IV) recorders should be located and attached to the foundations and roofs of LNG tanks, and in the control room. The systems should have the capability to also produce response spectra for each recorded time history.

The purpose of the instrumentation is to permit a comparison of measured responses of Seismic Category I structures and selected components with predetermined results of analyses that predict when damage might occur. Also, to permit facility operators to understand the possible extent of damage within the facility immediately following an earthquake and to be able to determine when an SSE event has occurred that would require the emptying of the tank(s) for inspection as specified in section 4.1.3.6 (c) of NFPA 59A-2001.

Part II
Data Submittal Requirements

1. Introduction

This Part of the document provides guidance on the data submittal requirements and the method of presentation to permit FERC seismic design review of proposed new LNG facilities or proposed significant changes to existing LNG facilities. Seismic Design Guidelines for LNG Facilities are provided in Part I of this document.

2. Levels of Submittals

There are two levels of submittals for seismic review:

1) Submittals at the Pre-filing (PF) and Application Review Stage; and,

2) Submittals at the Completion of Design and Prior to Construction

Submittals at the PF/application stage are those typically contained in Resource Report 13 (18 CFR 380.12 (o)). Guidance for filing Resource Report 13 is found in Ref. 20. This level of detail will reflect the front end engineering design (FEED) by the applicant's engineering firm. Information and data to permit seismic review is required by Section 13.3.15 of Ref. 20. Section 3 of this Part provides details of what is needed in Resource Report 13 to permit seismic review. As noted in Appendices D and E, respectively, a Seismic Design Criteria document and a Foundation Design Criteria document should also be provided.

If the project is authorized by the FERC, the company will finalize a contract with an engineering, procurement, and construction firm (EPC) and start final design. Submittals at the completion of design and prior to the construction stage are typical of those submitted to building departments in jurisdictions which perform detailed plan checks of structure designs before they are permitted for construction (i.e. building permits). It is expected that design and construction of the facility will be done in discrete steps and that construction approval packages will be prepared for each step. The required content of the construction approval packages is given in Section 4 of this Part. It is advisable for the applicant to submit the packages at least 60 days prior to scheduled construction of a particular package to permit time for FERC review. The time required for FERC review depends on the complexity and scope of the facility design and the completeness of the approval package.

3. Application Stage Seismic Review Submittals

Each applicant's Resource Report 13 should contain the seismic review data and information listed below in Subsections 3.1 through 3.14.

A Seismic Review cross reference table should be provided in Resource Report 13 indicating in which folder or document (and section as applicable) items, information and reports corresponding to each of the following subsections are located.

3.1 Plant Description

The plant description should include a brief discussion of the principal design criteria, operating characteristics, and safety considerations for the engineered safety features and emergency systems; the instrumentation, control, and electrical systems, and the LNG handling and storage systems. The general arrangement of major structures and equipment should be indicated by the use of plan and elevation drawings in sufficient number and detail to provide a reasonable understanding of the general layout of the plant. Those features of the plant likely to be of special interest with respect to safety (Seismic Category I and II structures, systems and components) should be identified.

3.2 Summary of Site Investigation and Facility Status

The applicant should document the current status of the site evaluation study. Planned and anticipated further investigation should also be identified and described. The applicant should document the current design status of the facility and describe the remaining work required to transition the facility design from current stage to a final design. The applicant should also identify engineering computations performed to support the current design stage and the remaining studies, data gathering, calculations and documentations yet to be done. Such items as unusual site characteristics, solutions to particularly unique and difficult engineering problems, and significant extrapolation in technology represented by the design should be identified.

3.3 Requirement for Further Technical Information

Identify, describe, and discuss those structures, systems or components for which further technical information is required in support of the issuance of a FERC approval, but which has not been supplied. This information should include:

1) Detailed descriptions of any development programs that will be required for final determination of design adequacy.

2) A description of the specific technical information that must be developed or obtained to demonstrate acceptable resolution of critical issues associated with a new design concept.

3) A schedule for project completion and commissioning. The schedule should include the current plan for submission of construction approval packages that identify the number and type of packages that will be submitted (see Section 4 for more details).

3.4 Geotechnical Report, Geotechnical Calculations and Analysis

A geotechnical report should be prepared as described in Appendix A and Section 3.4.1 below.

3.4.1 Report Content

The following information as a minimum should be provided in the geotechnical report:

1) Project Description: Detailed description, sizes, loads, and relative location and Seismic Category (I, II, or III) of major structures such as LNG tanks, containment systems, buildings, storage tanks, vaporizers, and other plant components including unloading and docking facilities.

2) Field Exploration: Soil borings, standard penetration tests, rock coring, test pits, cone penetration tests, seismic refraction and downhole/crosshole seismic velocity measurements, other in-situ measurements.

3) Laboratory Testing: Soil identification tests (moisture content dry density, gradation, plasticity index, specific gravity, etc.), strength tests (direct shear, unconfined compression, pocket penetrometer, torvane, triaxial), compressibility (consolidation, expansion index, collapse potential), corrosivity (pH, electrical resistivity, sulfates, chlorides), CBR/ R-value.

4) Geologic and Seismic Setting: Regional and local geologic and seismic setting of the site including faults and seismic sources.

5) Site Conditions: Site surface conditions including site elevations, topography, drainage, etc. Site subsurface soil and groundwater conditions, description of soils / rock layers, including geotechnical cross-sections, and representative soil parameters.

6) Seismic Hazards: Fault rupture, tsunamis, seiche, subsidence, ground motions (a short description of these items should be provided and the site-specific seismic hazard report referenced for more details). Liquefaction potential, liquefaction-related settlement, potential for sand boils and other surface manifestation of liquefaction, lateral spreading, seismic slope stability, seismic compaction, and need for ground improvement to mitigate liquefaction hazard, if present, should be addressed in detail in the geotechnical report.

7) Site Class Determination: Geotechnical information should be provided that is needed to establish the Site Class in accordance with Chapters 11 and 20 of ASCE 7-05 (Ref. 6). Evaluations should also be provided that make recommendations on how the geotechnical information will change for any ground improvement options that are recommended in the report. Site Classes should be determined for all structures at the site based on Chapters 11 and 20 of ASCE 7-05 for the various ground improvement options that are provided in the report.

8) Poor Soil Conditions: Presence of poor or unusual soil conditions, such as highly compressible or highly expansive soils, corrosive soils, collapsible soils, erodible soils, liquefaction-susceptible soils, frost heave susceptible soils, frozen soils, or sanitary landfill etc. should be identified and remedial measures including ground improvement methods should be recommended, if such soils are present.

9) Foundations Recommendations:

   (a) LNG Tank Foundations/Tank Loading:

      (i) Shallow Foundations: ultimate bearing capacity, factor of safety and allowable bearing capacity, settlement criteria, mat foundations, estimated total and differential settlements, liquefaction settlements, settlement monitoring, lateral resistance.

      (ii) Deep Foundations: foundation type(s), axial pile capacity, lateral pile capacity, group effects, settlement of pile groups, lateral movement of pile groups, pile installation, load tests, pile driving analyzer, indicator pile programs.

      (iii) Ground Improvement: need for ground improvement, type(s) of ground improvement, surcharge, stone columns, vibroflotation, soil-cement columns, dynamic compaction, other types of ground improvement. Address the effects of ground improvements on soil properties and seismic ground motions.

   (b) Other Foundations - Buildings, Tanks, Vaporizers, containment berms, other foundations/Foundation Loading:

      (i) Shallow Foundations: ultimate bearing capacity, factor of safety and allowable bearing capacity, settlement criteria, mat foundations, estimated total and differential settlements, liquefaction settlements, settlement monitoring, lateral resistance.

      (ii) Deep Foundations: foundation type(s), axial pile capacity, lateral pile capacity, group effects, settlement of pile groups, lateral movement of pile groups, pile installation, load tests, pile driving analyzer, indicator pile programs.

10) Slope Stability: Both static and seismic stability including effects of dredged slopes for loading-unloading facilities on the stability of the tanks and other safety related structures.

11) Corrosion: Evaluation of soil corrosivity for metal and concrete in contact with onsite soils. Need for special types of cement and corrosion protection of utilities.

12) Pavement Design: Recommendations for pavement design for both asphalt and Portland cement concrete pavements for the plant.

3.5 Seismic Ground Motion Hazard Analysis Study

A seismic hazard analysis study should be prepared that includes evaluation of the following hazards at the propose site:

1) ground surface rupture,
2) seismic shaking (ground motions),
3) liquefaction,

4) seismic compaction,
5) seismic slope stability including lateral spreading,
6) tsunamis and seiche.

3.5.1 Site-Specific Ground Motions

The seismic ground motion hazard analysis portion of the study should be prepared as described in Appendix B of this document except the OBE and SSE ground motions should be determined in accordance with NFPA 59A-2001 (Ref. 2) and the limitations and guidance provided in the Seismic Design Guidelines found in Part I of this document.

The following information and data should be submitted as part of the study:

1) Longitude and latitude of the site (to 3 significant digits beyond the decimal point).

2) Site Class for each of the various recommended ground improvement options recommended in the geotechnical report.

3) S_S and S_1 determined for the site by USGS MCE maps found in ASCE 7-05 Chapter 22.

4) T_L determined for the site from ASCE 7-05 Chapter 22 maps.

5) 5 % Damped Spectral Acceleration at 0.2 sec and 1.0 second determined for the site from the 2002 USGS National Seismic Hazard Maps for a 475 year return period (10% probability of exceedance in 50 years).

6) F_a values corresponding to the Site Class at the proposed site for S_S and 0.2 second spectral values determined using the USGS National Seismic Hazard Maps at 475 year return period (10% probability of exceedance in 50 years) based on Table 11.4-1 of ASCE 7-05. For Site Class F, report Site Class E values.

7) F_v values corresponding to the Site Class at the proposed site for S_1 and 1.0 second spectral values determined using the USGS National Seismic Hazard Maps at 475 year return period (10% probability of exceedance in 50 years) based on Table 11.4-2 of ASCE 7-05. For Site Class F, report Site Class E values.

8) Any significant differences in assumptions (e.g. attenuation relationships, activity levels of earthquakes, slip rates, time-dependent analysis, etc.) between site specific probabilistic seismic hazard analysis (PSHA) and those made in preparing 2002 USGS National Seismic Hazard Maps. Provide justification for significant differences and any written communications from USGS that indicate USGS agreement and intent to incorporate same into the next version of the National Seismic Hazard Maps. Also provide a comparison of PSHA results from the Applicant's study versus PSHA results derived from the same probabilistic model used in the Applicant's study except using the 2002 USGS assumptions. The purpose of this comparison is to demonstrate the validity of the Applicant's probabilistic analysis.

9) Provide technical data, supporting documents and justification for site-specific recommendations for very long period spectral accelerations at the sloshing periods of the LNG tanks (typically 8 to 10 seconds). Discuss any differences between the T_L values in ASCE 7-2005.

10) If site response analyses are performed, provide the range of uncertainties of soil properties used in analyses and how these properties relate to the geotechnical report and various ground improvement recommendations provided in the report (uncertainty margins should satisfy limitations provided in Section 6 of Part I of this document). Provide model properties used in evaluation. Indicate how the ground motions used were selected and scaled (scaling should satisfy the limitations provided in Section 6 of Part I of this document). Provide scaling factors and response spectra of time histories of scaled records. Provide a visual record and electronic file of scaled time histories used for site response analysis.

11) Provide time histories and their response spectra that are provided to the designers for determining soil structure interaction (scaling should satisfy limitations provided in the Seismic Design Guidance in Part I of this document).

12) Provide recommended OBE and SSE response spectra; plotted spectral acceleration versus period for 0 to 10 seconds, and show in spectra plots how the recommended site specific OBE and SSE motions satisfy both NFPA 59A-2001 and the limitations provided in the Seismic Design Guidelines provided in Part I of this document.

3.5.2 Other Seismic Hazards

The following data and information should be provided regarding other seismic hazards at the site. There may be some overlap between the geotechnical report (Section 3.4) and the Seismic Hazard Report (Section 3.5). In general, the geotechnical report should address all seismic hazards whereas, the seismic hazard report, provides detailed assessment of ground motions and additional data and details on seismic hazards.

1) Location of the site with respect to active faults and distance to these faults. Potential for surface rupture at the site due to faulting and if present, magnitude of anticipated vertical and horizontal deformation under the plant due to fault rupture including their probability of occurrence or return period.

2) Liquefaction potential at the site, factor of safety against liquefaction and settlement due to liquefaction. If settlement due to liquefaction is more than can be tolerated by the structure(s), recommendations for ground improvement to mitigate the liquefaction potential. Estimates of lateral spreading movements due to liquefaction should be made and their effects on the structures evaluated. Estimation of potential for and settlement due to dynamic compaction of sands above the water table.

3) Calculation of seismic slope stability of existing or future slopes, including those for the LNG marine receiving terminals, using pseudo-static screening analysis as discussed in Section 7.4.2, Part 1. If the calculated factor of safety is less than 1.0, include calculation

of lateral deformation due to shaking and its impact on the various category (Seismic Category I, II, and III) plant structures.

4) Calculations of deformations due to lateral spreading. Calculations of lateral deformation using finite difference analyses such as FLAC (Itasca, 2000, Ref. 19). Recommendations for ground improvement, if lateral deformations are more than the values that can be tolerated by various seismic categories of structures.

5) Tsunamis and seiche. Tsunami run-up should be evaluated for 100 and 500 year return periods and seismic sources consistent with the SSE. Run-up projections should be made considering the proposed structure foundation elevations and proposed seawalls or berms that provide tsunami protection. For sites where seiche are also a possibility, seiche run-ups should be evaluated for 100 and 500 year return periods and seismic sources consistent with the SSE considering the proposed foundation elevations and proposed seawalls or berms that are proposed for seiche protection. Locations of bodies of water where waves or breach of existing dams could cause flooding at the site should also be evaluated.

6) Subsidence due to earthquakes, groundwater or oil withdrawal is a significant geologic/seismic risk. Areal movements due to these effects should be evaluated and their effects on site flooding and differential settlement of the plant structures should be evaluated.

3.6 Identification and Seismic Classification of LNG Facility Structures, Components and Systems

The seismic category assignments for all LNG facility structures, components and systems located within the facility security fence should be provided. The seismic category assignments should be all-inclusive according to the definitions given for Seismic Categories I, II and III in Part I, Section 2, of this document. If only portions of structures and systems are Category I or II, they should be listed and, where necessary for clarity, the boundaries of the Category I and II portions should be shown on piping and instrumentation diagrams. An example of a categorized list for an LNG facility is provided in Appendix C of this document.

3.7 Design Criteria and Analytical Approach for LNG Facility Structures, Components and Systems

Seismic design criteria (also sometimes called design basis for structures, components and systems) should be provided for Seismic Category I, II and III structures, components and systems. These criteria can be provided in one document or separate documents at the discretion of the Applicant. However criteria for all items for all Seismic Categories should be provided.

The criteria should include, as applicable, information or references needed to perform a design including design response spectra, seismic design coefficients, load combinations, damping values, damping value reduction factors, ductility or inelastic reduction factors to be used with the OBE and SSE, the allowable stresses, strength capacities and ϕ-factors for each load combination, intended methods of analysis, building codes and material standards to be used and all other criteria necessary to perform the design of each structure, component and system.

The seismic design criteria should, as a minimum, satisfy NFPA 59A-2001 and the additional limitations and guidance provided in Part I of this document. Items to be considered in preparing the seismic design criteria documents are provided in Appendix D. The seismic design criteria should also include the ASCE 7-05 Design Earthquake seismic coefficients and seismic design parameters that are to be used in the design of structures, systems and components that are assigned Seismic Category II and III.

3.8 Site Improvement and Foundation Design for Seismic Loads

Proposed foundations for all buildings, structures and equipment should be described and discussed for all viable ground improvement options and specific proposed designs identified. Allowable total and seismic settlement for all foundation options should be identified for all applicable design level seismic motions. Foundation allowable settlements should satisfy the Seismic Design Guidance provided in Part I of this document. Additional guidance for what is to be included in the discussion of the design of Category I structures is provided in Appendix E. A specific option for ground improvement and foundation design upon which the application is based should be identified. The reasons for selecting the identified option should be discussed and preliminary calculations and analysis that justify the proposed site improvement approach should be included with the submitted geotechnical report. Preliminary site preparation specifications and civil site improvement drawings included with Report 13 should include and be consistent with the selected site improvement option identified in the geotechnical report.

3.9 Tank and Containment Preliminary Design Drawings and Calculations

Preliminary design drawings and structural calculations should be provided for the LNG tanks, containment structures and their proposed foundations. Particular attention should be given to providing a physical description of the storage tanks and impounding systems, including plan and section views in sufficient detail to define the primary structural aspects. The arrangement of the containment, particularly the relationship and interaction of each storage tank with its surrounding floor, should be provided to establish the effect that the structures could have on the design boundary conditions. If the bottom of the tank is steel and the surface is not continuous, the method of anchorage of the steel shell walls to the concrete base slab should be described. Other major structural attachments should also be described.

3.10 Seismic Specifications for Procured Equipment

Provide seismic specifications for items to be procured. The specifications should satisfy the Seismic Design Guidance provided in Part I of the document. At the discretion of the applicant, separate specifications can be provided for Seismic Category I, II and III items and/or other equipment subsets as deemed practicable.

3.11 Materials, Quality Control, and Special Construction Techniques

The applicant should provide quality assurance procedures, as required for "essential" facilities in Chapter 17 of the 2006 IBC (Ref. 3) at a minimum, for all Seismic Category I structures, systems and components including requirements for special inspection to assure quality and seismic performance. Quality assurance procedures and special inspection should also be provided for Seismic Category II and III structures, systems and components as required by 2006 IBC and other industry standards, as applicable.

A special inspector should be employed by the applicant during construction to observe the work to be certain it conforms to the design drawings and specifications. The inspector should furnish inspection reports to the engineer or architect of record, and other designated persons. All discrepancies should be brought to the immediate attention of the contractor for correction, then if uncorrected, to the engineer or architect of record. The inspector should submit a final signed report stating whether the work requiring special inspection was, to the best of his/her knowledge, in conformance with approved plans and specifications and the applicable workmanship provisions. A copy of the report should be filed with FERC.

3.12 Seismic Instrumentation

3.12.1 Description of Instrumentation

The proposed seismic instrumentation should be discussed (See for example NRC Reg.Guide 1.12, Ref. 31). Seismic instrumentation such as triaxial peak accelerographs, triaxial time history accelerographs, and triaxial spectrum recorders that will be installed in selected Category I structures and on the selected Category I components should be described. The bases for selection of these structures and components and the location of instrumentation, as well as the extent to which this instrumentation will be employed to provide detection, alarms, emergency response, and post-event verification of structural integrity, should be specified.

3.12.2 Control Room Operator Notification

The procedure to be used by the control room operator to respond to seismic alarms and data should be described and included in the facility's Emergency Response Plan. The procedure may reference peak acceleration or spectral response data or other post-processed information and data as applicable for the type of seismic instrumentation proposed for installation, as well as contact information on who should be notified.

3.12.3 Comparison of Measured and Predicted Responses

Provide the criteria and procedures that will be used to compare measured responses of Category I structures and selected components in the event of an earthquake with the results of the seismic system and subsystem analyses.

3.13 Regulations

A list of codes, standards, specifications, regulations, general design criteria, and other industry standards used in the design, fabrication, and construction should be provided. The specific edition should be provided. The listed documents should be consistent with the list provided in the Seismic Design Guidance provided in Part I of this document.

3.14 References

A list of references used in developing the data and information provided to satisfy the data submittal requirements of Sections 3.1 through 3.13, above.

3.15 Determination of LNG Liquid Levels for Seismic Forces and Freeboard

A study should be provided that determines the liquid levels of LNG in the LNG tanks in accordance with Section 7.1 of Part I of this document. Liquid levels should be determined for both OBE and SSE design earthquakes. These will be determined for the full range of expected loading and unloading sequences that will occur in a given year once the facility is in normal operation. To determine the 1% or 5% values, the determination can be made either on an hourly or daily basis. For example, for a given height, the number of hours that the given height is exceeded in a year divided by the number of hours in a year times 100 is the percentage.

4. Submittals at the Completion of Design and Prior to Construction

Prior to commencing construction, the applicant should submit the documents indicated below in Subsection 4.1 through 4.4 to FERC for review and approval. At the discretion of the applicant, the documents can be submitted as a series of construction approval packages. The documents should be submitted a minimum of 60 days prior to the date that specific fabrication or construction contained with package is schedule to commence. If the project is to be constructed in series of construction packages, a schedule should be provided at the beginning overall construction listing the proposed construction approval packages and the planned date when each package would be submitted.

4.1 Description of Package

A description of the content of each package should be provided. A plot plan should be included with a description showing where the construction is located on the plot.

4.2 Design Drawings

Design drawings for the proposed construction should be provided. The drawings should be stamped and sealed by the engineer-of-record responsible for design. The engineer-of-record should be a registered professional engineer in the state of jurisdiction for the site of the LNG facility and practicing pursuant to the regulations of the professional engineering board of that state. All geologic and seismic reports should be prepared by a Registered Engineering Geologist or appropriate Registered Design Professional.

4.3 Design Level Report

The final geotechnical report should provide the selected foundation option for the tanks and other structures and should demonstrate that the Seismic Category I structures can withstand the OBE and SSE with the required performance objectives. Seismic Category II and III structure foundations should be demonstrated to meet the requirements in the Seismic Design Guidelines provided in Part I of this document and the appropriate codes. Include:

a) detailed recommendations for additional field and laboratory investigations proposed for the design level geotechnical investigation;
b) number, locations, and depths of borings;
c) cone penetration tests;
d) seismic velocity measurements;
e) rock coring; etc.
f) analyses of ground improvement option(s) selected for mitigation of liquefaction, lateral spreading, or poor soil conditions, its impact on soil conditions and seismic site characterization should be evaluated.
g) detailed analyses of liquefaction settlements and lateral spreading movements before and after the selected ground improvements should be provided.

4.4 Design Calculations

Design calculations for the proposed construction should be provided. The cover sheet of the calculations should be stamped and signed by the engineer of record. A table of contents for the calculations should be provided following the cover page. The calculations should include the seismic design criteria used in performing the design, the materials used, analysis models, analyses, summary of results and comparison with allowables and design of connections. Include any additional geotechnical investigations that support the design foundations in the construction approval package under consideration. Also include the analyses associated with development of in-structure response spectra needed for design and/or seismic qualification of components and systems.

4.5 Seismic Qualification Documentation

Seismic Qualification documentation for equipment that requires qualification that is installed as part of the construction approval package should be provided. The in-structure spectra that the equipment is being qualified to satisfy should be included in the documentation.

References

1. 49 CFR 193, *Liquefied Natural Gas Facilities*: The Code of Federal Regulations , As Revised in 2003

2. NFPA 59A, *Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG)*, 2001 Edition.

3. International Code Council (ICC), *International Building Code*, 2006 Edition

4. ACI 318-05, *Building Code Requirements for Structural Concrete and Commentary*, 2005

5. AISC 341-05 Including Supplement No. 1, *Seismic Provisions for Steel Buildings*, 2005

6. ASCE 7-05 Including Supplement No.1, *Minimum Design Loads for Buildings and Other Structures*, 2005

7. ASCE 4-98, *Seismic Analysis of Safety Related Nuclear Structures and Commentary*, 1998

8. API – 650 Appendix E, *Welded Steel Tanks for Oil Storage*, 10th Edition, Addendum 4, 2005

9. FEMA 450-1, *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures*, 2003 Edition

10. API 620-2007, *Design and Construction of Large, Welded, Low Pressure Storage Tanks*, 2007 Edition.

11. Youd, T. L., et. al., "*Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils*, Journal of Geotechnical and Geoenvironmental Engineering, Vol. 127, No. 10, October 2001.

12. Tokimatsu, Kohji, and Seed, H.B., *"Evaluation of Settlements in Sands Due to Earthquake Shaking,"* Journal of Geotechnical Engineering, Vol. 113, No. 8, Proc. Paper No. 21706, August 1987.

13. Bartlett, S. F., and Youd, T. L., *"Empirical Prediction of Liquefaction- Induced Lateral Spread"*, Journal of Geotechnical Engineering, ASCE, Vol. 121, No. 4, April, 1995.

14. Ishihara, K. and Yoshimine, M., *"Evaluation of Settlements in Sand Deposits Following Liquefaction During Earthquakes"*, Soils and Foundation, Vol. 32, No. 1, March, 1992, pp. 173-188.

15. MOTEMS, *Marine Oil Terminal Engineering and Maintenance Standards*, California State Lands Commission, 2005

16. U.S. Geological Survey, *"National Seismic Hazard Maps"*, 2002 http://earthquake.usgs.gov/research/hazmaps/products_data/index.php

17. Frankel, A., Petersen, M. Mueller, C., Haller, K., Wheller, R., Leyendecker, E., Wesson, R., Crammer, C., Perkin, D., and Rukstales, K., 2002, *Documentation for the 2002 Update of the National Seismic Hazard Maps*, USGS Open File Report 02-240

18. Makdisi, F. I., and Seed H.B., *"Simplified Procedure for Estimating Dam and Embankment Earthquake-Induced Deformations"*, Journal of the Geotechnical Engineering Division, Proceedings of the ASCE, Vol. 104, No. G.T. 7, July 1978, pp. 849-867

19. Itasca Consulting Group, Inc., 2000. *FLAC – Fast Lagrangian Analysis of Continua*, User's Manual.

20. FERC, *Draft Guidance for Filing Resource Reports 11 & 13 for LNG Facility Applications*, Federal Energy Regulatory Commission, December 2005.

21. Martin, G. R., and Lew, M., *"Recommended Procedures for Implementation of DMG Special Publication 117, Guidelines for Analyzing and Mitigating Liquefaction Hazards in California"*, Southern California Earthquake Center, University of Southern California, March 1999.

22. California Department of Conservation, Division of Mines and Geology, DMG Note 49 – *"Guidelines for evaluating the hazard of surface fault rupture"*, 1998.

23. Bartlett, S. F., and Youd, T. L., *"Empirical Analysis of Horizontal Ground Displacement Generated by Liquefaction-Induced Lateral Spread"*, Technical Report NCEER-92-0021, National Center for Earthquake Engineering Research, Buffalo, New York, 1992.

24. Newmark, N. M., *"Effects of Earthquakes on Dams and Embankments"*, *Geotechnique,* Vol. 15, No. 2, pp. 139-160, 1965.

25. Cornell, C. A., 1968, *Engineering Seismic Risk Analysis*, Bulletin of the Seismological Society of America, No. 58.

26. Frankel, A.D., Mueller, C., Barnhard, T., Perkins, D., Leyendecker, E.V., Dickman, N., Hanson, S., and Hopper, M., 1996, *National Seismic-Hazard Maps: Documentation, June, 1996,* U.S. Geological Survey Open-File Report 96-532.

27. Algermissen, S. T. and Perkins, D. M. 1976, *"A Probabilistic Estimate of Maximum Acceleration in Rock in the Contiguous United States"*, U. S. Geological Survey Open-File Report 76-416.

28. API, RP-2A, *"Recommended Practice for Planning, Designing and Construction Fixed Offshore Platforms – Working Stress Design"*, Section 6, Foundation Design, July 1, 1993.

29. Blake, T. F., Hollingsworth, R. A., and Stewart, J. P., *"Recommended Procedures for Implementation of DMG Special Publication 117 Guidelines for Analyzing and Mitigating Landslide Hazards in California"*, Southern California Earthquake Center, USC, June 2002.

30. American Society of Testing Materials (ASTM), *Annual Book of ASTM Standards*, Vol. 04.08, Soil and Rock (I): D420-D5779 (Latest Edition).

31. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.12, "*Nuclear Power Plant Instrumentation For Earthquakes*", 1997

32. Jibson R. W., and Jibson, M. W., *" Java programs for using Newmark's method and simplified decoupled analysis to model slope performance during earthquakes,"* USGS Open File Report 03-005, Version 1.0, 2003.

Appendix A
Geotechnical Report Requirements

Appendix A
Geotechnical Report Requirements

1. Contents of Report

1.1 Plant Description

The general arrangement of major structures and equipment should be indicated by the use of plan and elevation drawings in sufficient number and detail to provide a reasonable understanding of the general layout of the plant. The sizes and loading of the critical structures should be provided.

1.2 Summary of Site Investigation and Facility Status

The applicant should document the current status of the site evaluation study. Additional planned investigations should also be described. The applicant should document the current design status of the facility such as conceptual design or final design. The applicant should also identify what level of computations have been performed to arrive at the current design stage and what studies, data gathering, calculations and documentation remains to be done. Such items as unusual site characteristics, solutions to particularly difficult engineering problems, and significant extrapolation in technology represented by the design should be highlighted.

2. Exploration

Discuss the type, quantity, extent, and purpose of all explorations. Provide plot plans that graphically show the location of all site explorations such as borings, trenches, borrow pits, seismic lines, cone penetration tests, piezometers, wells, geologic profiles, and the limits of required construction excavations. The locations of the Seismic Category I, II and III facilities should be superimposed on the plot plan. Also, furnish selected geologic cross-sections and profiles that indicate the location of borings and other site exploration features, groundwater elevations, and final foundation grades. The location of safety-related foundations should be superimposed on these sections and profiles.

Logs of all borings and test pits should be provided. Furnish logs and maps of exploratory trenches and geologic maps and photographs of the excavations for the facilities of the LNG plant.

2.1 Logs of Borings/CPTs

Present the logs of borings, CPTs, test pits and trenches that were completed for the evaluation of foundations, slopes, and borrow materials to be used for slopes.

Logs should indicate elevations, depths, soil and rock classification information, groundwater levels, exploration and sampling methods, recovery, RQD, and blow counts from standard penetration tests. Provide specific details of how the Standard Penetration Test was performed. Discuss drilling and sampling procedures and indicate where samples were taken on the logs. In areas where liquefaction potential is high, borings should be performed by rotary drilling method in accordance with the requirements for obtaining standard penetration blow count N-values outlined by Youd, et al., 2001 (Ref.11) and Martin & Lew, 1999 (Ref. 21). Cone penetration tests should be performed to define the soil profile accurately and to utilize both N-values and CPT data for evaluation of liquefaction potential and settlements due to liquefaction. A minimum of three explorations (borings / CPTs) should be performed under each LNG tank and the depth of the exploration should be 20 ft deeper than deepest anticipated foundations and liquefaction potential (at least 100 feet if bedrock is not encountered).

All local, state, and Federal environmental regulations regarding obtaining permits for the geotechnical borings and wells, clearing of underground utilities, disposal of cuttings and drilling mud should be followed.

Where groundwater is present at depths which could affect the foundations or liquefaction potential, selected borings should be converted into wells to define stabilized groundwater. Historic high groundwater should be determined from published literature for liquefaction evaluation.

2.2 Geophysical Surveys

Results of compressional and shear wave velocity surveys performed to evaluate the occurrence and characteristics of the foundation soils and rocks should be provided in tables and profiles. Discuss other geophysical methods used to define foundation conditions. The depth of explorations for performing downhole or cross-hole shear wave velocity measurements should be at least 100 feet.

3. Laboratory Testing

3.1 General

Laboratory testing should include the following tests. Actual tests should depend on the type of soil encountered. All testing should be performed in accordance with the most recent ASTM standards (Ref. 30), where applicable. Adequate number and type of tests should be performed on representative samples in order to characterize the subsurface soils and to develop representative strength, compressibility, and corrosivity properties of the soils as indicated in this specification.

3.2 Identification Tests

Moisture Content (ASTM D2216)
Unit Weight
Specific Gravity (ASTM D854)
Sieve Analysis (AS TM D422)
Atterberg Limits (ASTM D4318)

3.3 Engineering Property Characterization Tests

Compaction (ASTM D1557, or D698)
California Bearing Ratio (ASTM D1883)

R-value (ASTM D2844)
Unconfined Compression Test of Cohesive Soils (ASTM D2166)
Unconsolidated-Undrained Triaxial Compression Test (ASTM D2850)
Consolidation Test with time readings (ASTM D2435)
Swell Test (ASTM D4546)
Expansion Index Test (ASTM D4829)
Collapse test (ASTM D 5333)
Consolidated-Drained Triaxial Compression Test
Consolidated-Undrained Triaxial Compression Test with Pore Pressure Measurements (ASTM D4767)
Direct Shear Test (ASTM D3080)
Soil Permeability (ASTM D5084 and D2434)
Corrosivity (Chloride, Sulfate, Electrical Resistivity)
pH Value for Soil Corrosivity (ASTM G51)

4. Geologic and Seismic Setting

This section of the report should discuss general geologic and seismic information relevant to foundation design such as geologic setting, regional geology, site geology, faulting. Specific geologic features that may affect site stability and foundation design such as the following should be discussed.

1) Areas of actual or potential surface or subsurface subsidence, uplift, or collapse and the causes of these conditions;

2) Previous loading history of the foundation materials, i.e., history of deposition and erosion, groundwater levels, and glacial or other preloading influences on the soil;

3) Rock jointing pattern and distribution, depth of weathering, zones of alteration or irregular weathering, and zones of structural weakness composed of crushed or disturbed materials such as slickensides, shears, joints, fractures, faults, folds, or a combination of these features. Especially note seams and lenses of weak materials such as clays and weathered shales;

4) Unrelieved residual stresses in bedrock;

5) Rocks or soils that may be hazardous, or may become hazardous, to the plant because of their lack of consolidation or induration, inhomogeneity, variability, high water content, solubility, or undesirable response to natural or induced site conditions; and

6) Requirements of the detailed site geology, seismicity, and faulting as they relate to site Ground Motion Study are provided in Appendix B.

5. Site Conditions

5.1 Surface Conditions

The surface conditions at the site should be described. Presence of any unusual site features should be identified. Site topography including existing contours should be provided. Site drainage should be discussed. Include a current aerial photograph of the site, and if available, provide historic aerial photographs of the site that demonstrate any past conditions or uses of the site relevant to the proposed facility design.

5.2 Subsurface Soil Conditions

Site subsurface conditions should be described in detail. Generalized subsurface profiles including various soil strata should be presented in various cross-sections across the site specifically through the LNG tank area. Soil properties assigned to each strata should be tabulated for bearing capacity, settlement, pile capacity, and slope stability calculations. The basis for selected soil parameters (laboratory testing, blow counts, CPT data, experience) should be stated. A discussion on the selection of engineering parameters is required. When published correlation relationships are used to determine the engineering parameters, references should be given.

A conversion ratio between blow counts from penetration tests not performed per ASTM D 1586 (standard penetration test) should be discussed and provided, if applicable. This includes nonstandard samplers, nonstandard hammer energy delivery systems, and considerations of hammer efficiency.

5.3 Groundwater Conditions

The analysis of groundwater at the site should include the following points:

1) A discussion of groundwater conditions relative to the stability of Seismic Category I safety-related facilities;

2) A discussion of design criteria for the control of groundwater levels or collection and control of seepage;

3) Requirements for dewatering during construction and a discussion of how dewatering will be accomplished;

4) Records of field and laboratory permeability tests;

5) History of groundwater fluctuations, including those due to flooding and recommended design groundwater level for the plant and for liquefaction analyses;

6) Information related to the periodic monitoring of local wells and piezometers;

7) Direction of groundwater flow, gradients, and velocities; and

8) Discussion of or reference to the groundwater monitoring program during the life of the plant to assess the potential for subsidence.

6. Seismic Hazards

Seismic hazards include fault rupture, ground motions, liquefaction, lateral spreading, seismic slope stability, seismic compaction, tsuamis and seiche. Details of fault rupture, ground motions, tsunamis, and seiche, should be provided in the site-specific seismic ground motion report. These items should be summarized in the geotechnical report.

Liquefaction potential, liquefaction-related settlement, potential for sand boils and other surface manifestation of liquefaction, lateral spreading, seismic slope stability, seismic compaction, and need for ground improvement to mitigate these hazards, if present, should be addressed in detail in the geotechnical report.

6.1 Fault Rupture

Distances from significant faults should be identified and potential for fault rupture should be discussed in the geotechnical report. The site-specific ground motion report should be referenced for more details.

6.2 Site Class

Site Class should be identified per ASCE 7-05 or IBC 2006.

6.3 Ground Motions

A seismic hazard study should be performed to establish ground motions for the site for four levels of shaking, the OBE, the SSE, the MCE, and the DE. Details of the requirements for the determination of the ground motions are presented in Appendix B.

6.4 Seismic Slope Stability

The LNG tanks should have a minimum calculated static factor of safety of 1.5 for slope stability with respect to any nearby slopes of berthing slips or other existing or future slopes. Pseudo-static screening analyses, as discussed in Section 7.4.2, Part 1 may be used to determine seismic slope stability, provided the soils are not liquefiable or expected to lose shear strength significantly during deformation. Detailed deformation analyses as discussed in Section 7.4.2, Part 1 should be performed where pseudo-static screening analyses indicate that factor of safety is less than 1.0.

6.5 Liquefaction Evaluation

When the field investigation reveals that potentially liquefiable soils and conditions including lateral spreading exist and they pose a hazard to the project site, a quantitative geotechnical evaluation of such a potential should be conducted. In-situ testing, soil sampling, and laboratory testing on potentially liquefiable soils must be properly planned and conducted to obtain reliable data for the geotechnical evaluation. If liquefaction is likely to occur, its consequences should be assessed, its impact on foundations should be addressed, and mitigation measures should be specified. Elevations of the liquefiable layer(s) should be presented in the Foundation Report. Assumptions, analytical or empirical methods used, and conclusions for liquefaction evaluation should be stated with relevant data and analysis attached in Appendices. Potential for surface manifestation of liquefaction in form of sand boils and surface displacement should be identified. Total and differential settlements due to liquefaction should be estimated and provided. If liquefaction settlements are beyond the tolerance of the proposed structures, remedial measures to mitigate liquefaction potential should be provided. All liquefaction evaluations should be performed in accordance with latest published guidelines (e.g., Youd, T. L., et. al., 2001 (Ref. 11), and Martin, G. R., and Lew, M., 1999 (Ref. 21)).

6.6 Lateral Spreading

If liquefaction potential exists, potential for lateral spreading should be evaluated and calculations of lateral movements made by Newmark simplified approach (Makdisi, F. I., and Seed H.B, 1978 and by Bartlett & Youd (1995)) method. The effects of calculated lateral spreading movements on the stability of the plant structures should be evaluated and remedial measures proposed, if the movements exceed the design criteria.

6.7 Tsunamis and Seiche

Tsunami run-up should be evaluated for 100 and 500 year return periods from any credible source that could affect the site plus tsunamis generated by seismic sources consistent with the SSE. Run-up projections should be made considering proposed structure foundation elevations and proposed seawalls or berms that provided for tsunami protection. For sites where seiches are also a possibility, seiche run-ups should be evaluated for seismic sources consistent with the SSE considering proposed foundation elevations and proposed seawalls or berms that are proposed for seiche protection. Locations of bodies of water where waves or breach of existing dams could cause flooding at the site should also be evaluated.

6.8 Subsidence

Subsidence due to earthquakes, groundwater or oil withdrawal is a significant geologic/seismic risk. Areal movements due to these effects should be evaluated and their effects on the differential settlement of the plant structures, or general effects on the site (e.g., should be evaluated.

7. Poor Soil Conditions

See Section 3.4 of Part II of this document for recommended report requirements.

8. Foundation Recommendations

Complete, concise, and definite foundation recommendations should be provided for various categories (Seismic Categories I, II, and II) structures. The selection of a specific foundation type depends on factors such as surface and subsurface conditions at the site, geotechnical capacity, dynamic and static demands, environmental concerns, economics, and construction issues. The recommended foundation type should be cost-effective, performance-proven, and constructible.

Alternative foundation types should be discussed and the reasons why those alternatives are not recommended should be stated. Solutions to potential construction problems should be discussed. A sufficient and adequate geotechnical evaluation for the recommended foundation should be performed.

In general, any foundation design should meet four essential requirements: (1) adequate geotechnical capacity of soil/rock surrounding the foundation with a specified safety against ultimate failure; (2) acceptable total or differential settlements under static and dynamic loads; (3) adequate overall stability of slopes in the vicinity of a footing/mat; and (4) constructability with solutions for anticipated problems.

8.1 LNG Tanks

8.1.1 Tank Loading and Settlement Criteria

For LNG tanks the loading from the tanks and criteria for adequate factor of safety against bearing capacity failure and settlement should be discussed.

8.1.2 Shallow Foundations

LNG tanks supported on shallow foundations are generally supported on a mat. Ultimate bearing capacity of the mat should be calculated and should provide a minimum factor of safety of 3.0 for the applied tank loading during hydrotest. Effects of adjacent slopes, if present, on the bearing capacity should be evaluated. The reduction of the factor of safety due to liquefaction or other effects should be evaluated and addressed. Total and differential settlement of the mat foundation should be calculated under various applied loads such as during hydrotest, operation, and seismic conditions including liquefaction, if present. The total and differential settlements should meet the criteria identified in the Seismic Design Guidelines that are provided as Part I of this document.

Recommendations for monitoring of the settlements during hydrotest should be provided. Lateral stability of the tanks under seismic and wind loads should be calculated and it should be demonstrated that an adequate factor of safety is present. If lateral spreading is a seismic issue, lateral stability of the tanks due to lateral spreading movements should be demonstrated. Overall lateral stability of the foundation for static and seismic conditions including any adjacent slopes, if present, should be evaluated.

8.1.3 Deep Foundations

For Deep Foundations, the report should address, but not be limited to, the following when applicable:

1. Pile Types, Axial Compressive and Tensile, and Settlement

    a. Recommended pile types should be identified as driven Precast Prestressed Reinforced Concrete piles, Steel H or Pipe piles, Cast-In-Drilled-Hole (CIDH) piles, Auger Cast Piles or others. Alternatives should be discussed and the reasons why those alternatives are not recommended should be stated.

b. Whether compressive and/or tensional geotechnical capacities are derived from skin friction, end bearing, or a combination of both for a single or group pile(s) should be discussed.

c. Pile Design Tip Elevations (DTE) may be controlled by demands from compression, tension, lateral loads, scour potential, or liquefaction. The pile Specified Tip Elevation (STE) equals the lowest pile DTE as estimated above.

d. The portion of the axial capacities for pile foundations in and above liquefiable soils should be neglected.

e. Negative skin friction (down-drag) on pile shaft due to settlements of new fills or compressible soil layers should be eliminated prior to pile installation. Downdrag from settlements due to liquefaction should be calculated.

f. When a situation such as liquefaction potential exists that does not allow for mitigation and elimination of negative skin friction, the magnitude of the downdrag forces should be estimated and provided to the structural designer for him/her to incorporate those forces into Design Loading. The magnitude of estimated settlement should also be provided to the structural engineer.

g. Lateral pile capacity should be estimated using the p-y method or equivalent. Group reduction factors depending on soil types, pile spacing, and anticipated lateral movement should be considered when evaluating lateral capacity for a group of piles. Formulation of p-y curves for liquefiable soils and weak rocks, effects of pile diameters on lateral soil modulus and soil strain parameters, evaluation of liquefaction or lateral spreading forces imposed on pile, and reduced moment of inertia for concrete piles should be addressed.

h. The single and/or group pile settlement should not exceed the tolerable amount as established by the structural designer or as identified in Seismic Design Guidelines that are provided as Part I of this document.

2. Special Considerations for Cast-In-Drilled-Hole (CIDH) Piles

   a. When battered piles are required, CIDH piles should not be used because of the increased risk of caving and the difficulty of placing concrete in a sloping hole.

   b. If pile tips are below the groundwater table or wet construction method is used, CIDH piles should be designed at a diameter equal to or greater than 24 in.

   c. When CIDH piles are used under water, no end bearing should be used unless positive measures to verify the end bearing are recommended.

3. Installation of Driven Piles

Pile drivability should be evaluated by wave equation analyses. An indicator pile program including Pile Driving Analyzer (PDA) measurements should be planned to verify the pile driveability and the estimated capacity. A load test program should be developed to verify the capacity of selected piles both under axial and lateral conditions.

4. Installation of Drilled or Auger Cast Piles

   Gamma-Gamma testing should be performed on CIDH piles installed underwater by the wet method to verify the integrity of the piles.

An axial and lateral load test program should be implemented to verify the axial and lateral capacity of the piles. Pile Load Test can be used for determining pile capacity at failure (ultimate capacity), and for establishing field acceptance criteria. A load test remains the definitive way to determine whether the professional's estimate of capacity and specified tip elevations is appropriate in design and to determine whether the production piles meet the specifications during construction. The equipment and procedures for conducting pile axial compressive load tests can be found in literature such as ASTM D 1143. Static axial tension tests should be performed per ASTM D 3689. Static lateral load tests should be performed per ASTM D 3966.

8.1.4 Ground Improvement

See Section 3.4 of Part II of this document for recommended report requirements.

8.1.5 Other Foundations

See Section 3.4 of Part II of this document for recommended report requirements.

9. Corrosion

An assessment of the corrosiveness of a site based on the review of relevant corrosion test data should be made. Corrosion test data should include pH, electrical resistivity, water soluble sulfates and chlorides. Sufficient information regarding the number and location of soil borings for corrosion testing should be included to allow a thorough review of the recommendations. Recommendations regarding concrete and metals in contact with onsite soils should be provided.

10. Pavement Design

Recommendations for design of asphalt and Portland cement concrete pavements for the plant area should be provided based on the onsite soil R-value or CBR.

11. Design Level Report

See Section 4.3 of Part II of this document for recommended report requirements.

Appendix B
Seismic Ground Motion Hazard Study

Appendix B
Seismic Ground Motion Hazard Study

1. General

A seismic ground motion hazard analysis study should be performed to determine the site-specific OBE and SSE ground motions in accordance with NFPA 59A-2001 requirements and the MCE and DE ground motions in accordance with ASCE 7-05 requirements. The recommended site specific design ground motions should satisfy the limitations provided in the Seismic Design Guidelines provided in Part I of this document. In addition to the specific data needed to support and justify the site specific ground motion recommendations, the study should include geologic and seismic data requested in this appendix and a discussion of other seismic hazards such as fault rupture, tsunamis, and seiche.

Liquefaction potential, liquefaction-related settlement, potential for sand boils and other surface manifestation of liquefaction, lateral spreading, seismic slope stability, seismic compaction, and need for ground improvement to mitigate these hazards, if present, should be addressed in detail in the geotechnical report as outlined in Appendix A.

2. Geology

In addition to standard geotechnical information needed to develop foundation recommendations, the additional geological information requested herein should be provided in the seismic ground motion hazard study report. Information obtained from published reports, maps, private communications, or other sources should be referenced. Information from surveys, geophysical investigations, borings, trenches, or other investigations should be adequately documented by descriptions of techniques, graphic logs, photographs, laboratory results, identification of principal investigators, and other data necessary to assess the adequacy of the information.

2.1 Regional Geology

Discuss all geologic, seismic, and manmade hazards within the site region and relate them to the regional physiography, tectonic structures and tectonic provinces, geomorphology, stratigraphy, lithology, and geologic and structural history and geochronology. This information should be discussed and shown on maps needed to illustrate actual or potential hazards such as landslides, subsidence, uplift, or collapse resulting from natural features such as tectonic depressions and cavernous or karst terrains that are significant to the site.

Identify and describe tectonic structures such as folds, faults, basins, and domes underlying the region surrounding the site, and include a discussion of their geologic history. A regional tectonic map showing the structures of significance to the site should be provided. The detailed analyses of faults to determine their capacity for generating ground motions at the site and to determine the potential for surface faulting should be included. Refer to Section 3 of this Appendix for additional detail.

Provide geologic profiles showing the relationship of the regional and local geology to the site location. The geologic province within which the site is located and the relation to other geologic provinces within 100 miles of the site should be indicated. Regional geologic maps indicating the site location and showing both surface and bedrock geology should also be included.

2.2 Site Geology

A site topographic map showing the locations of the principal plant facilities should be included. Regional hazard identified in Section 2.1, e.g., landslides, should be evaluated for the site.

The thicknesses, physical characteristics, origin, and degree of consolidation of each lithologic unit should also be described for the site, including a local stratigraphic column. Furnish summary logs of borings and excavations such as trenches used in the geologic evaluation. Boring logs included in Appendix A, Section 2.1, may be referenced.

A detailed discussion of the structural geology in the vicinity of the site should be provided with particular attention to specific structural units of significance to the site such as folds, faults, synclines, anticlines, domes, and basins. Provide a large-scale structural geology map (1:5,000) of the site showing bedrock surface contours and including the locations of Seismic Category I structures. A large-scale geologic map (1:24,000) of the region within 5 miles of the site that shows surface geology and that includes the locations of major structures of the LNG plant, including all Seismic Category I structures, embankments, and pipelines should be described in detail. Areas of bedrock outcrop from which geologic interpretation has been extrapolated should be distinguished from areas in which bedrock is not exposed at the surface. When the interpretation differs substantially from the published geologic literature on the area, the differences should be noted and documentation for the new conclusions presented.

Include an evaluation from an engineering-geology standpoint of the local geologic features that affect the plant structures. Deformational zones such as shears, joints, fractures, and folds, or combinations of these features should be identified and evaluated relative to structural foundations. Describe and evaluate zones of alteration or irregular weathering profiles, zones of structural weakness, unrelieved residual stresses in bedrock, and all rocks or soils that might be unstable because of their mineralogy or unstable physical or chemical properties. The effects of man's activities in the area of the site should be evaluated; for example, withdrawal or addition of subsurface fluids or mineral extraction. Site groundwater conditions should be described.

3. Faulting

3.1 Investigation of Quaternary Faults

Identified faults, any part of which is within 5 miles of the site, should be investigated in sufficient detail, using geological and geophysical techniques of sufficient sensitivity that demonstrate the age of the most recent movement on each. The type and extent of investigation varies from one geologic province to another and depends on site-specific conditions.

For Quaternary faults, any part of which is within 5 miles of the site, determine the following:

1) length of the fault;
2) relationship to regional tectonic structures;
3) nature, amount, and geologic displacement along the fault; and
4) outer limits of the fault zone.

3.2 Determination of Active Faults

Determine the geologic evidence of fault offset at or near the ground surface at or near the site. Any lineaments identified on topographic maps, aerial photos, or satellite imagery linears identified as part of this study should be discussed.

List all historically reported earthquakes that can be reasonably associated with faults, any part of which is within 5 miles of the site. A plot of earthquake epicenters superimposed on a map showing the local tectonic structures should be provided.

The structure and genetic relationship between the site area faulting and regional tectonic framework should be discussed. In tectonically active regions, any detailed geologic and geophysical investigations conducted to demonstrate the structural relationships of site area faults with regional faults known to be seismically active should be discussed.

3.3 Fault Rupture Investigation

A detailed faulting investigation should be conducted within one mile of the storage tank(s) foundation(s) and, as necessary, along any active faults identified under Section 3.2 of this Appendix which may reasonably have a potential for affecting faulting on the site or provide significant information concerning such faulting. This investigation should be in sufficient detail to determine the potential for faulting and the magnitude of displacement that could be experienced by the safety-related facilities of the plant. The report of the investigation should be coordinated with the investigation and report under Sections 3.1 and 3.2 of this Appendix and should include information in the form of boring logs, detailed geologic maps, geophysical data, maps and logs of trenches, remote sensing data, and seismic refraction and reflection data. If faulting exists, it should be defined as to its attitudes, orientations, width of shear zone, amount and sense of movement, and age of movements. Site surface and subsurface investigations conducted to determine the absence of faulting should be reported, including information on the detail and areal extent of the investigation. The geologic studies included in a Fault Rupture Investigation should conform to established guidelines such as California DMG Note 49 (Ref. 22).

Based on geologic studies, if it is determined that there is a potential for fault rupture hazard, and the structure is to be located either within 500 feet of a known fault or the possibility of a fault rupture passing through the proposed structure cannot be excluded, then seismic fault rupture analysis should be performed. This may include, but not be limited to magnitude, slip rates and recurrence models, type of fault (e.g., strike slip, normal), horizontal and vertical components of offset, style of faulting.

4. Tsunamis and Seiche

Tsunami run-up should be evaluated for 100 and 500 year return periods and seismic sources consistent with the SSE. Run-ups projections should be made considering proposed structure foundation elevations and proposed seawalls or berms that are provided for tsunami protection. For sites where seiches are also a possibility, seiche run-ups should be evaluated for 100 and 500 year return periods and seismic sources consistent with the SSE considering proposed foundation elevations and proposed seawalls or berms that are proposed for seiche protection. Locations of bodies of water where waves or breach of existing dams could cause flooding at the site should also be evaluated.

5. Ground Motions

5.1 Historic Seismicity

A complete list of all historically reported earthquakes affecting the region surrounding the site should be provided. The listing should include, as a minimum, all earthquakes of Modified Mercalli Intensity greater than IV or magnitude greater than 3.0. A map should also be provided that shows all listed earthquake epicenters. The following information describing each earthquake should be provided whenever it is available:

1) epicenter coordinates,
2) depth of focus,
3) origin time,
4) highest intensity,
5) magnitude (including moment magnitude),
6) source mechanism,
7) source dimensions,
8) stress drop,
9) any strong motion recordings relevant to a determination of the ground motion or design response spectra, and
10) references from which the specified information was obtained.

In addition, any earthquake-induced geologic hazards (e.g., liquefaction, landsliding, land spreading, or lurching) that have been reported on or within 5 miles of the site should be described in detail, including the level of strong motion that induced failure and the properties of the materials involved.

This discussion should include identification of the methods used to locate the earthquake epicenters and an estimate of their accuracy.

5.2 Geologic Structures and Tectonic Activity

Identify the regional geologic structures and tectonic activity that are significant in determining regional earthquake potential. All tectonic provinces any part of which occurs within 100 miles of the site should be identified. The identification should include a description of those characteristics of geologic structure, tectonic history, present and past stress regimes, and seismicity that distinguish the various tectonic provinces and particular areas within those provinces where historical earthquakes have occurred. Alternative models of regional tectonic activity from available literature sources should be discussed. The discussion in this section should be augmented by a regional-scale map showing the tectonic provinces, earthquake epicenters, the locations of geologic structures and other features that characterize the provinces, and the locations of any Quaternary faults.

When an earthquake epicenter cannot be reasonably correlated with geologic structures, the epicenter should be discussed in relation to tectonic provinces. Subdivision of tectonic provinces should be supported on the basis of evaluations that consider, but should not be limited to, detailed seismicity studies, differences in geologic history, and differences in stress regime.

5.3 Maximum Earthquake Potential

The largest earthquake or earthquakes associated with each geologic structure or tectonic province should be identified. Where the earthquakes are associated with a geologic structure, the largest earthquake that could occur on that structure should be evaluated based on considerations such as the nature of faulting, fault length, fault displacement, and earthquake history. The largest historical earthquakes within the province should be identified and, whenever reasonable, the return period for the earthquakes should be estimated. A table of faults with fault length, type of fault, distance at closest point to the site, maximum earthquake, etc. should be provided.

5.4 Near-Fault Effects

For each set of conditions describing the occurrence of the maximum potential earthquakes, determined in Section 5.3 above, the types of seismic waves (such as directivity, fault normal, and fault parallel) producing the maximum ground motion and the significant frequencies at the site should be determined.

5.5 Determination of Site Class

Site Class definitions are provided in ACSE 7-05 (Chapter 20) or IBC 2006 (Table 1613.5.2). Site classes range from Class A for hard rock to Class F for liquefiable or other very poor soil conditions. Site Class should be determined by seismic velocity data and other geotechnical data provided in the geotechnical report in accordance with the procedure in Sections 1613.5.5 and 1613.5.5.1 of IBC 2006 or Chapter 20 of ASCE 7-05.

5.6 Deterministic Seismic Hazard Analysis

A deterministic seismic hazard analysis should be performed which computes the peak ground horizontal acceleration and spectral response accelerations for periods of at least 0.2s and 1.0s from the maximum earthquake on each of the faults found within 100 miles from the site. The computation of the peak acceleration and spectral accelerations is based on the closest distance between the site and each fault and the selected attenuation relationships. In general, a minimum of three attenuation relationships should be used consistent with the geologic and seismic setting of the site and type of faulting. The closest active fault and the fault generating the maximum acceleration at the site should be identified. Differences between the selected attenuations and the attenuations used in the latest USGS National Seismic Hazard Maps should be discussed.

5.7 Probabilistic Hazard Analysis

Probabilistic seismic hazard evaluation involves obtaining, through a formal mathematical process, the level of ground motion parameters that have a selected probability of being exceeded during a specified time interval.

The probabilistic approach incorporates the contributions from historical seismicity and all faults and considers the likelihood of the occurrence of earthquakes at any point on the fault. It also incorporates the contributions from various magnitude earthquakes up to and including the maximum earthquake. This approach is described in a number of sources such as Cornell, 1968 (Ref. 25), Algermissen et al, 1976 (Ref. 27) and Frankel, 1996, 2002 (Ref. 26).

A probablisitic seismic hazard analysis should be performed using at least three attenuation relationships consistent with the geologic and seismic setting of the site. Differences between the selected attenuations and the attenuations used in the latest USGS National Seismic Hazard Maps should be discussed. Based on the site-specific probabilistic analyses, two levels of site ground motions, the OBE and SSE ground motions should be developed in accordance with the guidelines provided in Section 5.2 of Part I of this document.

5.8 Code Values of Ground Motions

The code values should be determined using either ASCE 7-05 or IBC 2006 since both of these yield identical results. Two levels of shaking are identified as follows:

Maximum Considered Earthquake (MCE) Ground Motion

MCE ground motions have a 2 percent probability of exceedance within a 50 year period (2475 year return period) with deterministic limits. These ground motions may be read from the published maps in ASCE 7-05 or IBC 2006 adjusted for site class. These ground motions may also be obtained using a ground motion calculator that is available at the USGS web site (http://earthquake.usgs.gov/research/hazmaps/design/). A site specific MCE may be developed in accordance with Chapter 21 of ASCE 7-05 including the 80% limits.

Design Earthquake (DE) Ground Motion

DE will be ground motions are 2/3 of the MCE motions as defined above adjusted for Site Class.

Appendix C
Example Categorization of LNG Structures, Components and Systems

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Example Categorization of LNG Structures, Components and Systems

1. Seismic Categorization

For purposes of design, all structures, components and systems important to normal operation of the LNG facility operations should be classified into one of the three Seismic Categories that are defined below.

1.1 Seismic Category I

The following structures, components and systems that are specified in Section 4.1.3.3 of NFPA 59A-2001 should be classified as Seismic Category I.

1) LNG storage containers and their impounding systems

2) System components required to isolate the LNG container and maintain it in a safe shutdown condition

3) Structures and systems, including fire protection systems, the failure of which could affect the integrity of (1) or (2) above.

1.2 Seismic Category II

All structures, components and systems not included in Category I that are required to maintain safe plant operation should all be classified as Seismic Category II.

1.3 Seismic Category III

All other structures, components and systems of the LNG facility that are not included in Categories I and II should all be classified as Seismic Category III.

2. Supporting Elements and Enclosures

A structure, component, or system of a given Seismic Category may be supported or enclosed by a structure classified in a different category, provided it is demonstrated that the supported item can maintain its functional requirements specified by its Seismic Category.

3. Example Categorization

The following structures, components, systems, etc., are divided into the appropriate Seismic Categories.

3.1 SEISMIC CATEGORY I Structures, Components, and Systems:

LNG storage tanks and their foundations
LNG storage tank containment dikes
Diesel driven power generator(s) and fuel supply at the dock and plant
Emergency lighting
Fire protection systems, to include:
- Building sprinkler systems
- Halon system
- Interconnecting wiring for above
- Dry chemical units
- Fire retardant foam units
- Firewater Systems that include
- Dock firewater pump (diesel driven)
- Fire hydrants
- Firewater piping systems
- Plant firewater pump (diesel driven)
- Seawater intake line reinforced concrete, prestressed concrete, etc.
- Seawater supply pump structure
- Seawater velocity cap
- Firewater supply, if not seawater

Fire and leak detection systems that include:
- Combustible gas detectors
- Detection panel in control room
- Fire alarm boxes
- High temperature detectors
- Low temperature detectors Smoke detectors
- Ultraviolet detectors
- Interconnecting wiring for all the above items

Radio communications system
All permanent mounted wireless radios
Shutdown system:
- Control valves
- Instrumentation
- Related control panel
- Uninterruptible Power System (U.P.S.)
- Batteries (in rack)
- Battery charger
- U.P.S. inverter
- Vent and relief system
- All liquid and vapor relief valves in natural gas service

3.2 SEISMIC CATEGORY II Structures, Components, and Systems:

LNG sendout system controls
Fired vaporizers
Fuel gas system for fired equipment Instrumentation

Interconnecting piping systems
Metering system
Odorizing system
Primary LNG pumps
Seawater vaporizers
Secondary LNG pumps
Trim heater
Vapor absorber
LNG unloading and transfer system controls
Instrumentation
LNG recirculation system
Offshore piping from dock to abutment
Onshore piping systems from abutment to storage tanks
Unloading arms
Control Building
Electrical distribution systems fire station/warehouse
Instrument & utility air system
Afterfliter
Air receiver
Compressors
Controls
Dryer
Instrumentation
Piping systems
Main control panel and components
Marine trestle and dock (includes structures such as unloading platform, service platform, trestle, dock operator's building and control tower on dock)
Nitrogen systems
Power generation system controls
Fuel gas heater
Fuel gas system Instrumentation
Power generation building
Standby power generators
Seawater supply and return system controls instrumentation
Piping to vaporizers
Seawater pumps
Seawater return line screening equipment
Standby plant lighting
Substation buildings
Vapor compression system
Compressor suction drum controls instrumentation
Interconnecting piping systems
Unloading compressors

3.3 SEISMIC CATEGORY III Structures, Components and Systems:

Administration building

Bunker fuel system
Diesel fuel system except as needed for Category I or II equipment
Dock service equipment
Incoming electrical power systems including switchyard normal plant lighting system
Waste treatment building

Appendix D
Seismic Design Information

Appendix D
Seismic Design Information

1. General

A seismic design criteria document (also called design basis document) that specifies in detail the seismic criteria to be used in the design of Category I, II and III structures, components and systems should be provided. It should include all seismic design coefficients and inelastic reduction factors, load combinations and allowable stress/strength factors and ϕ-factors permitted for each load combination. The additional information requested in this appendix should be included in the document. The information provided should be consistent with the recommendations in the Seismic Design Guidelines that are found in Part I of this document.

2. Seismic Design

2.1 Design Response Spectra

Design response spectra for the OBE, SSE, MCE, and DE should be provided. The response spectra applied at the finished grade in the free field or at the various foundation locations of Category I structures should be provided. The ASCE 7-05 seismic design parameters that should be used at the various locations of Category II and III structures should also be provided.

2.2 Design Time History

For the time history analyses, the response spectra derived from the actual or synthetic earthquake time-motion records should be provided. A comparison of the response spectra obtained in the free field at the finished grade level and the foundation level (obtained from an appropriate time history at the base of the soil/structure interaction system) with the design response spectra should be submitted for each of the damping values to be used in the design of structures, systems, and components. Alternatively, if the design response spectra for the OBE and SSE are applied at the foundation levels of Category I structures in the free field, a comparison of the free-field response spectra at the foundation level (derived from an actual or synthetic time history) with the design response spectra should be provided for each of the damping values to be used in the design. The period intervals at which the spectral values were calculated should be identified.

2.3 Critical Damping Values

The specific percentage of critical damping values used for Category I structures, systems, and components and soil should be provided for both the OBE and SSE (e.g., damping values for the type of construction or fabrication such as prestressed concrete and welded pipe). The basis for any proposed damping values should be included. Damping values should satisfy the limitations provided in the Seismic Design Guidelines provided in Part I of this document.

2.4 Supporting Media for Category I Structures

A description of the supporting media for each Category I structure should be provided. Include in this description foundation embedment depth, depth of soil over bedrock, soil layering characteristics, width of the structural foundation, total structural height, and soil properties such as shear wave velocity, shear modulus, and density. This information is needed to permit evaluation of the suitability of using either a finite difference or lumped spring approach for soil/structure interaction analysis, if necessary.

3. Seismic System Analysis for Category I Structures

3.1 Seismic Analysis Methods

The applicable methods of seismic analysis (e.g., modal analysis response spectra, modal analysis time history, equivalent static load) should be identified and described. Descriptions (sketches) of typical mathematical models used to determine the response should be provided. Indicate how the dynamic system analysis method includes in the model consideration of foundation torsion, rocking, and translation. The method chosen for selection of significant modes and adequate number of masses or degrees of freedom should be specified. The manner in which consideration is given in the seismic dynamic analysis to maximum relative displacement among supports should be indicated. In addition, other significant effects that are accounted for in the seismic analysis (e.g., hydrodynamic effects and nonlinear response) should be indicated. If tests or empirical methods are used in lieu of analysis, the testing procedure, load levels, and acceptance bases should also be provided.

3.2 Natural Frequencies and Response Modes

The significant natural frequencies and response modes determined by seismic system analyses should be provided for Category I structures. In addition, the response spectra at critical Category I elevations and points of support should be specified.

3.3 Procedure Used for Modeling

The criteria and procedures used for modeling in the seismic system analyses should be provided. Include the criteria and bases used to determine whether a component or structure should be analyzed as part of a system analysis or independently as a subsystem.

3.4 Soil/Structure Interaction

As applicable, the methods of soil/structure interaction analysis used in the seismic system analysis and their bases should be provided. The following information should be included:

a) the extent of embedment
b) the depth of soil over rock, and
c) layering of the soil strata.

If the finite difference approach is used, the criteria for determining the location of the bottom boundary and side boundary should be specified. The procedure by which strain dependent soil properties (e.g., damping and shear modulus) are incorporated in the analysis should also be specified. The material given in Section D.2.4 of this document may be referenced in this section.

If lumped spring methods are used, the parameters used in the analysis should be discussed. Describe the procedures by which strain-dependent soil properties, layering, and variation of soil properties are incorporated into the analysis. The suitability of a lumped spring method used for the particular site conditions should also be discussed.

Any other methods used for soil/structure interaction analysis or the basis for not using soil/structure interaction analysis should be provided.

The procedures used to consider effects of adjacent structures on structural response in soil/structure interaction analysis should be provided.

3.5 Development of Floor Response Spectra

The procedures for developing floor response spectra considering the three components of earthquake motion should be described. If a modal response spectrum method of analysis is used to develop floor response spectra, the basis for its conservatism and equivalence to a time history method should be provided.

3.6 Three Components of Earthquake Motion

Identify the procedures for considering the three components of earthquake motion in determining the seismic response of structures, systems, and components.

3.7 Combination of Modal Responses

When a response spectra method is used, a description of the procedure for combining modal responses (shears, moments, stresses, deflections, and accelerations) should be provided.

3.8 Interaction of Non-Category I Structures with Category I Structures

Provide the design criteria used to account for the seismic motion of non-Category I structures or portions thereof in the seismic design of Category I structures or portions thereof. In addition, describe the design criteria that will be applied to ensure protection of Category I structures from the structural failure of non-Category I structures due to seismic effects.

3.9 Effects of Parameter Variations on Floor Response Spectra

The procedures that will be used to consider the effects of expected variations of structural properties, damping, soil properties, and soil/structure interaction on floor response spectra (e.g., peak width and period coordinates) and time histories should be described.

3.10 Use of Constant Vertical Static Factors

Where applicable, identify and justify the application of constant static factors as vertical response loads for the seismic design of Category I structures, systems, and components in lieu of a vertical seismic system dynamic analysis method.

3.11 Method Used to Account for Torsional Effects

The method used to consider the torsional effects in the seismic analysis of the Category I structures should be described. Where applicable, discuss and justify the use of static factors or any other approximate method in lieu of a combined vertical, horizontal, and torsional system dynamic analysis to account for torsional accelerations in the seismic design of Category I structures.

3.12 Comparison of Responses

Where both modal response and time history methods are applied, the responses obtained from both methods at selected points in major Category I structures should be provided, together with a discussion of the comparative responses.

3.13 Determination of Category I Structure Overturning Moments

A description of the dynamic methods and procedures used to determine Category I structure overturning moments should be provided.

3.14 Analysis Procedure for Damping

The analysis procedure used to account for the damping in different elements of the model of a coupled system should be described.

4. Design and Analysis Procedures

The procedures that will be used in the design and analysis of all internal Category I structures should be described, including the assumptions made and the identification of boundary conditions. The expected behavior under load and the mechanisms for load transfer to these structures and then to the foundations should be provided. Computer programs that are utilized should be referenced to permit identification with published programs. Proprietary computer programs should be described to the maximum extent practical to establish the applicability of the program and the measures taken to validate the programs with solutions derived from other acceptable programs or with solutions of classical problems.

5. Structural Acceptance Criteria

The acceptance criteria relating stresses, strains, gross deformations, and other parameters that identify quantitatively the margins of safety should be specified. The information provided should address the containment as an entire structure, and it should also address the margins of safety related to the major important local areas of the Category I structures important to the safety function. For each applicable loading condition listed below, the allowable limits should be provided, as appropriate for stresses, strains, deformation, and factors of safety against structural failure. The extent of compliance with the various applicable codes should be presented. The load conditions to consider include but are not limited to:

a) Loads encountered during seasonal plant startup, including dead loads, live loads, thermal loads due to operating temperature, and hydrostatic loads.

b) Loads that would be sustained in the event of severe environmental conditions, including those induced by the Operating Basis Earthquake.

c) Loads that would be sustained in the event of extreme environmental conditions, including those that would be induced by the Safe Shutdown Earthquake.

Appendix E
Foundation Design Criteria

Appendix E
Foundation Design Criteria

1. General

A foundation design criteria document should be provided that states how Seismic Category I, II and III structures will be designed. This document will be consistent with recommendations provided in the geotechnical report. In addition, the foundation criteria document should include the items requested in this appendix.

2. Foundation Design

All Seismic Category I structures constructed of materials other than soil for the purpose of transferring loads and forces to the basic supporting media should be addressed in more detail. In particular, the information described below should be provided.

2.1 Description of the Foundations

This section should provide descriptive information, including plan and section views of each foundation, to define the primary structural aspects and elements relied upon to perform the foundation function. The relationship between adjacent foundations, including any separation provided and the reasons for such separation, should be described. In particular, the type of foundation and its structural characteristics should be discussed. The general arrangement of each foundation should be provided with emphasis on the methods of transferring horizontal shears, such as those seismically induced, to the foundation media. If shear keys are utilized for such purposes, the general arrangement of the keys should be included. If waterproofing membranes are utilized, their effect on the capability of the foundation to transfer shears should be discussed.

Information should be provided to adequately describe other types of foundation structures such as pile foundations, caisson foundations, retaining walls, abutments, and rock and soil anchorage systems.

2.2 Applicable Codes, Standards, and Specifications

This section should provide information, as applicable, on the foundations of all Seismic Category I structures.

2.3 Loads and Load Combinations

This section should provide information, as applicable, on the foundations of all Category I structures.

2.4 Design and Analysis Procedures

This section should provide information, as applicable, on the foundations of all Category I structures.

In particular, the assumptions made on boundary conditions and the methods by which lateral loads and forces and overturning moments, thereof, are transmitted from the structure to the foundation media should be discussed, along with the methods by which the effects of settlement are taken into consideration.

2.5 Structural Acceptance Criteria

This section should provide information applicable to foundations of all Category I structures.

In particular, the design limits imposed on the various parameters that serve to define the structural stability of each structure and its foundations should be indicated, including differential settlements and factors of safety against overturning and sliding.

2.6 Materials, Quality Control, and Special Construction Techniques

This section should provide information for the foundations of all Category I structures.