

DEP SPECIFICATION

EARTHQUAKE DESIGN FOR ONSHORE FACILITIES – SEISMIC HAZARD ASSESSMENT

DEP 34.00.01.10-Gen.

February 2017

DESIGN AND ENGINEERING PRACTICE

DEM1



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1. INTRODUCTION

1.1 SCOPE

This DEP specifies requirements and gives recommendations for seismic hazard quantification and seismic design of 'new build' onshore and nearshore facilities.

This DEP covers all steel and concrete structures, storage tanks, refrigerated liquefied gas (RLG) storage tanks and plant piping. To achieve a consistent seismic philosophy the minimum performance requirements of this DEP can also be applied to plant equipment.

The requirements in this DEP are based on current best practice. The seismic design of foundations is covered in DEP 34.11.00.12-Gen.

This DEP contains mandatory requirements to mitigate process safety risks in accordance with Design Engineering Manual (DEM) 1 - Application of Technical Standards.

This is a revision of the DEP of the same number dated February 2016; see (1.5) regarding the changes.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

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This DEP is intended for use in oil refineries, chemical plants, gas plants, onshore exploration and production facilities and supply/distribution installations. This DEP may also be applied in other similar facilities.

When DEPs are applied, a Management of Change (MOC) process shall be implemented; this is of particular importance when existing facilities are to be modified.

If national and/or local regulations exist in which some of the requirements could be more stringent than in this DEP, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable with regards to the safety, environmental, economic and legal aspects. In all cases, the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned, the objective being to obtain agreement to follow this DEP as closely as possible

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is the party that carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party that manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party that initiates the project and ultimately pays for it. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The capitalised term **SHALL [PS]** indicates a process safety requirement.

The word **should** indicates a recommendation.

The word **may** indicates a permitted option.

1.3.2 Specific definitions

Term	Definition
Accelerogram	A record of acceleration versus time measured during an earthquake by an instrument (accelerometer) located within a structure or on the ground. Also known as “strong motion recording” or an earthquake “time history”.
Accelerometer	An instrument used to measure ground accelerations caused by an earthquake
Aftershock Level Earthquake (ALE)	ALE ground motion is defined as one-half SSE, as per NFPA 59A.
Behaviour factor	Also known as a force reduction or ductility factor. This is the factor used for design purposes to reduce the forces obtained from a linear analysis, in order to account for the yielding mechanisms within the structure.
Damage Limitation State	Damage limitation states are those associated with the damage beyond which specified performance requirements are no longer met
Damping	The rate at which natural vibration decays as a result of the absorption of energy. In buildings it is an inherent nature to resonate inefficiently to vibration depending on structural connections, kinds of materials and non-structural elements used. Damping in a structure is typically expressed as a percentage of critical damping.
Design Basis Earthquake/ Design Earthquake	The earthquake effects that are two-thirds of the corresponding Maximum Considered Earthquake (MCE) effects.
Design response spectrum	A smoothed response spectrum used in design and often used for linear dynamic response calculations.
Deterministic Seismic Hazard Assessment (DSHA)	An analysis procedure that computes the ground motion (e.g., peak ground acceleration or response spectra) at a site from a given earthquake postulated to occur at a given distance (typically on an active fault).
Effective Peak (ground) Acceleration (EPA)	A coefficient (acceleration) representing ground motion for periods in the range of 0.1 sec to 0.5 sec. It is calculated by dividing the smoothed, damped, spectral acceleration ordinates by the appropriate constant of proportionality.

Term	Definition
Exceedence probability	The probability that a specified level of ground motion of an earthquake will be exceeded at a site or in a region during a specified exposure time. The value of the probability of exceedance, PR, in TL years of a specific level of the seismic action is related to the mean return period, TR, of this level of the seismic action in accordance with the expression $TR = -TL/\ln(1-PR)$. So for a given TL, the seismic action may equivalently be specified either via its mean return period, TR, or its probability of exceedance, PR in TL years.
Fatal Flaw	A fatal flaw is considered to be any hazard that would affect the economic viability of a proposed facility. Earthquake ground motion is not considered to be a fatal flaw at this conceptual stage because proven design solutions are available to limit adverse effects from the shaking.
Ground Motion Predictive Equations (GMPE)	These are also known as “attenuation equations”. These are used to predict ground motion at a site for a known magnitude and distance of an earthquake event. Attenuation equations are structured in order to predict ground motion for a number of frequencies (or periods), enabling the production of a response spectrum.
Importance factor	Structures are classified according to importance classes, depending on the consequences of collapse for human life, on their importance for public safety and civil protection in the immediate post-earthquake period, and on the social and economic consequences of collapse. Importance factors are used to modify the zero period accelerations to increase the notional return period of the design earthquake and hence increase the Factor of Safety.
Magnitude	A logarithmic scale of earthquake size, based on seismograph records. The magnitude is related to the total energy released by the earthquake. A number of different magnitude scales exist, including Richter or local (ML), surface wave (MS), body wave (Mb) and duration (Md) magnitudes. The most widely used magnitude range in current practice is moment magnitude (Mw), which is a function of the energy released in an earthquake.
Maximum Considered Earthquake (MCE)	The most severe earthquake effects considered that results in the largest maximum response to horizontal ground motions. A ground motion, which has a 2 % chance of exceedance in 50 years (mean return period of 2475 years).
Maximum capable earthquake	A ground motion computed from a deterministic analysis of the maximum earthquake postulated on a known fault, also known as Maximum Credible Earthquake.
Operating Basis Earthquake (OBE)	The OBE ground motion is the motion represented by an acceleration response spectrum having a 10 percent probability of exceedance within a 50-year period (mean return period of 475 years).
Peak Ground Acceleration (PGA)	The largest absolute value of ground acceleration in a given time record of acceleration.

Term	Definition
Peak Ground Velocity (PGV)	The largest absolute value of ground velocity in a given time record of velocity. It is correlated to peak ground strain and used in the seismic design of pipelines.
Permanent ground deformation	The earthquake-induced permanent movement or final displaced position of the ground or soil/rock mass.
Probabilistic seismic hazard assessment (PSHA)	An analysis procedure that computes the probabilities of exceeding specified levels of ground motion (e.g., levels of peak ground acceleration or response spectral ordinates) during a specified time period (typically the design life, nominally 50 years).
Response Reduction Factor	The ratio of the theoretical seismic base shear, which would develop in a linearly elastic system, to the prescribed design base shear. It is a measure of the ability of the system to absorb energy and sustain cyclic inelastic deformations without collapse.
Response spectrum	A plot of structural period against peak response (absolute acceleration, relative velocity or relative displacement) of an elastic, single degree of freedom system, for a specified earthquake ground motion and percentage of critical damping. Relative motions are measured with respect to the ground. Damping levels for the reference response spectrum should be 5 %.
Return period	The return period is an estimate of the interval of time between earthquakes of a certain intensity or size. It is a statistical assessment denoting the average recurrence interval over an extended period of time. Refer to definition for exceedence probability.
Safe shutdown earthquake (SSE)	SSE is represented by a ground motion response spectrum in which the spectral acceleration at any period, T , shall be equal to the spectral acceleration of the MCE ground motion.
Seiche	Seiches are stationary or standing waves set up in an enclosed body of water. Seismic seiches are standing waves set up on rivers, reservoirs, bays, ponds, and lakes when seismic waves from an earthquake pass through the area.
Soil Structure Interaction (SSI)	The process in which the response of the soil influences the motion of the structure and the motion of the structure influences the response of the soil.
Specialist consultants	In the context of this DEP, consultants who have done site-specific seismic hazard assessments in the past for other projects for reputed national and international Oil and Gas companies. They are accepted by the Principal as having expertise in carrying out such studies.
T_D	T_D represents the start of the constant displacement portion of the response spectrum.

Term	Definition
Time histories	These are modified or actual accelerograms recorded during earthquakes, Refer to (7.2.2.3).
Tsunami	A tsunami is a large destructive sea waves generated by earthquakes, volcanic eruptions, or large landslides.
Ultimate Limit State (ULS)	The state associated with collapse or with other similar forms of structural failure.
Uniform hazard response spectrum	A multi-parameter description of ground motion that can be generated from a probabilistic seismic hazard assessment. It is composed of a number of points which each have an equal likelihood of being exceeded in a given time period.

1.3.3 Abbreviations

Term	Definition
ALE	Aftershock Level Earthquake
CPT	Cone Penetration Test
DBE	Design Basis Earthquake
DSHA	Deterministic Seismic Hazard Assessment
FERC	Federal Energy Regulatory Commission (US)
GMPE	Ground Motion Predictive Equation
LRFD	Load and Resistance Factor Design
MCE	Maximum Considered Earthquake Also referred to as the Maximum Capable Earthquake (the largest possible earthquake)
MCE_R	Risk Targeted MCE, as per ASCE 7-10
NEHRP	National Earthquake Hazards Reduction Program
OBE	Operating Basis Earthquake
PAER	People, Assets, Environment, Reputation as per Shell RAM Matrix
PGA	Peak Ground Acceleration
PGD	Peak Ground Displacement
PGV	Peak Ground Velocity
PSHA	Probabilistic Seismic Hazard Assessment
RAM	Risk Assessment Matrix
RLG	Refrigerated Liquefied Gas (storage tanks)

Term	Definition
SHA	Seismic Hazard Assessment
SPT	Standard Penetration Test
SSE	Safe Shutdown Earthquake
SSI	Soil Structure Interaction

1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section or clause number is shown in brackets ().

Other documents referenced by this DEP are listed in (8).

1.5 SUMMARY OF MAIN CHANGES

This DEP is a revision of the DEP of the same number dated February 2016. The only changes are to DEP cross-references to reflect changes in the DEP library in 2017.

1.6 COMMENTS ON THIS DEP

Comments on this DEP may be submitted to the Administrator using one of the following options:

Shell DEPs Online (Users with access to Shell DEPs Online)	Enter the Shell DEPs Online system at https://www.shelldeps.com Select a DEP and then go to the details screen for that DEP. Click on the "Give feedback" link, fill in the online form and submit.
DEP Feedback System (Users with access to Shell Wide Web)	Enter comments directly in the DEP Feedback System which is accessible from the Technical Standards Portal http://www.shell.com/standards . Select "Submit DEP Feedback", fill in the online form and submit.
DEP Standard Form (other users)	Use DEP Standard Form 00.00.05.80-Gen. to record feedback and email the form to the Administrator at standards@shell.com .

Feedback that has been registered in the DEP Feedback System by using one of the above options will be reviewed by the DEP Custodian for potential improvements to the DEP.

1.7 DUAL UNITS

This DEP contains both the International System (SI) units, as well as the corresponding US Customary (USC) units, which are given following the SI units in brackets. When agreed by the Principal, the indicated USC values/units may be used.

1.8 NON NORMATIVE TEXT (COMMENTARY)

Text shown in italic style in this DEP indicates text that is non-normative and is provided as explanation or background information only.

Non-normative text is normally indented slightly to the right of the relevant DEP clause.

2. GENERAL

2.1 OBJECTIVES

The main objective of this DEP is to provide minimum performance requirements for earthquake design in addition to the requirements specified in ASCE 7. This DEP also addresses clearly studies and investigations that shall be carried out at different phases of the project life cycle such as Seismic Hazard Assessment (SHA) and Geohazards studies for 'new build' onshore and near shore facilities.

As the extent of work required to determine the seismic design parameters usually depends on the severity of the earthquake ground motion and the potential consequence of the various hazards due to earthquake, this DEP provides guidelines on classification of facilities based on an overall importance category and consequence classification for different structures/systems/components within the facilities based on consequence of failure.

1. Determination of appropriate seismic design parameters for design of structures/systems/components shall be based on importance category classification and consequence classification as outlined in this DEP.

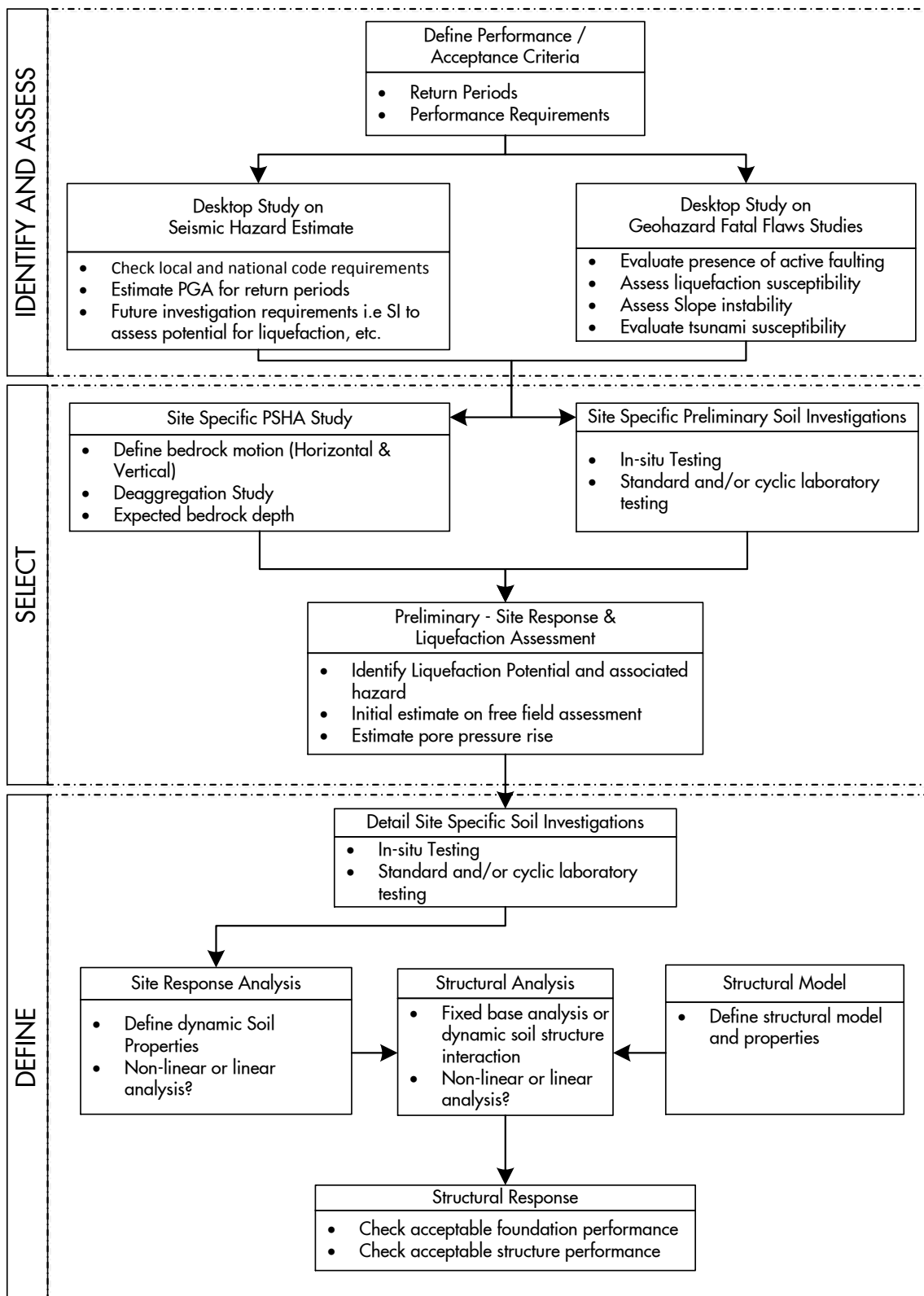
2.2 BACKGROUND DATA

This document provides guidance on facility categorisation i.e. LNG, LPG, petrochemical which drives the type of geohazard investigation; and the subsequent classification of structures within a facility i.e. the target performance based on the consequences of structural failure.

In addition clear guidance is provided as to Geohazard identification, Seismic Hazard Assessment (SHA) and site response requirements linked to the respective phase of the Opportunity Realisation Process. This DEP provides minimum performance requirements for structures in terms of design seismic events to be considered, importance factors and response reduction factors, for each consequence category. In addition minimum allowances are included on the margins of uncertainty of soil properties to be considered when performing site response and soil-structure interaction analysis. Specific additional guidance is also provided for design of structures, components and systems including piping.

1. In general, the requirements provided in this DEP are aligned with ASCE 7 (and NFPA 59A for LNG). Depending on the project location and local regulations, additional requirements may be required. As a minimum the performance expectations of this DEP shall be met in all instances.
2. The seismic design activities that shall be carried out to evaluate the level of seismic risks for facility appropriate to the IDENTIFY and ASSESS, the SELECT and the DEFINE phases are summarised in the flowchart given in Figure 1.

Figure 1 Seismic design flowchart



3. SEISMIC PERFORMANCE REQUIREMENTS

3.1 GENERAL

The following section defines the minimum seismic performance requirements for all new facilities (both greenfield and brownfield) to be constructed on land that is subjected to seismic loading. The scope covers all portions of the facility located within the facility security fence, including loading docks.

The section addresses the following:

- *Facility Importance Category*
- *Hazard Consequence Categories for structures*
- *Seismic Design Motions*
- *Performance Criteria*

3.2 FACILITY IMPORTANCE CATEGORY

3.2.1 General

Importance Categories are assigned to various facilities for planning and initiating Seismic Hazard Assessment (SHA) and Geohazards identification studies at respective stages of the project lifecycle.

1. All new facilities shall be classified into one of the following three Importance Categories:
 - a. High importance (3.2.2)
 - b. Medium importance (3.2.3)
 - c. Normal importance (3.2.4)

3.2.2 High importance category

These are facilities having hazards that can lead to consequences equivalent to RAM 5 PAER.

LNG facilities or chemical/petrochemical facilities containing acute toxic material are typically classified under high importance category.

3.2.3 Medium importance category

These are facilities having hazards that can lead to consequences equivalent to RAM 3/4 PAER.

Chemical/Petrochemical facilities not containing any acute toxic materials, based on HSE assessment are classified under medium importance category.

3.2.4 Normal importance category

These are facilities having hazards that can lead to consequences equivalent to RAM 2 PAER.

3.3 HAZARD CONSEQUENCE CATEGORIES FOR STRUCTURES (ASCE 7)

3.3.1 General

Hazardous consequence categories are assigned to individual structures/ systems/components within a particular facility for establishing performance criteria for individual structures/systems/components, irrespective of the facility importance category.

1. As a minimum, hazard consequence categories SHALL [PS] be assigned to various structures/systems/components within a facility as per Table 1, to specify adequate performance requirements, based on the consequence of failure.
2. Three hazard consequence categories shall be used as defined in (3.3.2), (3.3.3) and (3.3.4) as per ASCE 7 Risk Categorization.

Table 1 Hazard Consequence Categories for structures/sytems/components

Normal Consequence (ASCE Category I & II)	Medium Consequence (ASCE Category III)	High Consequence (ASCE Category IV)
Other piping and supports Plants containing toxic materials (Category D services under Appendix J of DEP 31.38.01.11-Gen.) (3.3.1, Item 3) Service buildings (warehouse) Waste water treatment facility Construction camps Material offloading facilities (MOF) Temporary facilities	Pressurised storage including but not limited to LPG, ethylene. Generally all pressurized and hazardous storage Plants containing toxic materials (Category N services under Appendix J of DEP 31.38.01.11-Gen.) (3.3.1, Item 3) Process facilities except as included under high consequence Utility systems Substation Buildings Power generation systems including buildings Water intake facilities Jetties and marine structures supporting pipelines and equipment handling low consequence products Cooling water system Controlled discharge facilities Effluent treatment facility All flammable gas or LNG process piping and supports Flare and related facilities (including burners, piping, knock out drums) Administration buildings, workshop, security building Any structure whose failure can impact a medium consequence structure (3.3.1, Item 4)	LNG storage tanks and foundations including impounding systems, piping up to first isolation valves. System components required to isolate the LNG tank system and maintain it in a safe shutdown condition. Atmospheric refrigerated storage including but not limited to LPG, ethylene, ethane, liquid Oxygen and liquid Nitrogen tanks Plants containing toxic materials (Category M & Category K services under Appendix J of DEP 31.38.01.11-Gen.) (3.3.1, Item 3) Jetties and marine structures supporting pipelines and equipment with inventories including but not limited LNG, LPG, ethane and ethylene and associated emergency shutdown, safety and fire fighting systems. Fire protection, emergency power and Leak detection systems. Shutdown system (including control valves, Instrumentation, relief systems) Control rooms and FARs Any structure whose failure can impact a high consequence structure (3.3.1, Item 4)

3. The consequence of failure of toxic plants shall be determined individually, based on HSSE Assessment.
4. Projects shall review target performance levels for structures/systems/components based on how critical that structure/system/component is to:
 - a. the facility achieving the required availability
 - b. support the safe shutdown of the facility i.e. firefighting systems.
5. In all cases where the performance of a lower category structure will affect a higher category structure, the design requirements for the higher category SHALL [PS] apply to the lower category structure (e.g., fire water lines mounted on pipe racks).

Certain components of a facility might be required for safe operation or shutdown of a higher consequence structure even though these individual structures/systems/components may fall under lower consequence category.

3.3.2 High consequence structures (Equivalent ASCE 7 Category IV)

Failure of these structures/systems/components designated as essential facilities as per ASCE 7, would result in a substantial hazard to the community. This also includes structures/systems/components that are required to be operational post event and maintain the functionality of other high consequence structure.

The failure of these structures/systems/components can lead to consequences equivalent to RAM 5 PAER.

3.3.3 Medium consequence structures (Equivalent ASCE 7 Category III)

Structures/systems/components that are not included under high consequence structures as defined above. Failure of these structures/systems/components would result in substantial risk to human life and has a potential to cause significant economic impact.

This also includes structures/systems/components that are required to maintain the functionality of other medium consequence structures.

The failure of these structures/systems/components can lead to consequences equivalent to RAM 3 / 4 PAER.

3.3.4 Normal consequence structures (Equivalent ASCE 7 Category I & II)

Includes structures/systems/components not assigned to either the medium or high consequence categories. Failure of these structures/systems/components pose low risk to human life.

The failure of these structures/systems/components can lead to consequences equivalent to RAM 2 PAER or below.

3.4 SEISMIC DESIGN MOTIONS

3.4.1 General

This section defines the seismic ground motions to be considered for design of various facilities and structures as covered by this DEP.

1. The OBE and SSE ground motions shall be:
 - a. determined by site-specific evaluations;
 - b. defined in terms of 5 percent damped response spectra.

3.4.2 Operating basis earthquake (OBE)

The OBE is a rare event that the site may be subjected to during its design life. OBE ground motions at the site are defined as ground motion with a 10 % probability of exceedance within a 50 year period (mean 475 year return period).

1. Site specific OBE spectral accelerations at any period used for design shall not be taken less than 80 % of the 475 year return period motion, considering appropriate site effects, as per ASCE 7 Tables 11.4.1 and 11.4.2.
 - a. Applicable requirements for OBE spectral accelerations under local standards shall be checked.

3.4.3 Safe shutdown earthquake (SSE)

The SSE is a very rare earthquake of extreme magnitude for the facility location. SSE ground motion at site is defined as the maximum of:

- 2 % probability of exceedance within a 50 year period (mean 2475 year return period);
 - Where local regulations require using higher return period greater 2475 year return period;
1. Site specific SSE spectral accelerations at any period used for design shall not be taken less than 80 % of the ASCE 7 MCE response spectra adjusted for site effects, as per ASCE 7, Section 11.4.5.
 - a. Applicable requirements for SSE spectral accelerations under local standards shall be checked.
 2. For projects in the US, risk targeted MCE (MCE_R) shall be used as per ASCE 7.

3.5 PERFORMANCE CRITERIA

3.5.1 General

1. For the design of High, Medium and Normal consequence structures/systems/components, the requirements provided under (3.5.3), (3.5.4) and (3.5.5) shall be followed.
2. The requirements of ASCE 7 shall be followed as a minimum for design of all the structures/systems/components except for LNG facilities,
3. For LNG facilities the minimum performance requirements of NFPA 59A shall be met.

In this respect, NFPA 59A explicitly defines the performance of the tanks, process structures, buildings and piping with respect to ASCE 7 and ASME B31.3.
4. Where local code requirements take precedence, minimum performance criteria as per this DEP shall be met.
5. Foundations shall be designed as per DEP 34.11.00.12-Gen. and recommendations provided in the project specific geotechnical report.
6. Allowable drifts shall be as per Table 12.12.1, ASCE 7 or as per local codes, whichever is more stringent.

3.5.2 Performance levels

1. Design of High, Medium and Normal consequence structures/systems/components, shall be based on the appropriate target performance levels as Table 2.

Table 2 provides definition for target performance levels for structure post-seismic event, as per FEMA 356.