RECLAMATION

Managing Water in the West

Design Standards No. 9

Buildings

Chapter 13: Seismic Design
Phase 4 (Final)

U.S. Department of Interior
Bureau of Reclamation

October 2012

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Design Standards Signature Sheet

Design Standards No. 9

Buildings

DS-9(13)-1: Phase 4 (Final)
October 2012

Chapter 13: Seismic Design

Foreword

Purpose

The Bureau of Reclamation (Reclamation) design standards present technical requirements and processes to enable design professionals to prepare design documents and reports necessary to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public. Compliance with these design standards assists in the development and improvement of Reclamation facilities in a way that protects the public's health, safety, and welfare; recognizes needs of all stakeholders; and achieves lasting value and functionality necessary for Reclamation facilities. Responsible designers accomplish this goal through compliance with these design standards and all other applicable technical codes, as well as incorporation of the stakeholders' vision and values, that are then reflected in the constructed facilities.

Application of Design Standards

Reclamation design activities, whether performed by Reclamation or by a non-Reclamation entity, must be performed in accordance with established Reclamation design criteria and standards, and approved national design standards, if applicable. Exceptions to this requirement shall be in accordance with provisions of *Reclamation Manual Policy*, Performing Design and Construction Activities, FAC P03.

In addition to these design standards, designers shall integrate sound engineering judgment, applicable national codes and design standards, site-specific technical considerations, and project-specific considerations to ensure suitable designs are produced that protect the public's investment and safety. Designers shall use the most current edition of national codes and design standards consistent with Reclamation design standards. Reclamation design standards may include exceptions to requirements of national codes and design standards.

Proposed Revisions

Reclamation designers should inform the Technical Service Center (TSC), via Reclamation's Design Standards Website notification procedure, of any recommended updates or changes to Reclamation design standards to meet current and/or improved design practices.

Chapter Signature Sheet
Bureau of Reclamation
Technical Service Center

Design Standards No. 9

Buildings

Chapter 13: Seismic Design

DS-9(13)-1:[1] Phase 4 (Final)
October 2012

Chapter 13 - Seismic Design is a new chapter within Design Standards No. 9 and was developed to provide:

- An overview of the Bureau of Reclamation (Reclamation) criteria and methods for analyzing and designing buildings, including pumping plants and powerplants, for seismic loading

- A general description of Reclamation criteria and methods used for the seismic evaluation of existing buildings

- A list of key technical references used for each major task involved with seismic analysis and design of new buildings and the seismic evaluation of existing buildings

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[1] DS-9(13)-1 refers to Design Standards No. 9, chapter 13, revision 1.

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Chapter 13

Seismic Design

13.1 Purpose

The design standards present clear and concise technical requirements and processes to enable design professionals to prepare design documents and reports necessary to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public. Compliance with these design standards assists in the development and improvement of Bureau of Reclamation (Reclamation) facilities in a way that protects the public's health, safety, and welfare; recognizes all stakeholder needs; and achieves the lasting value and functionality necessary for Reclamation facilities. The responsible designer(s) accomplishes this through processes that enable compliance with these design standards and all other applicable technical codes, as well as incorporation of the stakeholder's vision and values, that are then reflected in the construction project.

13.2 Application of Design Standards

All Reclamation design work, whether performed by the Technical Service Center (TSC), the regional offices, area offices, or an architectural/engineering firm, will conform to the design standards.

Reclamation's use of its design standards requires designers to also integrate sound engineering judgment with applicable national standards, site-specific technical considerations, and project-specific considerations to ensure suitable designs and to protect the public.

The design standards are not intended to provide cookbook solutions to complex engineering problems. Strict adherence to a handbook procedure is not a substitute for sound engineering judgment. The designer should be aware of and use state-of-the-art procedures. Designers are responsible for using the most current edition of referenced codes and standards, and they should be aware that Reclamation design standards may include exceptions to requirements of these codes and standards.

13.3 Deviations and Proposed Revisions

Design activities must be performed in accordance with established Reclamation design criteria; Reclamation engineering, architectural, or technical standards;

and approved national design standards. Exceptions to this requirement will be pursued in accordance with provisions of Reclamation Manual Policy, *Performing Designs and Construction Activities*, FAC P03.

Reclamation designers should inform the TSC, via the Web site notification procedure, of any recommended updates or changes for the design standards to meet current design practices.

13.4 Seismic Analysis Criteria

13.4.1 Introduction

This chapter establishes the minimum seismic design criteria for pumping plants, powerplants, and other buildings required for Reclamation facilities and attempts to clarify the associated logic followed in developing that criteria. If the general term “plants” is used, it refers to pumping plants and powerplants, while the term “buildings” refers to general purpose buildings designed for Reclamation projects. Higher performance criteria may be applied in specific cases should that criteria be deemed necessary and economically viable.

The state-of-the-art seismic provisions for the design and evaluation of plants and buildings are performance based. That is, the seismic design or evaluation parameters are driven by two aspects:

1. Seismic event that the facility is expected to withstand

2. Facility’s performance level (i.e., acceptable level of damage) during and after that event

It is important to note here a distinction between those portions of plants that are above grade (superstructure) and those portions that are below grade (substructure and/or intermediate structure). The criteria and methods used for analysis and design and described in the following paragraphs primarily apply to that portion of the building (structure) that is above grade or free to respond to ground motions. Significant portions of the structure for plants are buried below ground. The substructures and intermediate structures will use separate criteria and methods for analysis and design for seismic loading. Specific criteria and methods that apply to substructures and intermediate structures are addressed in section 13.4.3.2.2.

The following sections discuss the selection of the design seismic event and performance level for Reclamation plants and buildings.

13.4.2 Historical Criteria

Prior to 1971, Reclamation predominantly used static force methods to design for seismic forces. The chronology of development for these methods generally mirrored the developmental stages and procedures presented in the Uniform Building Code.

In 1971, Reclamation began using what is termed the maximum credible earthquake (MCE) as the earthquake loading for its structures that were considered critical to the safe operation of dam facilities, power generation facilities, and some water distribution facilities. This is recorded in a document titled, *Bureau of Reclamation Design Earthquake Selection Procedures* [9]. In 1976, Reclamation adopted the use of a design basis earthquake (DBE) and an operating basis earthquake as design loadings for certain types or portions of its structures, where applicable, in addition to the MCE loading.

In a 1988 Reclamation design guide titled, *Design of Pumping Plants and Powerplants for Earthquakes* [10], the functional description of these earthquakes and the structural response requirements for each were defined as follows:

> *Maximum credible earthquake* – This earthquake would produce the most severe vibratory ground motion capable of being produced at the project site under the presently known tectonic framework. It is a rational and believable event that is in accord with all known geological and seismological facts. In determining the MCE, little regard is given to its probability of occurrence. Only the parts of the plant vital to retention or release of a reservoir would be designed for the loading from this event and would be required to function without permitting either a sudden, uncontrolled release of a reservoir or compromise the controlled evacuation of a reservoir.
>
> *Design basis earthquake* – This earthquake would be one that would have a reasonable likelihood of occurrence during the economic life of the structure. The recurrence interval for this earthquake for the project site is established by the designers. The magnitude of this event would be determined for each applicable area from recurrence relationships, if an adequate amount of seismic history data existed and, if not, would be estimated considering the geology and seismology of the area. Under loading from this event, the plant would be designed to sustain the earthquake with repairable damage; however, those structures, systems, and components important to safety would remain functional. The degree of damage that would be acceptable could be based on an economic analysis or estimate of the cost of repair versus the initial cost to control the damage.
>
> *Operating basis earthquake* – This earthquake would be one that could be expected to occur several times during the economic life of the structure. The recurrence interval for this earthquake at the project site would also be

established by the designers. It is anticipated that this earthquake would be provided only for sites near highly seismically active areas for which the necessary information for developing recurrence relationships would be available. Structures, systems, and components necessary to the function of a plant would be designed to remain operable under the vibratory ground motion of this event. The vast majority of plants and buildings that are not appurtenant structures to a dam are not considered vital to the structural integrity of the dam and its foundation or to the retention or the safe release of the reservoir, and therefore, their failure does not adversely impact the dam and its foundation. Accordingly, these plants and buildings should not be assessed using the MCE but, rather, they should be evaluated to the DBE. For plants hydraulically or structurally integral with a dam or reservoir, refer to discussion of current criteria below.

13.4.3 Current Criteria

Current practice for the seismic analysis and design of new and existing plants and buildings establishes the DBE as a fraction of what is known as the MCE. The MCE is a term introduced by the Building Seismic Safety Council (BSSC), which is an expert panel established by the National Institute of Building Sciences to develop national earthquake design standards. In most of the Nation, the MCE is defined as a probabilistic ground motion having a 2-percent probability of being exceeded in 50 years, or it has an approximate return period of 2,500 years [7]. (See appendix A for an example calculation depicting the relationship between exceedance probability and the return period.) In regions near faults, deterministic values establish the MCE, which remains equal to or less than the 2,500-year event. The BSSC acknowledges that stronger shaking than the MCE could occur; however, it was judged that it would be economically impractical to design for such very rare ground motions and that the selection of the 2,500-year event as the MCE ground motion would result in acceptable levels of seismic safety for the Nation. The BSSC further substantiates their selection of the MCE by two aspects: (1) the seismic margin (i.e., built-in conservatism) in actual current design provisions is estimated to be at least a factor of 1.5 and (2) the positive experience in recent earthquakes with the response of newly designed buildings in coastal California. Based on the above discussion, the MCE selected for most new plants and buildings should be the 2,500-year event.

Following current standards for building design, the DBE for plants and buildings should be considered as 2/3 of the MCE. This reduction is based largely on the estimated seismic margin believed to be embedded in current design standards. This seismic margin is based on several factors, including the inherent conservatism in the analysis procedure, ratio of actual-to-specific material strength, and most importantly, prescriptive ductile detailing.

As mentioned above, the second aspect of a performance-based seismic evaluation is the expected performance level of the facility at the selected evaluation event. For most Reclamation plants and buildings, the minimum performance level to be satisfied is one that provides life safety for the occupants and visitors. In some instances however, given the economical value of the plant or building, its content, or its operation, it is desirable to satisfy a higher performance level, which allows for minimal damage in the structure and the equipment.

Given the small tolerances necessary for functional operation of hydraulic equipment, many plant substructures should remain elastic under the DBE. This performance condition will be the standard applied to that portion of the plant structure that is below ground or supports critical hydraulic equipment. For those portions of the structure that are above grade, the seismic design provisions in the International Building Code (IBC) [2] and the American Society of Civil Engineers/Structural Engineering Institute - Minimum Design Loads for Buildings and Other Structures (ASCE/SEI 7) [3] are intended to be followed in their entirety because the reductions applied to the seismic loads are coupled with specific detailing requirements described in those provisions. In order to reduce the seismic loads, the superstructure must absorb the earthquake energy through nonlinear deformations, which could only be realized if proper detailing is provided. It should also be understood that the lower the acceptable level of damage for the plant, the lower the reduction factors should be.

It should be noted that the DBE ground motion level specified could result in both structural and nonstructural damage when evaluated for a life safety performance level. For essential facilities, it is expected that the damage from the DBE ground motion would not be so severe as to preclude continued occupancy and function of the facility.

Current practice is to characterize the seismic demand at a site with a design response spectrum, which comprises a relationship of the maximum response ordinate (commonly spectral response acceleration) over the entire response history record of a single-degree-of-freedom oscillator and the period or frequency of the oscillator, for a specified level of damping. Modern design standards such as ASCE/SEI 7 contain prescriptive provisions for developing a site design response spectrum using values of spectral response accelerations for short and long periods. These spectral accelerations are often obtained from national maps for the MCE and are adjusted for specific site classification or may be developed based on site-specific seismic hazard characterization.

In some cases for powerplants, damage to the powerplant waterway may result in an uncontrolled release of the reservoir through the powerplant. The potential for this to occur may require the powerplant and/or the powerplant waterway to be designed to seismic criteria for the dam which includes quantitative risk analysis methodology. This condition must be considered when establishing seismic design criteria for any powerplant waterway that is directly linked to a reservoir.

In many cases in which a powerplant waterway is directly linked to a reservoir, an uncontrolled release through the powerplant waterway may not produce sufficient flows to exceed the safe downstream channel capacity (i.e. there is no potential for property damage) and therefore may not constitute a dam safety issue. However, in these cases of uncontrolled releases through the powerplant waterway, consideration should be given to the impacts (e.g. economic, public trust, or technical leadership[2]) of draining much, if not most, of the reservoir and loss of this source of water for an estimated period of time. The assessment of impacts to the loss of the reservoir water will vary depending on the size of the reservoir and its normal operational frequency for filling and draining (i.e., assessment of impacts and associated decisions will differ for a small volume reservoir that typically fills and drains during a season versus a large volume reservoir that stores water for multiple purposes and requires reservoir water levels be maintained). If the decision is that the potential loss of the reservoir for a period of time is acceptable (when considering the probability of the loading that would be required to initiate an uncontrolled release) , then the seismic design criteria for the key components of the powerplant that could affect an uncontrolled release of the reservoir will typically be the DBE. If the decision is that the potential loss of the reservoir for a period of time is not acceptable (when considering the probability of the loading that would be required to initiate an uncontrolled release), then the seismic design criteria for some of the powerplant components associated with gates, controls and their enclosure (i.e., components that can stop the uncontrolled release) may be similar to the dam and may be greater than the DBE. A decision on the appropriate design level for key components of the powerplant should be based on the incremental costs of the additional protection and the magnitude of the additional protection achieved. Information on quantitative risk analysis and the decision process can be obtained from the *Dam Safety Risk Analysis Best Practices Training Manual* [18] and the *Safety of Dams Project Management Guidelines* [19].

13.4.3.1 Site-Specific Determination of the MCE and DBE

In some cases, a site-specific seismic hazard study will be required. The site-specific study is based on either a probabilistic maximum considered earthquake or a deterministic maximum considered earthquake. In general, a probabilistic seismic hazard characterization may be available since it is the preferred procedure used in dam analysis.

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[2] Reclamation, as a Federal agency, is responsible for maintaining a standard of practice and quality assurance that not only incorporates state-of-the-art practices and methods but also provides a benchmark for quality assurance and public safety in design engineering and construction.

Current code requirements noted in ASCE/SEI 7 require site-specific ground motion spectra of the design earthquake and the maximum considered earthquake be developed if:

1. The structure is located on a Site Class F[3]
2. The structure is located at a site with the 1-second spectral response acceleration parameter (S_1) greater than or equal to 0.60

If a site-specific probabilistic seismic hazard characterization is performed, the value of the peak horizontal ground acceleration (PHA) for the 2,500-year recurrence period (2-percent probability of exceedance within a 50-year period) will be extracted from the mean hazard curve developed in the site-specific study (see figure 13.4.3.1-1 for an example of extracting the PHA for a 2,500 year event from the mean hazard curve). This value for PHA will be considered the PHA for the MCE ground motion. The design spectral response acceleration at any period shall be determined as 2/3 of the MCE spectral response acceleration. These curves are not typically generated specifically for a building or plant; however, many Reclamation facilities, particularly dam sites, will have existing and recently developed data from site-specific seismic hazard analysis. The availability of this data should be investigated and considered for evaluation of existing buildings or development of designs for new buildings at or near a dam site. [4]

13.4.3.2 Prescriptive Determination of the MCE and DBE

In most cases, a site-specific, probabilistic seismic hazard characterization will not be performed for plant and building designs. A more common approach to determine the DBE demand is to develop the site design response spectra curve using values of spectral accelerations obtained from national maps for the MCE and modified based on site classification. National maps depicting spectral accelerations for the MCE are currently available from the U.S. Geological Survey Web site[5] (http://earthquake.usgs.gov/hazards/designmaps/buildings.php) [16].

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[3] Soils vulnerable to potential failure or collapse under seismic loading, such as liquefiable soils, quick and highly sensitive clays, and collapsible weakly cemented soils.

[4] Data may be obtained by contacting the Seismotectonics and Geophysics Group (86-68330) at the Technical Service Center in Denver, Colorado.

[5] Based on the process used to develop the MCE maps, there are some locations where the mapped acceleration response parameters in the MCE maps exceed the mapped acceleration response parameter in the 2-percent/50-year probabilistic maps. These locations occur primarily in the New Madrid, Missouri area; the Salt Lake City, Utah area; coastal California; and the Seattle, Washington area.

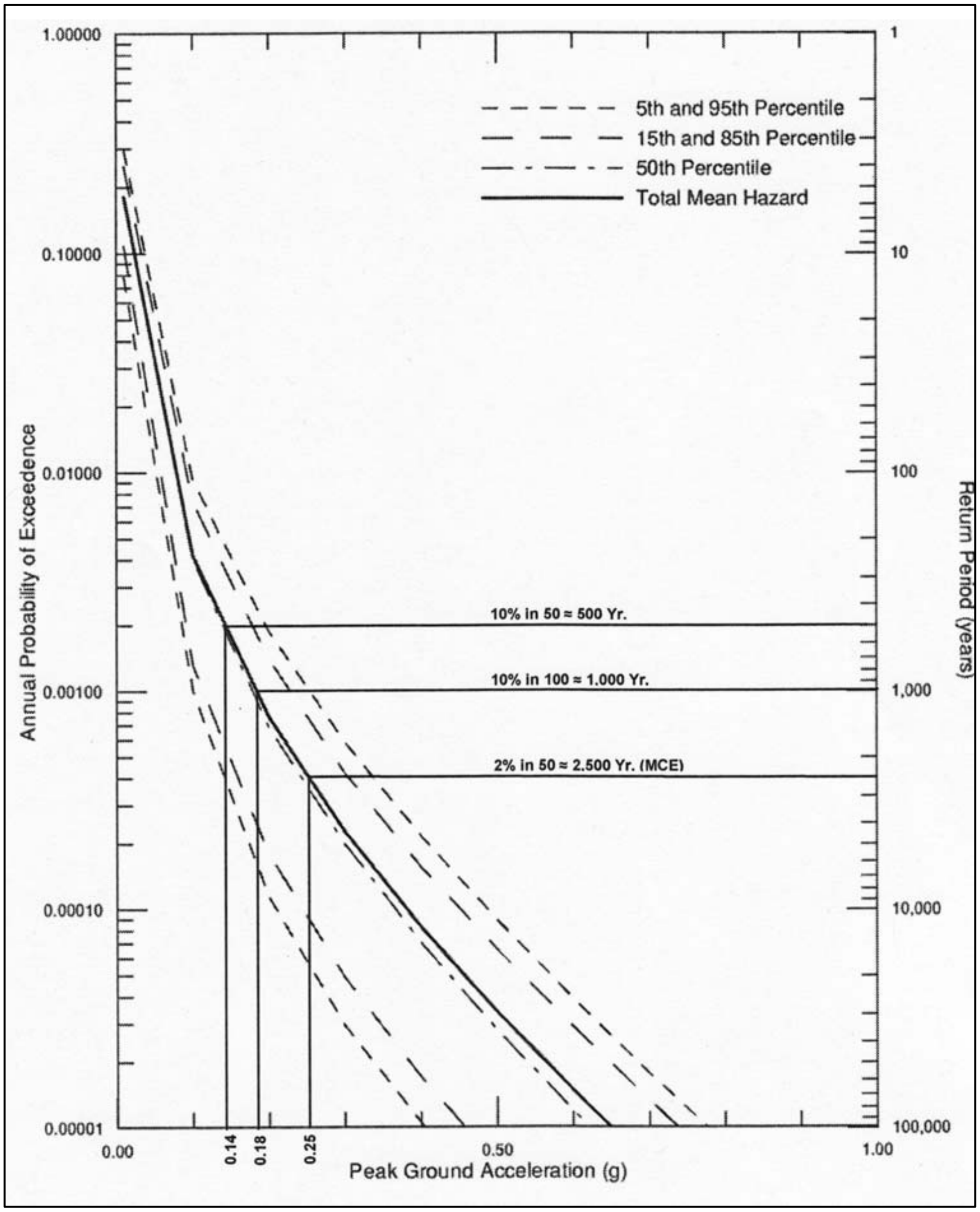


Figure 13.4.3.1-1. Example of extracting the PHA for a 2,500-year event from the mean hazard curve for a site-specific probabilistic seismic hazard characterization.

13.4.3.2.1 Seismic Analysis Procedures for Superstructures

Current seismic analysis for superstructures uses one of three analytical procedures in accordance with ASCE/SEI 7. These procedures are known as:

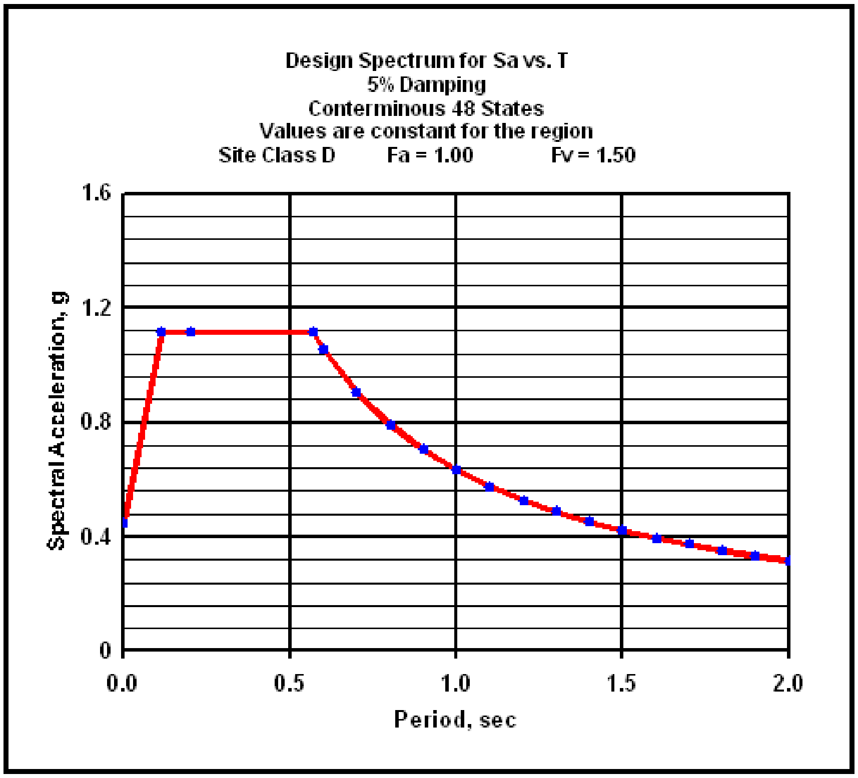
1. Equivalent Lateral Force Analysis (ELFA) Procedure
2. Modal Response Spectrum Analysis Procedure
3. Linear Response History Procedure

It should be noted that the ELFA Procedure may not be suitable for the seismic analysis and design of many new Reclamation plants. The required risk categories and the seismic design categories for many Reclamation facilities will eliminate this method from consideration. Also, the definitions for irregular structures in ASCE/SEI 7 can be difficult to correlate directly to Reclamation plants. Current Reclamation practice considers a plant with an overhead bridge crane to have a mass irregularity. Many of these plants are located in seismic areas with foundation conditions and risk categories that produce a Seismic Design Category of D or E. These conditions result in a requirement to use the Modal Response Spectrum Analysis or Seismic Response History Procedures. For a more detailed review of these conditions, see section 13.5.1

The Linear Response History Procedure requires extensive ground motion data as well as time to prepare the mathematical model and processing of the analysis and results. Based on current computer modeling methods and techniques, the preparation and processing costs in terms of time and money and the benefits obtained from this method do not justify its use for most Reclamation plants and buildings.

The use of the Modal Response Spectrum Analysis Procedure is well suited for structures supported above ground in which the structure undergoes various modes of vibrations having different periods in response to ground excitation. The structural response results in an amplification of the input ground acceleration. The total response of the structure is determined by combining the responses in the various modes of vibrations.

Common practice within Reclamation is to characterize the seismic demand at a site with a design response spectrum, which comprises a relationship of the maximum response ordinate (commonly spectral response acceleration) over the entire response history record of a single-degree-of-freedom oscillator and the period or frequency of the oscillator, for a specified level of damping. Modern standards such as ASCE/SEI 7 contain prescriptive provisions for constructing a site design response spectrum using values of spectral response accelerations for short and long periods, which are often obtained from national maps for the MCE and are adjusted for specific site classification or may be developed based on site-specific seismic hazard characterization. An example of a response spectrum curve produced using this method is shown in figure 13.4.3.2.1-1.



Period (sec)	Sa (g)
0.000	0.445
0.114	1.114
0.220	1.114
0.570	1.114
0.600	1.058
0.700	0.907
0.800	0.793
0.900	0.705
1.000	0.635
1.100	0.577
1.200	0.529
1.300	0.488
1.400	0.453
1.500	0.423
1.600	0.397
1.700	0.373
1.800	0.353
1.900	0.334
2.000	0.317

Figure 13.4.3.2.1-1. Example of a design response spectrum produced using ASCE/SEI 7 criteria.

13.4.3.2.2 Seismic Analysis Procedure for Structures Below Ground (Substructures and/or Intermediate Structures for Pumping Plants and Powerplants)

For underground structures, which will be the case for most pumping plant and powerplant substructures and intermediate structures, the dynamic response is different. It is reasonable to assume that these portions of the plant structure are restrained against free vibration, and hence, they only experience ground excitation. Accordingly, the DBE demand for plant substructures and intermediate structures will typically be represented by 2/3 of the PHA for the 2,500-year event. It should be understood, however, that systems and components within the plant structure may experience spectral accelerations higher than the PHA depending on their dynamic characteristics (i.e., stiffness and mass).

If the substructure for the plant is not cast against rock, but is buried by placing backfill or embankment against the substructure, the lateral earth pressures against the substructure are calculated similarly to the lateral earth pressures against retaining walls. Common Reclamation practice computes a total active fill force, P_{AE}, during a seismic event by adding a dynamic force component, $DP_{AE,}$ to the active static lateral earth pressure force. Refer to Reclamation's *Design Criteria for Retaining Walls* [11] for a detailed description of this method.

The design value for the PHA used for analysis and design of structures below ground is obtained by extracting the acceleration at period $T = 0$ seconds from the response spectrum curve. *Example*: Using the response spectrum shown on figure 13.4.3.2.1-1, the PHA for determining seismic lateral earth pressures according to the method cited above would be 0.445g. For values of the PHA at $T = 0$ seconds that are greater than 0.5g, methods other than that described in *Design Criteria for Retaining Walls* will be required.

The procedure described above for computing lateral earth pressures is based on Rankine's theory and the Mononobe-Okabe method for calculating lateral earth pressure. This method has been effectively and efficiently applied to a majority of plant substructures designed within Reclamation since 1971. However, the *Design Criteria for Retaining Walls* [11] is limited to specific values of the effective angle of internal friction for the backfill material and to values of PHA less than 0.5g. Other methods are available and have been developed since this method was initially adopted within Reclamation, including advanced computer modeling methods for soil/structure interaction in both the static and dynamic conditions. Other methods may be appropriate and/or required for computing lateral earth pressures for seismic loading particularly for large ground accelerations and/or unique soil conditions. For an in-depth discussion of more current methods developed to determine lateral earth pressures for larger values of PHA, see Chapter 2 – Structural Design Data and Criteria.

13.5 General Design Requirements for New Structures

Selection of categories, design factors, and load factors required to perform designs in accordance with the IBC and the ASCE/SEI 7 will be the responsibility of the design engineers. The following paragraphs discuss the basis and recommendations for selection of values for parameters commonly required in the design of plant superstructures and buildings designed by Reclamation. Selection of values for these parameters is based on Reclamation’s interpretation and application of the seismic design requirements found in the IBC and ASCE/SEI 7. Although the values for these parameters are assigned to every building on an individual basis, the paragraphs that follow present what is considered common practice within Reclamation.

More recently, ASCE/SEI 7 has adopted a risk-based assessment and terminology for occupancy categories. The term used in lieu of “Occupancy Category” is “Risk Category.” Essentially, the risk categories currently used by ASCE/SEI 7 retain the definition and categories commonly used by Reclamation for occupancy categories.

Common Reclamation practice is to assign a Risk Category of III to a plant or building if the loss of the facility would have substantial economic impact and/or cause a mass disruption of day-to-day civilian life. If a powerplant supplied power on the national grid, it would automatically be assigned a Risk Category of III regardless of whether the impacts of its functional loss were considered substantial. If the economic impacts and/or disruption to day-to-day civilian life were not considered substantial and, in the case of a powerplant, was not providing power on the national grid, a Risk Category of II would be assigned to the plant.

In some cases, a pumping plant or powerplant may supply water or power where delivery of that water or power is required during an emergency. Also, in some cases, water deliveries from a pumping plant are required to maintain water pressure for fire suppression. If these requirements exist for a plant or the plant is required to maintain the functionality of other Risk Category IV structures, then a Risk Category IV should be assigned to the plant.

A modification factor that accounts for the degree of risk to human life, health, and welfare associated with damage to property or loss of use or functionality is referred to as the importance factor. The importance factor originated with the seismic base shear equation in the 1976 Uniform Building Code (UBC) [12]. The concept and purpose of the importance factor at that time was to increase the design seismic forces in order to provide additional seismic resistance and prevent catastrophic collapse. Current practice within Reclamation uses ASCE/SEI 7 to assign importance factors of 1.0, 1.25, and 1.5 to buildings in Risk

Categories II, III and IV, respectively. Similar to the UBC approach, the intention is to achieve higher levels of seismic performance for these structures. The importance factors greater than 1.0 have the effect of reducing the potential for damage.

13.5.1 Seismic Design Considerations for Powerplants and Pumping Plants

13.5.1.1 Applicable Structural Building Systems per the IBC and ASCE/SEI 7

Powerplants and pumping plants are unique buildings not only in purpose and function but in their inherent geometric proportions, framing systems, mass distribution, load types and magnitudes, and stiffness properties. These characteristics significantly affect the response of the plant's superstructure to the DBE. The current seismic design provisions in the United States were written predominantly to address commercial and institutional buildings, and the normal design procedures presented in the building codes do not fully acknowledge the inherent differences between these buildings and plant structures. This can create uncertainty and problems for the engineer designing Reclamation plants and related facilities.

The types of structural systems and lateral-force-resisting (LFR) elements typically found in Reclamation plants use one of the three basic types of buildings structural systems defined in the IBC:

1. Bearing wall systems
2. Building frame systems
3. Moment-resisting frame systems

Bearing wall systems will typically use cast-in-place concrete or masonry walls along the exterior wall lines and at interior locations as necessary. Many of these bearing walls are used to resist lateral forces and are referred to as shear walls. This structural system is more commonly found in the smaller plant superstructures.

Building frame systems use three-dimensional space framing to support vertical loads and use shear walls or braced frames to resist lateral forces. The frame system is typically steel or reinforced concrete with steel-braced frames or concrete or masonry shear walls to resist lateral forces.

Moment-resisting frame systems used for Reclamation plants are typically steel or reinforced concrete. The three-dimensional space frame supports vertical loads, and some of those same frame elements are used to resist lateral forces. Shear walls are not used in this system.

Occasionally, a Reclamation plant will use a system defined as a dual system. These superstructures have a complete space frame that supports vertical loads and combine moment-resisting frames with either shear walls or braced frames to resist lateral forces.

13.5.1.2 Application of Current Seismic Requirements per the IBC and ASCE/SEI 7

The seismic design requirements presented in the current national codes and standards are based on the premise that inelastic behavior is expected in a structure designed to these provisions. This behavior is acknowledged in the various analysis approaches prescribed to predict earthquake forces in the building structure.

As noted in section 13.4.3.2.1, Seismic Analysis Procedures for Superstructures, the recommended method for predicting the expected behavior of a superstructure to an earthquake event is to characterize the seismic demand at a site with a design response spectrum. The ELFA procedure may also be satisfactory in certain cases.

For purposes of illustrating how the current code seismic design requirements can present uncertainty and even questionable results for plant superstructures, aspects of the ELFA procedure provide the most direct illustration. The equations that estimate the base shear associated with the design level earthquake use what is termed the response modification factor, *R*. The value for the response modification factor represents an adjustment factor used with a linear analysis model to approximate nonlinear dynamic response in the building structure. Therefore, appropriate detailing of the building structure is required to ensure that this approximation is justified. The response modification factor incorporates two effects: an overstrength factor and a ductility or ductility reduction factor.

Structural overstrength is attributed to members that are designed to or in excess of their design loads and drift limits that result in larger member sizes than required for strength limit states. If the superstructure design is controlled by other load combinations, which is common where wind loads, live loads, and crane loads are encountered, structural overstrength for seismic loading will also be present.

The second effect included in the R factor accounts for the ductility or ductility reduction. This effect is associated with two principle considerations:

1. As the structure begins to yield and deform inelastically, the natural period of the building will increase. This increase in period will typically result in decreased member forces.

2. The inelastic response in members dissipates energy, which is referred to as hysteretic damping.

The combination of these two effects was considered in developing the R values that are currently used in the United States. The R values provided are based predominantly on engineering judgment and the performance of various materials and systems for commercial and institutional buildings in past earthquakes.

13.5.1.3 Characteristics of Plant Superstructures and How They May Affect Seismic Performance

The following characteristics of plant superstructures can separate them from commercial and institutional buildings and affect the expected or required response of these structures to the DBE:

- Mass and stiffness properties of the building frames
- Building geometries
- Framing systems
- Bracing arrangements
- Loading considerations
- Lack of rigid diaphragms

13.5.1.3.1 Mass and Stiffness Properties of the Building Frame

Two types of plant superstructures can be identified and are common for Reclamation plants. The first type is more common to smaller pumping plants and some powerplants. These buildings commonly have light metal wall and roof panel systems and do not require an overhead crane or support large equipment loads. These buildings are therefore relatively light and are typically "pre-engineered" metal buildings. Guidance for the design of these buildings in accordance with IBC and ASCE/SEI 7 is provided in the Metal Building Manufacturers Association *Metal Building Systems Manual* [17].

Significant seismic characteristics for these buildings include structural frames that have significantly less weight or mass to be considered in a seismic event as compared to commercial or industrial buildings with similar footprints. Also, these buildings may be considerably more flexible than most commercial or institutional buildings. The expected response of the superstructure to the DBE results in smaller seismic base shears due to the low seismic weight and higher fundamental period, T, of the building. Therefore, seismic loads and/or seismic design criteria may then be overly conservative for these types of structures.

This conservatism can be produced through a number of means when the current code provisions are applied. In these frames, the overstrength component of the response modification factor may be significantly higher than that associated with a heavier building that would have higher seismic shears. Also, these buildings have higher fundamental periods than commercial or institutional buildings, as current codes provide an estimated value for the fundamental period based on typical mass and stiffness characteristics for commercial or institutional buildings. Additionally, current national codes prescribe an upper limit for the fundamental period, T_a. This upper limit on the fundamental period is also based on empirical studies and typical building mass and stiffness characteristics. In many cases, for the light superstructures for these types of plants, this upper limit on T for strength calculations may result in overly conservative designs.

In some cases, these pre-engineered metal buildings will include and support an overhead bridge crane. These buildings typically encounter many of the design conditions described below for the second type of plant superstructure.

The second type of plant superstructure includes potentially high equipment and/or live loads on the superstructure frame. Plants supporting heavy overhead bridge cranes are examples of these types of structures. These superstructures have relatively large, concentrated weight or mass positioned high on the structure. This weight may even exceed the weight of the supporting building frame and façade. This would be appropriately described as a mass irregularity. In these cases, the predicted vertical distribution of the seismic shear over the height of the superstructure may be affected. The equations used in the current codes to predict the vertical distribution of the seismic shear were developed for typical mass and stiffness characteristics in commercial and institutional buildings and may not be accurate for this type of superstructure. A dynamic analysis will be warranted in these cases to more accurately predict the distribution of forces.

13.5.1.3.2 Building Geometries

A common geometric difference for Reclamation plants are large floor-to-floor heights in service bays and large floor-to-roof heights in unit bays as well as long roof spans in both service and unit bays. These geometries are driven by equipment sizes as well as operational and handling requirements in these facilities. The effect of this on the expected response of the structure to a design level earthquake is:

1. Superstructure height requirements will often exceed height limits imposed by the current building codes for common, less-expensive framing systems such as ordinary moment frame and ordinary concentric braced frame systems. The mass and stiffness characteristics of a one-story, 60-foot-tall plant structure as compared to a five-story, 60-foot-tall commercial or institutional building are considerably different. Current national codes have not reviewed, commented on, or addressed this difference.

2. Many Reclamation plants have long roof spans that are framed with truss framing or precast concrete single or double tees. Also, long spans will typically require a slotted connection on one end of the truss or tee to allow movement (expansion and contraction) of the truss or tee. Developing a suitable lateral force resisting system under these conditions is difficult due to truss moment frame restrictions in the current codes.

Use of fixed base columns or cantilevered systems that are relatively flexible have height restrictions prescribed in current codes that eliminate these systems from consideration for many larger Reclamation plants. The engineer is left with the option of developing a separate moment frame system or making the building a braced building. Using a braced building system may be difficult due to aspect ratios of the building, large wall openings required for ventilation, and bracing restrictions.

13.5.1.3.3 Framing Systems

Equipment and handling requirements within Reclamation plants often drive the geometric proportions of a building and may also drive the type of framing system used in the building structure. If the space and building geometry do not allow for the practical use of discreet bracing, some form of rigid frame structure is often necessary to resist lateral forces.

For smaller plants, pre-engineered metal buildings will typically resist lateral loads in the transverse direction with a rigid frame that often use members with slender elements. The designer/design reviewer should be aware that the expected behavior of these types of rigid frames will differ from more conventional rigid frames used in commercial and institutional buildings. The potential for buckling within the slender elements prior to developing full yield strengths at a particular cross section should be thoroughly investigated. Also, the location of flexural hinges within the rigid frame may not be obvious because of nonprismatic frame profiles. See figure 13.5.1.3.3-1 for a typical rigid frame profile. Current IBC provisions preclude the use of slender elements in special moment frames and require tested connections for both special and intermediate moment frames. The most common practice for seismic categories D, E, or F is to design pre-engineered moment frame buildings as ordinary moment frames. However, it must be noted that the current version of the IBC restricts the building height and roof dead load for ordinary moment frames for these seismic categories.

Overhead bridge cranes are often included in larger Reclamation plants. The geometry for these superstructures is commonly defined by the dimensional characteristics of the bridge crane. (The bridge crane required will depend on equipment handling requirements – size, weight, clearances, etc.) The design of rigid frames for these types of superstructures can become demanding in terms of the development of shear and moment forces within the frame. Also, when the crane vertical support is integral with the rigid frame (column) or uses a separate column for crane support, the stiffness and flexural strength vary significantly above and below the crane girder. The stepped, laced, and battened column types shown in figure 13.5.1.3.3-2 depict these conditions. In these cases, the dynamic response of the structure will be affected by the column properties, and this must be considered in the design of the rigid frame or cantilevered columns.

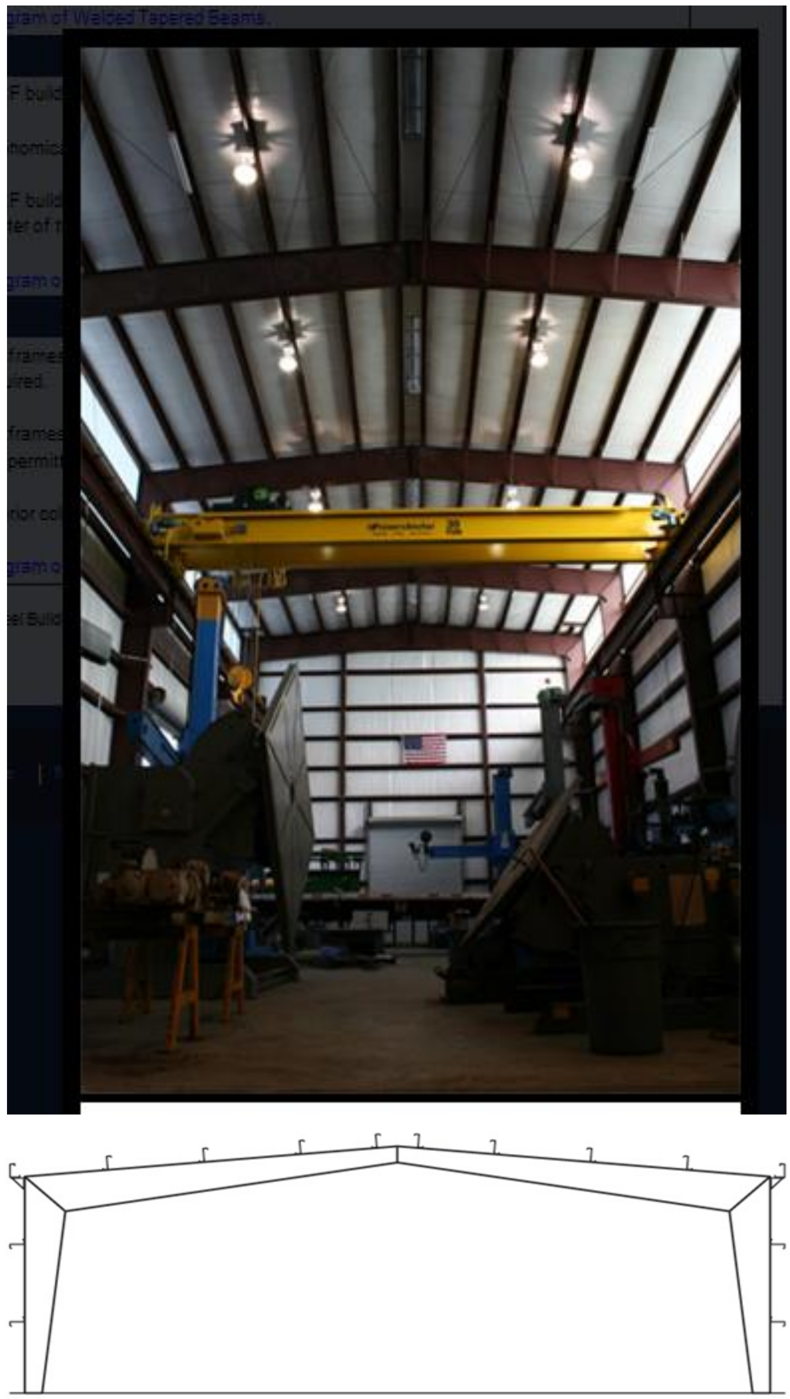


Figure 13.5.1.3.3-1. Picture and diagram of a rigid frame for a pre-engineered metal building.

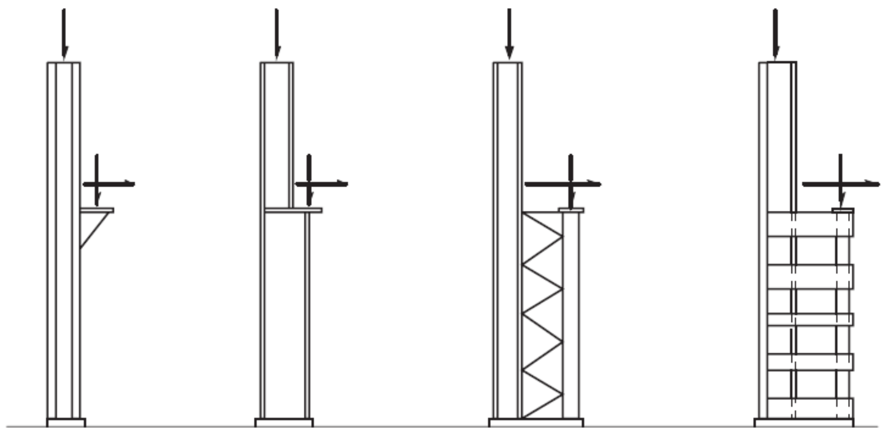


Figure 13.5.1.3.3-2. Column types for load sharing of crane loads – bracketed, stepped, laced, and battened columns for crane girder support.

If the superstructure height is below the current height restriction for use of cantilevered columns, the lateral force resisting system classifications in the current versions of the IBC allow the cantilevered column system with a relatively low R value. However, many Reclamation plants that house an overhead bridge crane will exceed this currently prescribed height restriction. In these cases, it is typical to find a moment frame for the lateral force resisting system with a separate truss or rafter system for the roof support. See figure 13.5.1.3.3-3 for a cross section of a plant depicting this lateral frame system with separate truss for roof support.

When support for an overhead bridge crane includes the use of a separate frame (columns) to support the crane girder, the framing system will typically have bracing ties between the crane support columns and the building frame columns. These columns are commonly referred to as laced or battened columns. A rational approach must be used here, however, to distribute the lateral shear forces over the height of the superstructure.

An important note about the consideration for the presence of the crane bridge and its effect on the seismic response of the building structure needs to be made here. Specifically, some designers may consider the bridge crane as an axial tie or strut between the supporting column lines that is limited by the frictional capacity of the crane wheel connection to the supporting rail and the crane wheel type (single flanged wheels or double flanged wheels). Current design practice within Reclamation does not consider the bridge crane stiffness (axial strut/tie capacity) between the building columns when computing and analyzing the lateral stiffness of the building frame. Although the crane bridge is not considered as an axial tie

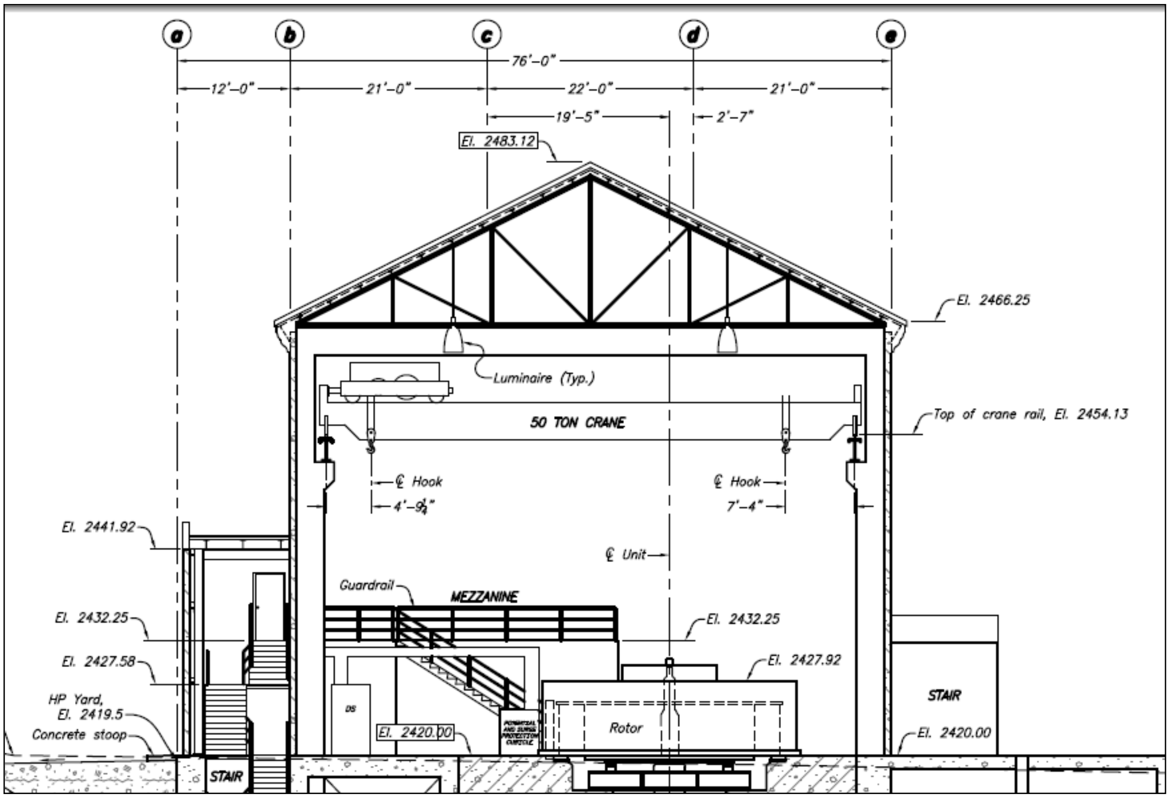


Figure 13.5.1.3.3-3. Transverse section of powerplant with moment frame and separate steel truss roof support system.

for design of the building frame, the design engineer may want to consider this behavior for the purposes of communicating possible axial forces within the crane bridge to the crane manufacturer.

13.5.1.3.4 Bracing Arrangements

For many Reclamation plants it is not possible to use a braced system for lateral force resistance. However, when bracing is possible, it may be difficult to obtain regular patterns of bracing for lateral resistance due to heating, ventilating, or air conditioning equipment and wall opening requirements. Multiple bracing offsets may be required if this method is used for lateral resistance. In most commercial and institutional buildings it is possible to avoid or limit the extent of these irregularities. The design engineer needs to be aware of these potential bracing irregularities in plants and try to avoid them if possible. However, it is likely that this type of irregularity cannot be avoided for many Reclamation plants and the design engineer will be required to address this condition.

13.5.1.3.5 Loading Considerations

When designing Reclamation plant superstructures for seismic loads, two load issues need to be addressed. The first issue deals with the mass or weight that should be included in W, the effective seismic weight of the building structure. In most cases, the hydraulic equipment that contains or conveys water and its related mass are distributed to resisting systems below grade and will not be considered in the design of the superstructure. However, current IBC seismic provisions require 25 percent of storage live loads, the weight of permanent equipment, and 20 percent of the flat roof snow load where this load exceeds 30 pounds per square foot (lb/ft^2). Some judgment will be required by the design engineer regarding how much floor live load (if any) should be included in the seismic weight of the building. In many Reclamation plants, the floor live loads are significant (500 – 1,000 lb/ft^2), and including a portion of this load in the seismic weight may be justified.

The second issue for loading considerations concerns the load combinations that are pertinent for Reclamation plant structures. For floor live loads, IBC allows a reduction of the load when considered in conjunction with earthquake loads. There may be conditions in which floor live loads are well known and typically present, and this reduction may not be warranted, or a larger percentage of the floor live load may be appropriate. Engineering judgment is required in determining when to apply or not apply a prescribed load reduction and when to include loads that are typically encountered in Reclamation plants.

If an overhead bridge crane is present it is typically parked (when not in use) in a bay near the end of the building. However, Reclamation practice is to design the plant superstructure assuming the bridge crane could be parked at any location within its operating range and that the cab and hoist location could be positioned at either end or midway across the bridge. The bridge crane live load (handling capacity) is not included in the seismic weight of the building. The premise here is that coincidental timing of crane operation and a seismic event is too remote to warrant its application in design. Current IBC provisions do not provide clear direction on this subject, but may address it in future revisions.

13.5.1.3.6 Lack of Rigid Diaphragms

Most one-story, small plants will have some form of a metal roof deck. With the exception of the standing seam metal roof cladding, most of these decks have diaphragm capability. Lateral displacement of these roof systems (diaphragms) may be appreciable and may raise some question as to whether they are rigid or flexible diaphragms. Current provisions within IBC provide some qualitative and quantitative definition for determining the type of diaphragm. A diaphragm is considered flexible if its lateral deflection is more than two times the average story drift of the vertical elements of the lateral force resisting system.

Noteworthy is that standing seam roofs are very popular in pre-engineered metal buildings. These roofs are a special type of metal deck cladding using formed metal sheets with side-lap joints that are joined together and supported on clips connected to the supporting roof structure. This joint system allows for independent movement parallel to the sheet between each sheet and between the sheets and supporting clips. This independent movement is advantageous in that it allows for differential thermal movement between the roof panel and supporting structure. Due to the nature of this joint, this roof does not typically provide appreciable diaphragm strength or stiffness, and a separate discreet bracing system is required to transfer lateral loads to the vertical load-resisting system (foundation).

13.5.1.4 Design Considerations for Plants

Section 13.5.1 has presented characteristics for Reclamation plants that make design of these structures unique for earthquake forces. Recognizing that current nationally adopted codes and standards do not completely or adequately address all of these characteristics, the design engineer is required to adapt these code provisions and apply engineering judgment to the current seismic design requirements when designing Reclamation plants for seismic loading. Design considerations that can assist in this regard are presented here.

The mass and stiffness characteristics for plants are such that a dynamic (response spectrum) analysis is typically warranted. The ELFA method currently prescribed in IBC and ASCE/SEI 7 will not, in many cases, adequately address mass and stiffness irregularities commonly encountered in pumping plants and powerplants. These irregularities occur in both the horizontal and vertical planes. Concerns arise in accuracy for values that would be used for the response modification factor, the fundamental building period, T, and the prescribed upper limit on the building period, T_{max}.

The plant irregularities often found in Reclamation plants will generate a seismic response in the building structure that varies significantly from that predicted by the equations presented with the ELFA procedure in either IBC or ASCE/SEI 7. This is particularly obvious when a stepped column profile is used to support an overhead bridge crane. A dynamic analysis should be performed in these instances to better determine the distribution of seismic shears over the height of the building structure.

Often, plant geometries produce conditions in which height limits or restrictions are exceeded for standard ordinary moment frames, ordinary concentrically braced frames, or cantilevered column systems in Seismic Design Categories D and E. Another characteristic for plant structures is that they require long roof spans over unit bays and service bays. These conditions often dictate that these frame systems be designed as moment frame systems. Several alternatives exist that may mitigate the seismic load demands on the moment frame. A roof truss system independent of the moment frame may be used to support gravity loads and live loads for the roof. An example of this framing system is shown on figure 13.5.1.3.3-3.

Although the laced or battened columns shown in figure 13.5.1.3.3-2 are not commonly found in Reclamation designed plants, supporting an overhead bridge crane with the use of a separate frame (columns) can help reduce the seismic load demands on the building moment frame system. Use of a separate column system to support an overhead bridge crane, independent of the moment frame or braced frame system, is more common in heavy industrial buildings requiring large, heavy overhead bridge cranes. Although these types of superstructures are less common, a few aspects of their behavior in relationship to provisions within current design codes and standards should be noted. If the crane support columns are tied or laced to the building columns, the effective flexural stiffness of the laced columns is typically much higher than the single column shaft extending above the laced column to the roof. The low R values prescribed for an inverted pendulum system in the building code are intended to apply to fixed-base columns or cantilevered systems that are relatively flexible. Also, height restrictions provided for cantilevered column systems may be overly restrictive in these cases.

Because these buildings use nonprismatic columns, a dynamic analysis should be performed to accurately predict the magnitude and distribution of seismic shears. Also, the large disparity in strength and stiffness between the lower, laced column shaft and the single, upper column shaft produces a potential location for inelastic demand under seismic loading. A recommended approach is to design this connection to develop the maximum expected flexural capacity of the single, upper column shaft. Attention to the integrity of the column base details is also required. The anchor bolts and column base plate details should be designed to provide ductile behavior.

Further research is required and is ongoing to address some of the unique aspects of seismic design for pumping plants and powerplants. Several areas that will likely be addressed in the near future include: appropriate R values for industrial buildings, appropriate modifications to height limits for one-story plant superstructures, dynamic response of superstructures that support overhead bridge cranes and/or use stepped or separate support columns, refinement to the importance factor for plants with limited public exposure, as well as specific consideration for water and power delivery requirements and dam safety related concerns.

Current analytical tools and computer modeling methods provide the design engineer with enhanced capabilities to more accurately determine the expected seismic response of unique structures. However, the design engineer will always need to incorporate simplicity, continuity, redundancy, and attention to detail regardless of the analytical method used. It remains difficult, if not impossible or impractical, to produce analytical models that account for all the behavioral aspects and many forms of inelastic response encountered in pumping plants and powerplants. Joint deformations, failures in shear and anchorage, severe discontinuities, and three-dimensional inelastic response, including torsion, are difficult to model confidently even when identified. The influence of these behaviors should be minimized by layout of the structural system and proportion and detail of its components.

13.5.1.5 Design Considerations for Plant Electrical Equipment

Transformers perform the vital function of transferring power between circuits operating at different voltages. At pumping plant sites, power transformers are located within substations and are generally pad mounted. At powerplant sites, the generator step-up (GSU) transformers are generally located within a designated transformer deck, which is supported by the plant substructure, intermediate structure, or can be found within adjacent or nearby switchyards. At Reclamation sites, the GSU transformer can be found mounted on pedestals and/or supported by rails with a transfer track arrangement to accommodate removal and replacement activities. Distribution transformers and station service transformers can be located in switchyards, substations, and within plants. Unit controls and switchgear will commonly be located adjacent to or near the units, and electrical control equipment may be located near the units or some distance away from the units in the service bay of a plant. Depending on voltage requirements at the plant, the weight of transformers and related electrical equipment can be heavy and may have a high center of gravity. The seismic loads imposed from this equipment during a seismic event can be significant and must be restrained, typically at the base, with an anchorage system of embedded plates and/or anchor bolts. In new facilities, it is recommended that plates be embedded within or attached to the structure that supports and/or surrounds the equipment (floor, walls, structural members). In existing facilities, an adequate anchorage system configuration that satisfies all strength requirements may be difficult to provide. Typical installations of these anchor systems will use post-installed anchors. Further discussion on this topic can be found in the *Guide to Improved Earthquake Performance of Electrical Power Systems* [13].

Electrical equipment appurtenances and attachments to any structural component of the plant or foundation system must be designed and qualified, depending on type and voltage, in accordance with the current version of the *Institute of Electrical and Electronics Engineers (IEEE) Recommended Practice for Seismic Design of Substations Standard No. 693* [14]. IEEE 693 provides recommended seismic design practices for transformers and other electrical equipment within plant structures as well as within substations and switchyards.

Additionally, some electrical equipment can contain large volumes of oil, and the integrity of the equipment vessels could be damaged as a result of a seismic event. In order to minimize or alleviate environmental impact of oil spills and their cleanup, oil spill prevention shall be in accordance with *IEEE Guide for Containment and Control of Oil and Spills in Substations Standard No. 980* [15]. IEEE 980 discusses typical designs and methods for dealing with oil containment and control of oil spills as required by the United States Code of Federal Regulations, Title 40 (40 CFR) Parts 110 and 112.

13.6 General Evaluation Requirements for Existing Buildings

The following paragraphs discuss the basis and recommendations for selecting values for parameters commonly required in the seismic evaluation of existing pumping plants, powerplants, and other buildings analyzed by Reclamation.

Plant superstructures and buildings are classified into two groups: (1) primary structures that are essential for the continued operation of the facility following a design level seismic event and (2) ancillary structures that are not required to be operational for the continued function of the facility particularly during the period immediately following a design level seismic event. Both classes of buildings are evaluated using the procedures outlined in ASCE/SEI 31, *Seismic Evaluation of Existing Buildings* [4], in accordance with their appropriate performance level. Buildings that are deemed outside the range of applicability of standard ASCE/SEI 31, either due to their configurations, classification, or required level of performance, are evaluated using ASCE/SEI 41, *Seismic Rehabilitation of Existing Buildings* [5].

Primary structures are evaluated to the immediate occupancy performance level at the ground motion level equivalent to an earthquake with a recurrence period of 1,000 years (~5-percent probability of exceedance in 50 years); this is typically equivalent to 3/4 of the MCE. This increased seismic loading requirement for the plant's primary structures is consistent with current U.S. Army Corps of Engineers' practices in the evaluation of their powerplants [6]. Ancillary structures are evaluated to the life safety performance level at the ground motion level of 2/3 MCE which is equivalent to an earthquake with a recurrence period of 475 years (~10-percent probability of exceedance in 50 years).

Current national seismic standards for the design of new buildings (i.e., IBC and ASCE/SEI 7) utilize an equivalent force approach, while ASCE/SEI 31 and ASCE/SEI 41 provisions for the evaluation of existing buildings are based on an equivalent displacement approach. Both methods are described as follows:

> *Equivalent Force Approach* – The equivalent force methodology accounts for nonlinear response to seismic loading by including a response modification factor in calculating a reduced equivalent base shear. Associated with the selection of the *R*-factor, specified prescriptive detailing requirements are required for the structure. These prescriptive requirements are primarily to ensure specific levels of ductility in the structure. To account for inelastic displacements, the deflection amplification factor, C_d, is provided to increase the displacements from the elastic analysis level. To implement higher performance levels for certain structures, an importance

factor, *I*, is used to increase the design level seismic demands. In summary, this procedure is based on equivalent lateral forces and pseudo displacements.

Equivalent Displacement Approach – In the equivalent displacement method, a pseudo lateral force is applied to the structure to obtain displacements from a design earthquake. These deformations are the expected deformations of the structure in its yielded state. A modification factor, *C*, per ASCE/SEI 31, or the product of modification factors C_1, C_2, and C_3, per ASCE/SEI 41, are used to adjust the static base shear (a pseudo force) to a value that would result from these displacements. In order to obtain what are considered actual force demands, a component modification factor referred to as "*m*" is used for the deformation-controlled action of each independent component or element instead of applying the global, ductility-related response modification factor to the applied loads. The selected value for *m* is dependent on the ductility of a component action being evaluated and the performance level required of the structure. In summary, this procedure is based on equivalent displacements and pseudo lateral forces.

The equivalent displacement approach is preferred and considered the appropriate approach for evaluation of existing buildings, including plants, and it is the approach used in the ASCE/SEI 31 and ASCE/SEI 41 provisions.

Using the equivalent force approach is more difficult or demanding to implement and may yield more uncertain results because it contains requirements governing building configuration, strength, stiffness, detailing, and special inspection as well as material testing. The strength and stiffness requirements are easily transferred to existing buildings; however, the other provisions are not. If the LFR elements of an existing plant do not have details of construction similar to those required for new construction, the basic assumptions of ductility are likely to be invalid, and the provisions for new buildings may not be appropriate for evaluating existing plants. By contrast, the equivalent displacement approach accounts for the specific detailing and ductility of individual components or elements of the structure, and the seismic performance of an existing structure can be assessed with a relatively high level of confidence.

The ASCE/SEI 31 seismic evaluation process is a three-tiered approach that allows identification of potential seismic deficiencies in a building or a structure. The aspects of a building that are evaluated include structural, nonstructural, geologic site hazards, and foundation conditions. Tier 1 is considered a screening phase, Tier 2 is a preliminary evaluation phase, and Tier 3 is a detailed evaluation phase. A building, or any of its components, is considered seismically deficient if it does not comply with the provisions of ASCE/SEI 31.

The ASCE/SEI 31 Tier 1 evaluation identifies potential deficiencies through the use of quick checklist statements. The ASCE/SEI 31 Tier 2 evaluation requires a linear elastic analysis of the building to further evaluate all of the potential deficiencies identified in the Tier 1 evaluation. If deficiencies remain after a Tier 2 evaluation, the evaluation may be concluded with a report of the potential deficiencies, or the evaluation may proceed to Tier 3 for a detailed seismic evaluation. This third tier of the evaluation may or may not eliminate potential deficiencies; therefore, the initiation of a Tier 3 analysis is guided by a cost-benefit assessment. (The cost of addressing deficiencies identified at the Tier 2 level may be less than conducting the Tier 3 analysis.) If the cost-benefit assessment justifies a Tier 3 analysis, this analysis is limited to the confirmation of deficiencies.

One of the first steps in the ASCE 31/SEI evaluation process is to classify the structure(s) as one of 24 common building types (CBT). The CBTs are standard designations that capture most of the common building structural configurations and lateral force resisting systems, such as reinforced masonry, wood light frame, steel moment frame, concrete shear walls, etc. A comprehensive list of CBTs can be found in ASCE/SEI 31. A set of basic and supplemental structural checklists, customized for the particular CBT, is completed during the ASCE/SEI 31 Tier 1 evaluation. Determining the applicability of a particular checklist is based on parameters such as level of seismicity and performance level. The CBT checklists address the structural issues for the building, while geologic site and foundation issues are addressed in separate checklists. The checklists, which are substantially completed onsite during the field inspection, focus on the features required for the desired level of building performance. Each of the evaluation statements is noted as compliant (C), noncompliant (NC), or not applicable (N/A). A NC response to any evaluation statement indicates a potential seismic deficiency, and additional analysis will be required to verify that particular deficiency. Examples of structural checklists for several different CBTs can be found in Appendix A of ASCE/SEI 31-03.

When the ASCE/SEI 41 provisions are used for the evaluations of plant structures, the screening phase (Tier 1) and the evaluation phase (Tier 2) are bypassed. This is a common situation for Reclamation plant structures, as these structural systems have geometric proportions, framing systems, and mass distribution that do not conform to typical commercial or institutional structures (see section 13.5.1). A detailed evaluation (Tier 3), including linear or nonlinear, static, or dynamic analysis is performed in many of these cases. Appropriate element demands are calculated and compared to element capacities within applicable acceptance criteria.

13.7 Seismic Design of Nonstructural Building Components

Nonstructural building components are elements within or attached to buildings to provide them with essential services and functions such as heating and cooling, lighting, elevators, stairs, electrical power, etc. These components are not a part of the building structural system and are not designed to contribute to the resistance of earthquake forces. In most building codes, nonstructural components are commonly grouped into three categories: (1) architectural, (2) mechanical, and (3) electrical.

Architectural nonstructural components include:

- Cladding
- Suspended ceilings
- Exterior and interior nonbearing walls and partitions
- Stairs or ladders
- Parapets
- Masonry and concrete fences at grade over 10 feet in height

Mechanical nonstructural components for plants include systems such as:

- Pumps
- Valves
- Piping systems
- Storage tanks
- Heating, ventilation, and air conditioning (HVAC) systems
- Elevator components

Electrical nonstructural components include:

- Pump motors
- Generators
- Electrical control and switchgear cabinets
- Overhead bus and cable trays
- Lighting fixtures

The current code requirements for nonstructural components are contained in ASCE/SEI 7-10, Section 13. This particular code provision for nonstructural components is a result of observed behavior in numerous instances of damage to nonstructural components during past earthquakes and subsequent research and engineering.

Code provisions developed to date for nonstructural systems are driven by the component importance factor, I_p, and the Seismic Design Category, which ranges from A through F and depends on the Risk Category (formerly referred to as the Occupancy Category). The most stringent design provisions are driven by the component importance factor, I_p. Any component with an I_p of 1.5 is considered a "Designated Seismic System" for which special provisions apply. This includes systems required to function for life safety purposes after an earthquake and includes sprinkler systems and egress stairways; components used to convey, support, or contain toxic substances or hazardous materials; or components needed for continued operation of essential facilities.

The seismic design forces are based on a variety of factors, including the weight of the item, the ground acceleration and soil type, the flexibility of the component and its attachments, the location in the building, and the importance factor.
In general, design forces are higher for flexible components and flexible attachments; higher for items anchored higher in the building; higher for items that contain hazardous materials, which are needed for life safety functions or that are needed for continued operation of an essential facility; and lower for items with high deformability or high ductility.

The following items are specifically exempt from the ASCE/SEI 7-10 seismic design requirements for nonstructural components:

1. Most furniture and temporary or movable equipment

2. Most components in Seismic Design Categories B and C

3. Mechanical and electrical components in Seismic Design Categories D, E, and F, where all of the following apply:

    a. I_p is equal to 1.0

    b. The component is positively attached to the structure

    c. Flexible connections are provided between the components and associated ductwork, piping, and conduit and either

        i. The component weighs 400 lbs or less and has a center of mass located 4 feet or less above the floor level; or

        ii. The component weighs 20 lbs or less or, for distribution systems, weighs 5 pounds per foot or less

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Appendix A

Example Calculation Showing Relationship Between Exceedance Probability and Return Period

Common expression:

Ground motions having a 2-percent probability of being exceeded in 50 years is equivalent to a ground motion having an approximate return period of 2,500 years (occurring once in 2,500 years).

This ground motion is commonly referred to as the 2,500-year event.

Exceedance probability (EP) = 0.02

Time period being considered (T) = 50 years

Event return period (RP)

$$RP = \frac{T}{-1*[\ln (1 - EP)]} \qquad (\ln \text{ or } \log_e(x) = \text{natural logarithm})$$

An approximation for ln (1- EP) may be used:

$$\ln (1 - EP) \sim EP * [1 + 0.5 * (EP)]$$

For a ground motion having a 2-percent probability of being exceeded in 50 years:

$$RP = \frac{T}{-1*[\ln (1 - EP)]} = \frac{50}{-1*[\ln (1 - 0.02)]} = 2{,}475 \text{ years}$$

TSC Security Review of Proposed Public Disclosure of Technical Information

Type: Design Standard

Design Standard: Design Standards No. 9 – Buildings

Chapters: 13 – Seismic Design

Brief Description of Information: Presents basic criteria and methods used within the Bureau of Reclamation to analyze and design pumping plants, powerplants, and buildings for seismic loading. Criteria and methods to evaluate existing buildings for seismic loading are also presented.

Requesting/Sponsoring Organization: Director, Technical Service Center

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Is Information Official Use Only / RESTRICTED? (Y/N)
(to be completed by reviewer)

(Sensitive or restricted information shall not be included in a design standard.)

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