Chapter 6
Direct Physical Damage - Essential and High Potential Loss Facilities

6.1 Introduction

This chapter describes methods for determining the probability of Slight, Moderate, Extensive and Complete damage to essential facilities. These methods are identical to those of Chapter 5 that describe damage to "Code" buildings, except that certain essential facilities are represented by "Special" building damage functions. Special building damage functions are appropriate for evaluation of essential facilities when the user anticipates above-Code seismic performance for these facilities. The flowchart of the methodology highlighting the essential and high potential loss facility damage components and showing its relationship to other components is shown in Flowchart 6.1.

This chapter also provides guidance for high potential loss (HPL) facilities. The methodology highlighting the Direct Physical Damage is shown in Flowchart 6.1.

6.1.1 Scope

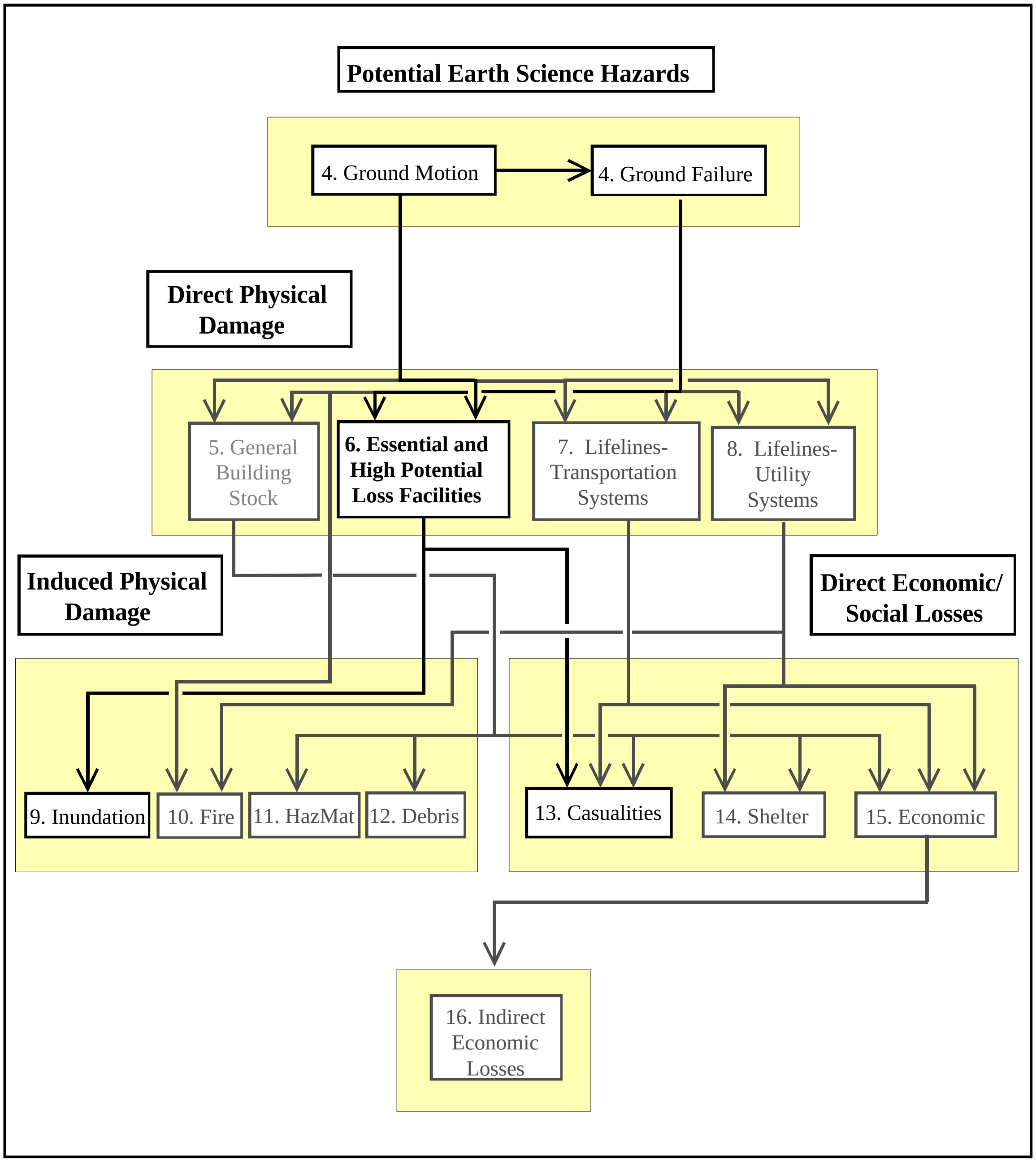
The scope of this chapter includes: (1) classification of essential facilities, (2) building damage functions for Special buildings, (3) methods for estimation of earthquake damage to essential facilities, given knowledge of the model building type and seismic design level, and an estimate of earthquake demand, and (3) guidance for expert users, including estimation of damage to high potential loss (HPL) facilities.

Special buildings and their damage functions are described in Sections 6.2 through 6.5. Evaluation of damage to essential facilities is given in Section 6.6 and guidance for expert users is given in Section 6.7. Typically, sections of Chapter 6 reference (rather than repeat) material of the corresponding section of Chapter 5.

6.1.2 Essential Facility Classification

Facilities that provide services to the community and those that should be functional following an earthquake are considered to be essential facilities. Examples of essential facilities include hospitals, police stations, fire stations, emergency operations centers (EOC's) and schools. The methodology adopted for damage assessment of such facilities is explained in this section.

Essential facilities are classified on the basis of facility function and, in the case of hospitals, size. Table 6.1 lists the classes of essential facilities used in the Methodology. Hospitals are classified on the basis of number of beds, since the structural and nonstructural systems of a hospital are related to the size of the hospital (i.e., to the number of beds it contains).



Flowchart 6.1: Essential and High Potential Loss Facility Component Relationship to other Components in the Methodology

Table 6.1 Classification of Essential Facilities

No.	Label	Occupancy Class	Description
		Medical Care Facilities	
1	EFHS	Small Hospital	Hospital with less than 50 Beds
2	EFHM	Medium Hospital	Hospital with beds between 50 & 150
3	EFHL	Large Hospital	Hospital with greater than 150 Beds
4	EFMC	Medical Clinics	Clinics, Labs, Blood Banks
		Emergency Response	
5	EFFS	Fire Station	
6	EFPS	Police Station	
7	EFEO	Emergency Operation Centers	
		Schools	
8	EFS1	Schools	Primary/ Secondary Schools (K-12)
9	EFS2	Colleges/Universities	Community and State Colleges, State and Private Universities

It is the responsibility of the user to identify each essential facility as either a Code building or a Special building of a particular model building type and seismic design level. This chapter provides building damage functions for Special buildings that have significantly better than average seismic capacity. Chapter 5 provides building damage functions for Code-buildings. If the user is not able to determine that the essential facility is significantly better than average, then the facility should be modeled using Code building damage functions (i.e., the same methods as those developed in Chapter 5 for general building stock).

6.1.3 Input Requirements and Output Information

Input required to estimate essential facility damage using fragility and capacity curves includes the following two items:

- model building type (including height) and seismic design level that represents the essential facility (or type of essential facilities) of interest, and

- response spectrum (or PGA, for lifeline buildings, and PGD for ground failure evaluation) at the essential facility's site.

The response spectrum, PGA and PGD at the essential facility site are PESH outputs, described in Chapter 4.

The "output" of fragility curves is an estimate of the cumulative probability of being in or exceeding, each damage state for the given level of ground shaking (or ground failure). Cumulative damage probabilities are differenced to create discrete damage state probabilities, as described in Chapter 5 (Section 5.6). Discrete probabilities of damage are used directly as inputs to induced physical damage and direct economic and social loss modules, as shown in Flowchart 6.1.

Typically, the model building type (including height) is not known for each essential facility and must be inferred from the inventory of essential facilities using the occupancy/building type relationships described in Chapter 3. In general, performance of essential facilities is not expected to be better than the typical building of the representative model building type. Exceptions to this generalization include California hospitals of recent (post-1973) construction.

6.1.4 Form of Damage Functions

Building damage functions for essential facilities are of the same form as those described in Chapter 5 for general building stock. For each damage state, a lognormal fragility curve relates the probability of damage to PGA, PGD or spectral demand determined by the intersection of the model building type's capacity curve and the demand spectrum. Figure 6.1 provides an example of fragility curves for four damage states: Slight, Moderate, Extensive and Complete.

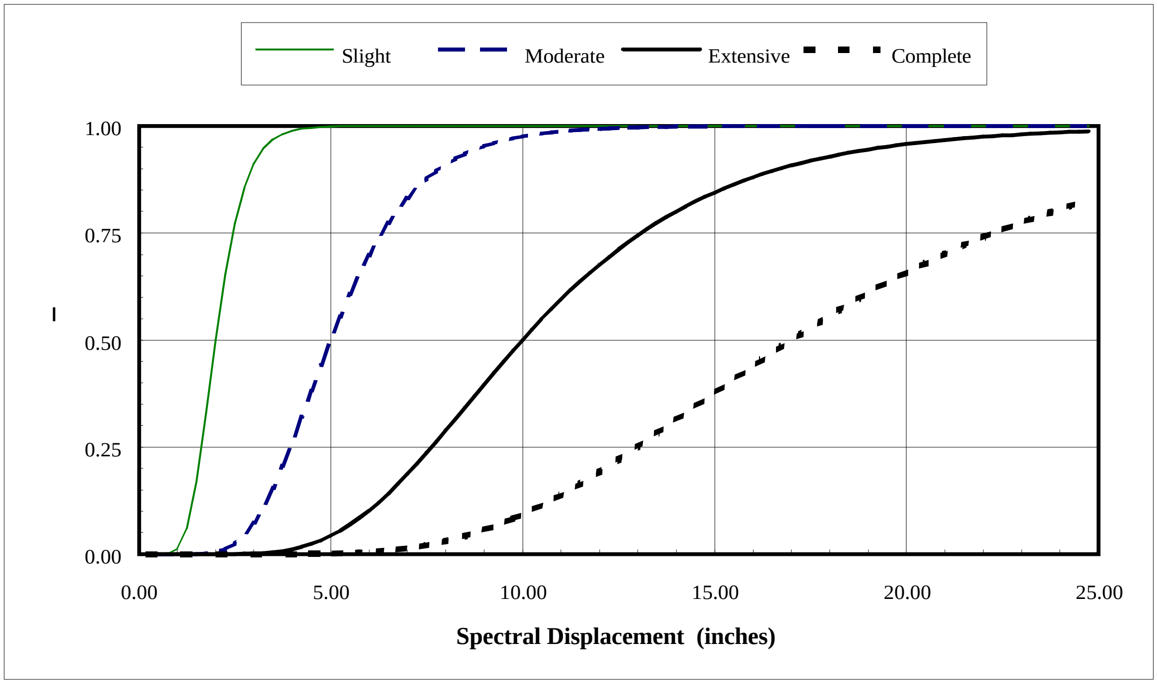


Figure 6.1 Example Fragility Curves for Slight, Moderate, Extensive and Complete Damage.

The fragility curves are driven by a PESH parameter. For ground failure, the PESH parameter used to drive fragility curves is permanent ground displacement (PGD). For ground shaking, the PESH parameter used to drive building fragility curves is peak spectral response (either displacement or acceleration), or peak ground acceleration (PGA) for essential lifeline facilities. Peak spectral response varies significantly for buildings that have different response properties and, therefore, requires knowledge of these properties.

Building response is characterized by building capacity curves. These curves describe the push-over displacement of each building type and seismic design level as a function of laterally-applied earthquake load. Design-, yield- and ultimate-capacity points define the shape of each building capacity curve. The Methodology estimates peak building response as the intersection of the building capacity curve and the demand spectrum at the building's location.

The demand spectrum is the 5%-damped PESH input spectrum reduced for higher levels of effective damping (e.g., effective damping includes both elastic damping and hysteretic damping associated with post-yield cyclic response of the building). Figure 6.2 illustrates the intersection of a typical building capacity curve and a typical demand spectrum (reduced for effective damping greater than 5% of critical).

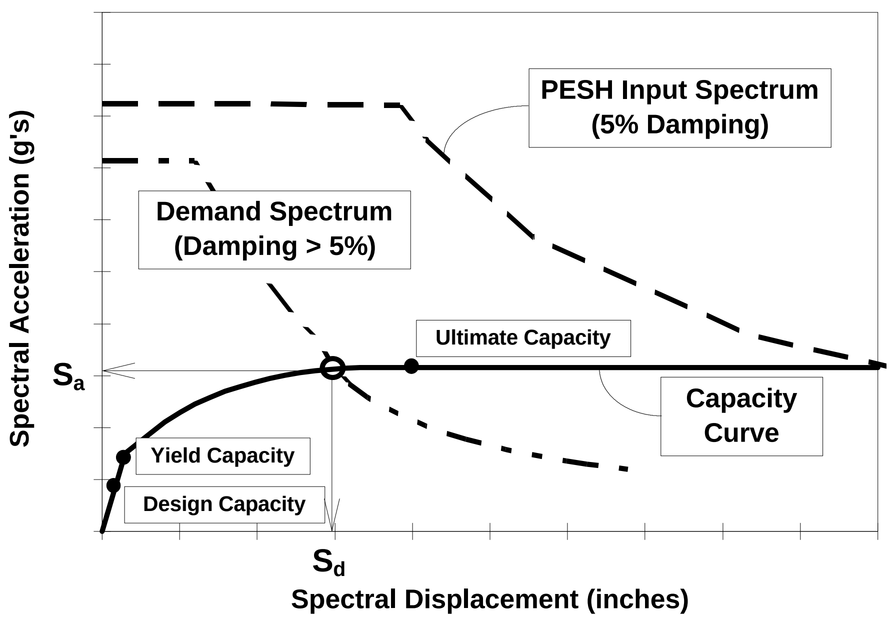


Figure 6.2 Example Building Capacity Curve and Demand Spectrum.

6.2 Description of Model Building Types

The model building types used for essential facilities are identical to those used for general building stock. These building types are described in Section 5.2 and listed in

Table 5.1. Typical nonstructural components of essential facilities include those architectural, mechanical and electrical, and contents listed in Table 5.2 for general building stock.

Essential facilities also include certain special equipment, such as emergency generators, and certain special contents, such as those used to operate a hospital. Special equipment and contents of essential facilities are considered to be acceleration-sensitive nonstructural components of these facilities.

6.3 Description of Building Damage States

Building damage states for structural and nonstructural components of essential facilities are the same as those described in Section 5.3 for general building stock.

6.4 Building Damage Due to Ground Shaking - Special Buildings

6.4.1 Overview

This section describes capacity and fragility curves used in the Methodology to estimate the probability of Slight, Moderate, Extensive and Complete damage to Special buildings of a given model building type designed to High-, Moderate-, or Low-Code seismic standards. Special building damage functions are appropriate for evaluation of essential facilities when the user anticipates above-Code seismic performance for these facilities.

Capacity curves and fragility curves for Special buildings of High-Code, Moderate-Code, or Low-Code seismic design are based on modern code (e.g., 1976 *Uniform Building Code*, 1996 *NEHRP Provisions*, or later editions of these model codes) design criteria for various seismic design zones, as shown in Table 6.2. Additional description of seismic design levels may be found in Section 6.7.

Table 6.2 Approximate Basis for Seismic Design Levels

Seismic Design Level (I = 1.5)	Seismic Zone (1994 *Uniform Building Code*)	Map Area (1994 *NEHRP Provisions*)
High-Code	4	7
Moderate-Code	2B	5
Low-Code	1	3

The capacity and fragility curves represent buildings designed and constructed to modern seismic code provisions (e.g.,1994 *UBC*) using an importance factor of I = 1.5. Moderate-Code and Low-Code seismic design levels are included for completeness. Most essential facilities located in Seismic Zones O, T, 2A or 2B have not been designed for Special building code criteria.

6.4.2 Capacity Curves - Special Buildings

The building capacity curves for Special buildings are similar to those for the general building stock (Chapter 5), but with increased strength. Each curve is described by three control points that define model building capacity:

- Design Capacity
- Yield Capacity
- Ultimate Capacity

Design capacity represents the nominal building strength required by current model seismic code provisions (e.g., 1994 *UBC*) including an importance factor of $I = 1.5$. Wind design is not considered in the estimation of design capacity and certain buildings (e.g., taller buildings located in zones of low or moderate seismicity) may have a lateral design strength considerably greater than based on seismic code provisions.

Yield capacity represents the true lateral strength of the building considering redundancies in design, conservatism in code requirements and true (rather than nominal) strength of materials. Ultimate capacity represents the maximum strength of the building when the global structural system has reached a fully plastic state. An example building capacity curve is shown in Figure 6-3.

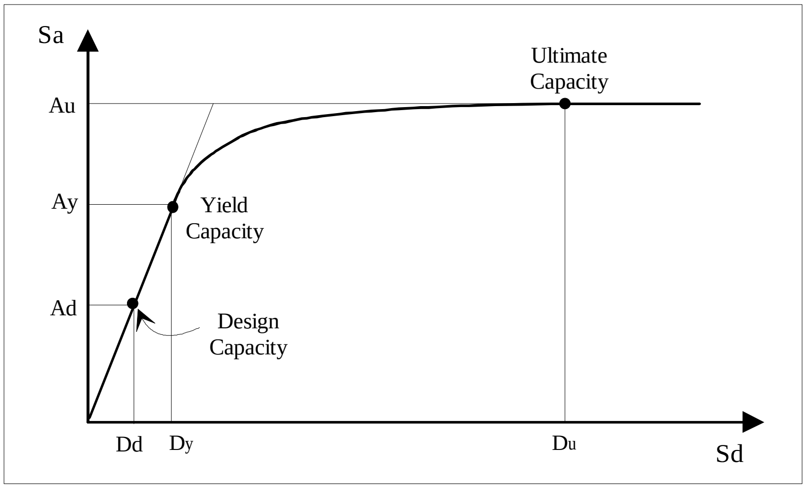


Figure 6.3 Example Building Capacity Curve.

The building capacity curves for Special buildings are constructed based on the same engineering properties (i.e., C_s, T_e, α_1, α_2, γ, λ, μ) as those used to describe capacity curves of Code buildings (i.e., Tables 5.4, 5.5 and 5.6), except for design strength, C_s, and ductility (μ). The design strength, C_s, is approximately based on the lateral-force design requirements of current seismic codes (e.g., 1994 *NEHRP* or 1994 *UBC*) using an importance factor of I = 1.5. Values of the "ductility" factor, μ, for Special buildings are based on Code-building ductility increased by 1.33 for Moderate-Code buildings and by 1.2 for Low-Code buildings. The ductility parameter defines the displacement value of capacity curve at the point where the curve reaches a fully plastic state.

Building capacity curves are assumed to have a range of possible properties that are lognormally distributed as a function of the ultimate strength (A_u) of each capacity curve. Special building capacity curves represent median estimates of building capacity. The variability of the capacity of each building type is assumed to be: $\beta(A_u) = 0.15$ for Special buildings. An example construction of median, 84th percentile (+1β) and 16th percentile (−1β) building capacity curves for a typical building is illustrated in Figure 6.4. Median capacity curves are intersected with demand spectra to estimate peak building response. The variability of the capacity curves is used, with other sources of variability and uncertainty, to define total fragility curve variability.

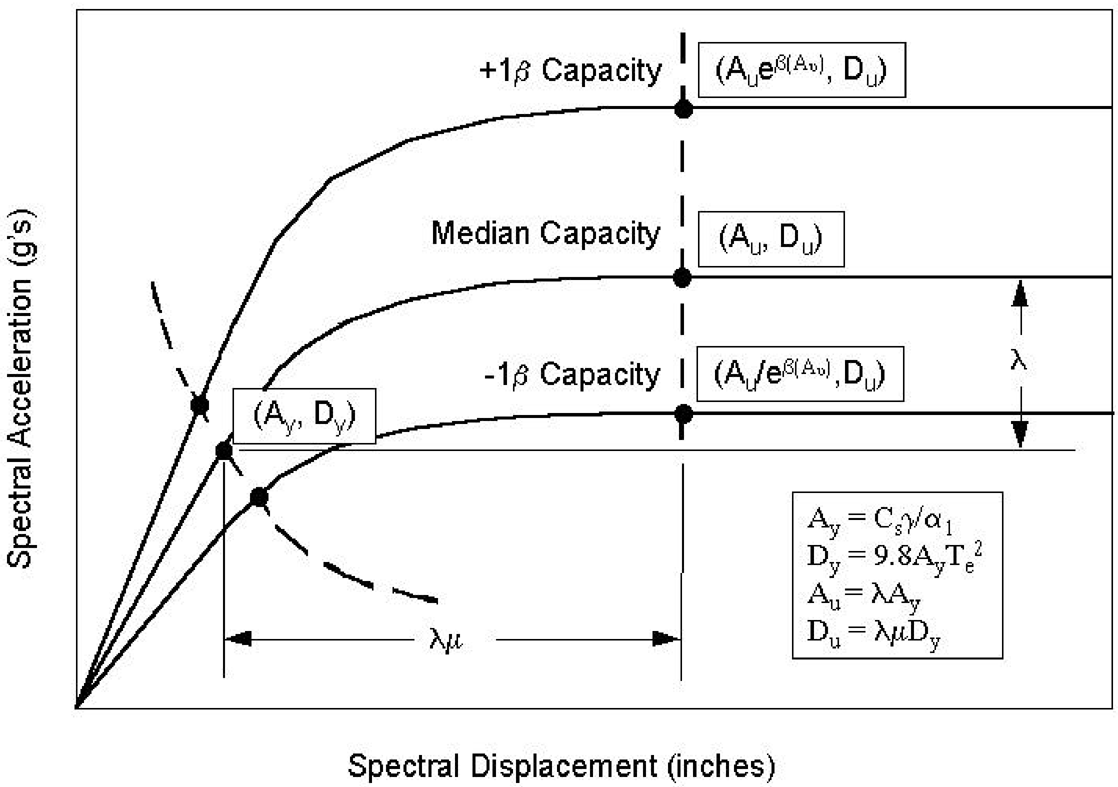


Figure 6.4 Example Construction of Median, +1β and -1β Building Capacity Curves.

Tables 6.3a, 6.3b and 6.3c summarize yield capacity and ultimate capacity control points for Special buildings of High-Code, Moderate-Code and Low-Code seismic design levels, respectively. Note that for the following tables, shaded boxes indicate types that are not permitted by current seismic codes.

Table 6.3a Special Building Capacity Curves - High-Code Seismic Design Level

Building Type	Yield Capacity Point		Ultimate Capacity Point	
	D_y (in.)	A_y (g)	D_u (in.)	A_u (g)
W1	0.72	0.600	17.27	1.800
W2	0.94	0.600	18.79	1.500
S1L	0.92	0.375	22.00	1.124
S1M	2.66	0.234	42.60	0.702
S1H	6.99	0.147	83.83	0.440
S2L	0.94	0.600	15.03	1.200
S2M	3.64	0.500	38.82	1.000
S2H	11.62	0.381	92.95	0.762
S3	0.94	0.600	15.03	1.200
S4L	0.58	0.480	10.36	1.080
S4M	1.64	0.400	19.65	0.900
S4H	5.23	0.305	47.05	0.685
S5L				
S5M				
S5H				
C1L	0.59	0.375	14.08	1.124
C1M	1.73	0.312	27.65	0.937
C1H	3.02	0.147	36.20	0.440
C2L	0.72	0.600	14.39	1.500
C2M	1.56	0.500	20.76	1.250
C2H	4.41	0.381	44.09	0.952
C3L				
C3M				
C3H				
PC1	1.08	0.900	17.27	1.800
PC2L	0.72	0.600	11.51	1.200
PC2M	1.56	0.500	16.61	1.000
PC2H	4.41	0.381	35.27	0.762
RM1L	0.96	0.800	15.34	1.600
RM1M	2.08	0.667	22.14	1.333
RM2L	0.96	0.800	15.34	1.600
RM2M	2.08	0.667	22.14	1.333
RM2H	5.88	0.508	47.02	1.015
URML				
URMM				
MH	0.27	0.225	4.32	0.450

Table 6.3b Special Building Capacity Curves - Moderate-Code Seismic Design Level

Building Type	Yield Capacity Point		Ultimate Capacity Point	
	D_y (in.)	A_y (g)	D_u (in.)	A_u (g)
W1	0.54	0.450	12.95	1.350
W2	0.47	0.300	9.40	0.750
S1L	0.46	0.187	11.00	0.562
S1M	1.33	0.117	21.30	0.351
S1H	3.49	0.073	41.91	0.220
S2L	0.47	0.300	7.52	0.600
S2M	1.82	0.250	19.41	0.500
S2H	5.81	0.190	46.47	0.381
S3	0.47	0.300	7.52	0.600
S4L	0.29	0.240	5.18	0.540
S4M	0.82	0.200	9.83	0.450
S4H	2.61	0.152	23.53	0.343
S5L				
S5M				
S5H				
C1L	0.29	0.187	7.04	0.562
C1M	0.86	0.156	13.83	0.468
C1H	1.51	0.073	18.10	0.220
C2L	0.36	0.300	7.19	0.750
C2M	0.78	0.250	10.38	0.625
C2H	2.21	0.190	22.05	0.476
C3L				
C3M				
C3H				
PC1	0.54	0.450	8.63	0.900
PC2L	0.36	0.300	5.76	0.600
PC2M	0.78	0.250	8.31	0.500
PC2H	2.21	0.190	17.64	0.381
RM1L	0.48	0.400	7.67	0.800
RM1M	1.04	0.333	11.07	0.667
RM2L	0.48	0.400	7.67	0.800
RM2M	1.04	0.333	11.07	0.667
RM2H	2.94	0.254	23.51	0.508
URML				
URMM				
MH	0.27	0.225	4.32	0.450

Table 6.3c Special Building Capacity Curves - Low-Code Seismic Design Level

Building Type	Yield Capacity Point		Ultimate Capacity Point	
	D_y (in.)	A_y (g)	D_u (in.)	A_u (g)
W1	0.36	0.300	6.48	0.900
W2	0.24	0.150	3.52	0.375
S1L	0.23	0.094	4.13	0.281
S1M	0.67	0.059	7.99	0.176
S1H	1.75	0.037	15.72	0.110
S2L	0.24	0.150	2.82	0.300
S2M	0.91	0.125	7.28	0.250
S2H	2.91	0.095	17.43	0.190
S3	0.24	0.150	2.82	0.300
S4L	0.14	0.120	1.94	0.270
S4M	0.41	0.100	3.69	0.225
S4H	1.31	0.076	8.82	0.171
S5L	0.18	0.150	2.16	0.300
S5M	0.51	0.125	4.09	0.250
S5H	1.63	0.095	9.80	0.190
C1L	0.15	0.094	2.64	0.281
C1M	0.43	0.078	5.19	0.234
C1H	0.75	0.037	6.79	0.110
C2L	0.18	0.150	2.70	0.375
C2M	0.39	0.125	3.89	0.313
C2H	1.10	0.095	8.27	0.238
C3L	0.18	0.150	2.43	0.338
C3M	0.39	0.125	3.50	0.281
C3H	1.10	0.095	7.44	0.214
PC1	0.27	0.225	3.24	0.450
PC2L	0.18	0.150	2.16	0.300
PC2M	0.39	0.125	3.11	0.250
PC2H	1.10	0.095	6.61	0.190
RM1L	0.24	0.200	2.88	0.400
RM1M	0.52	0.167	4.15	0.333
RM2L	0.24	0.200	2.88	0.400
RM2M	0.52	0.167	4.15	0.333
RM2H	1.47	0.127	8.82	0.254
URML	0.36	0.300	4.32	0.600
URMM	0.41	0.167	3.26	0.333
MH	0.27	0.225	4.32	0.450

6.4.3 Fragility Curves - Special Buildings

This section describes Special building fragility curves for Slight, Moderate, Extensive and Complete structural damage states and Slight, Moderate, Extensive and Complete nonstructural damage states. Each fragility curve is characterized by a median and a lognormal standard deviation (β) value of PESH demand. Spectral displacement is the PESH parameter used for structural damage and nonstructural damage to drift-sensitive components. Spectral acceleration is the PESH parameter used for nonstructural damage to acceleration-sensitive components.

Special building fragility curves for ground failure are the same as those of Code buildings (Section 5.5).

6.4.3.1 Background

The form of the fragility curves for Special buildings is the same as that used for Code buildings. The probability of being in, or exceeding, a given damage state is modeled as a cumulative lognormal distribution. Given the appropriate PESH parameter (e.g., spectral displacement, S_d, for structural damage), the probability of being in or exceeding a damage state, ds, is modeled as follows:

$$P\left[ds \middle| S_d\right] = \Phi\left[\frac{1}{\beta_{ds}} \ln\left(\frac{S_d}{\overline{S}_{d,ds}}\right)\right] \qquad (6\text{-}1)$$

where: $\overline{S}_{d,ds}$ is the median value of spectral displacement at which the building reaches the threshold of the damage state, ds,

β_{ds} is the standard deviation of the natural logarithm of spectral displacement of damage state, ds, and

Φ is the standard normal cumulative distribution function.

6.4.3.2 Structural Damage - Special Buildings

Structural damage states for Special buildings are based on drift ratios that are assumed to be slightly higher than those of Code buildings of the same model building type and seismic design level. It is difficult to quantify this improvement in displacement capacity since it is a function not just of building type and design parameters, but also design review and construction inspection. It is assumed that the improvement in displacement capacity results in a 1.25 increase in drift capacity of each damage state for all Special building types and seismic design levels. Special buildings perform better than Code buildings due to increased structure strength (of the capacity curves) and increased displacement capacity (of the fragility curves). In general, increased strength tends to most improve building performance near yield and improved displacement capacity tends to most improve the ultimate capacity of the building.

Median values of Special building structural fragility are based on drift ratios (that describe the threshold of damage states and the height of the building to point of push-over mode displacement using the same approach as that of Code buildings (Section 5.4.3.2).

The variability of Special building structural damage is based on the same approach as that of Code buildings (Section 5.4.3.3). The total variability of each structural damage state, β_{Sds}, is modeled by the combination of following three contributors to damage variability:

- uncertainty in the damage state threshold of the structural system ($\beta_{M(Sds)}$ = 0.4, for all structural damage states and building types)

- variability in capacity (response) properties of the model building type/seismic design level of interest ($\beta_{C(Au)}$ = 0.15 for Special buildings), and

- variability in response due to the spatial variability of ground motion demand ($\beta_{D(A)}$ = 0.45 and $\beta_{C(V)}$ = 0.50).is based on the dispersion factor typical of the attenuation of large-magnitude earthquakes as in the WUS (Chapter 4).

Each of these three contributors to damage state variability are assumed to be lognormally distributed random variables. Capacity and demand are dependent parameters and a convolution process is used to derive combined capacity/demand variability of each structural damage state. Capacity/demand variability is then combined with damage state uncertainty, as described in Section 5.4.3.3.

Tables 6.4a, 6.4b and 6.4c summarize median and lognormal standard deviation (β_{Sds}) values for Slight, Moderate, Extensive and Complete structural damage states of Special buildings for High-Code, Moderate-Code and Low-Code seismic design levels, respectively. Note that for the following tables, shaded boxes indicate types that are not permitted by current seismic codes.

Table 6.4a Building Structural Fragility - High-Code Seismic Design Level

Building Properties			Interstory Drift at Threshold of Damage State				Spectral Displacement (inches)							
Type	Height (inches)						Slight		Moderate		Extensive		Complete	
	Roof	Modal	Slight	Moderate	Extensive	Complete	Median	Beta	Median	Beta	Median	Beta	Median	Beta
W1	168	126	0.0050	0.0150	0.0500	0.1250	0.63	0.66	1.89	0.72	6.30	0.72	15.75	0.91
W2	288	216	0.0050	0.0150	0.0500	0.1250	1.08	0.69	3.24	0.77	10.80	0.89	27.00	0.85
S1L	288	216	0.0075	0.0150	0.0375	0.1000	1.62	0.67	3.24	0.70	8.10	0.71	21.60	0.68
S1M	720	540	0.0050	0.0100	0.0250	0.0667	2.70	0.62	5.40	0.62	13.50	0.63	36.00	0.71
S1H	1872	1123	0.0037	0.0075	0.0188	0.0500	4.21	0.63	8.42	0.62	21.06	0.62	56.16	0.63
S2L	288	216	0.0063	0.0125	0.0375	0.1000	1.35	0.69	2.70	0.80	8.10	0.89	21.60	0.84
S2M	720	540	0.0042	0.0083	0.0250	0.0667	2.25	0.62	4.50	0.66	13.50	0.66	36.00	0.71
S2H	1872	1123	0.0031	0.0063	0.0188	0.0500	3.51	0.62	7.02	0.63	21.06	0.63	56.16	0.66
S3	180	135	0.0050	0.0100	0.0300	0.0875	0.68	0.66	1.35	0.71	4.05	0.80	11.81	0.90
S4L	288	216	0.0050	0.0100	0.0300	0.0875	1.08	0.77	2.16	0.82	6.48	0.92	18.90	0.91
S4M	720	540	0.0033	0.0067	0.0200	0.0583	1.80	0.69	3.60	0.67	10.80	0.68	31.50	0.82
S4H	1872	1123	0.0025	0.0050	0.0150	0.0438	2.81	0.62	5.62	0.63	16.85	0.65	49.14	0.73
S5L														
S5M														
S5H														
C1L	240	180	0.0063	0.0125	0.0375	0.1000	1.13	0.69	2.25	0.74	6.75	0.82	18.00	0.81
C1M	600	450	0.0042	0.0083	0.0250	0.0667	1.87	0.63	3.75	0.65	11.25	0.66	30.00	0.71
C1H	1440	864	0.0031	0.0063	0.0188	0.0500	2.70	0.63	5.40	0.63	16.20	0.63	43.20	0.69
C2L	240	180	0.0050	0.0125	0.0375	0.1000	0.90	0.69	2.25	0.72	6.75	0.82	18.00	0.95
C2M	600	450	0.0033	0.0083	0.0250	0.0667	1.50	0.65	3.75	0.69	11.25	0.66	30.00	0.70
C2H	1440	864	0.0025	0.0063	0.0188	0.0500	2.16	0.62	5.40	0.63	16.20	0.64	43.20	0.69
C3L														
C3M														
C3H														
PC1	180	135	0.0050	0.0100	0.0300	0.0875	0.68	0.63	1.35	0.74	4.05	0.79	11.81	0.96
PC2L	240	180	0.0050	0.0100	0.0300	0.0875	0.90	0.76	1.80	0.80	5.40	0.87	15.75	0.97
PC2M	600	450	0.0033	0.0067	0.0200	0.0583	1.50	0.66	3.00	0.73	9.00	0.72	26.25	0.73
PC2H	1440	864	0.0025	0.0050	0.0150	0.0438	2.16	0.62	4.32	0.64	12.96	0.65	37.80	0.74
RM1L	240	180	0.0050	0.0100	0.0300	0.0875	0.90	0.70	1.80	0.74	5.40	0.76	15.75	0.98
RM1M	600	450	0.0033	0.0067	0.0200	0.0583	1.50	0.63	3.00	0.68	9.00	0.70	26.25	0.70
RM2L	240	180	0.0050	0.0100	0.0300	0.0875	0.90	0.66	1.80	0.70	5.40	0.76	15.75	0.97
RM2M	600	450	0.0033	0.0067	0.0200	0.0583	1.50	0.63	3.00	0.70	9.00	0.69	26.25	0.68
RM2H	1440	864	0.0025	0.0050	0.0150	0.0438	2.16	0.63	4.32	0.63	12.96	0.63	37.80	0.65
URML														
URMM														
MH	120	120	0.0050	0.0100	0.0300	0.0875	0.60	0.81	1.20	0.89	3.60	0.97	10.50	0.86

Table 6.4b Building Structural Fragility - Moderate-Code Seismic Design Level

Building Properties			Interstory Drift at Threshold of Damage State				Spectral Displacement (inches)							
Type	Height (inches)						Slight		Moderate		Extensive		Complete	
	Roof	Modal	Slight	Moderate	Extensive	Complete	Median	Beta	Median	Beta	Median	Beta	Median	Beta
W1	168	126	0.0050	0.0124	0.0383	0.0937	0.63	0.76	1.56	0.77	4.82	0.78	11.81	0.96
W2	288	216	0.0050	0.0124	0.0383	0.0938	1.08	0.79	2.68	0.86	8.27	0.88	20.25	0.84
S1L	288	216	0.0075	0.0130	0.0294	0.0750	1.62	0.73	2.80	0.71	6.35	0.70	16.20	0.77
S1M	720	540	0.0050	0.0086	0.0196	0.0500	2.70	0.64	4.67	0.65	10.58	0.66	27.00	0.75
S1H	1872	1123	0.0037	0.0065	0.0147	0.0375	4.21	0.62	7.29	0.62	16.51	0.66	42.12	0.70
S2L	288	216	0.0063	0.0108	0.0292	0.0750	1.35	0.82	2.34	0.85	6.30	0.89	16.20	0.85
S2M	720	540	0.0042	0.0072	0.0194	0.0500	2.25	0.66	3.90	0.66	10.50	0.68	27.00	0.81
S2H	1872	1123	0.0031	0.0054	0.0146	0.0375	3.51	0.62	6.08	0.63	16.38	0.65	42.12	0.71
S3	180	135	0.0050	0.0087	0.0234	0.0656	0.68	0.77	1.17	0.81	3.16	0.89	8.86	0.89
S4L	288	216	0.0050	0.0087	0.0234	0.0656	1.08	0.88	1.87	0.92	5.05	0.98	14.18	0.87
S4M	720	540	0.0033	0.0058	0.0156	0.0437	1.80	0.70	3.12	0.67	8.41	0.70	23.62	0.90
S4H	1872	1123	0.0025	0.0043	0.0117	0.0328	2.81	0.66	4.87	0.66	13.13	0.70	36.86	0.81
S5L														
S5M														
S5H														
C1L	240	180	0.0063	0.0108	0.0292	0.0750	1.13	0.80	1.95	0.82	5.25	0.84	13.50	0.81
C1M	600	450	0.0042	0.0072	0.0194	0.0500	1.87	0.66	3.25	0.67	8.75	0.66	22.50	0.84
C1H	1440	864	0.0031	0.0054	0.0146	0.0375	2.70	0.64	4.68	0.64	12.60	0.68	32.40	0.81
C2L	240	180	0.0050	0.0105	0.0289	0.0750	0.90	0.77	1.89	0.86	5.21	0.91	13.50	0.89
C2M	600	450	0.0033	0.0070	0.0193	0.0500	1.50	0.71	3.16	0.70	8.68	0.69	22.50	0.83
C2H	1440	864	0.0025	0.0053	0.0145	0.0375	2.16	0.64	4.55	0.65	12.51	0.66	32.40	0.79
C3L														
C3M														
C3H														
PC1	180	135	0.0050	0.0087	0.0234	0.0656	0.68	0.79	1.17	0.81	3.16	0.86	8.86	1.00
PC2L	240	180	0.0050	0.0087	0.0234	0.0656	0.90	0.83	1.56	0.89	4.21	0.97	11.81	0.89
PC2M	600	450	0.0033	0.0058	0.0156	0.0438	1.50	0.76	2.60	0.74	7.01	0.73	19.69	0.88
PC2H	1440	864	0.0025	0.0043	0.0117	0.0328	2.16	0.65	3.75	0.66	10.10	0.70	28.35	0.81
RM1L	240	180	0.0050	0.0087	0.0234	0.0656	0.90	0.80	1.56	0.85	4.21	0.92	11.81	0.97
RM1M	600	450	0.0033	0.0058	0.0156	0.0438	1.50	0.73	2.60	0.75	7.01	0.75	19.69	0.80
RM2L	240	180	0.0050	0.0087	0.0234	0.0656	0.90	0.77	1.56	0.81	4.21	0.92	11.81	0.96
RM2M	600	450	0.0033	0.0058	0.0156	0.0438	1.50	0.72	2.60	0.72	7.01	0.72	19.69	0.77
RM2H	1440	864	0.0025	0.0043	0.0117	0.0328	2.16	0.63	3.75	0.65	10.10	0.66	28.35	0.76
URML														
URMM														
MH	120	120	0.0050	0.0100	0.0300	0.0875	0.60	0.81	1.20	0.89	3.60	0.97	10.50	0.86

Table 6.4c Special Building Structural Fragility - Low-Code Seismic Design Level

Building Properties			Interstory Drift at Threshold of Damage State				Spectral Displacement (inches)							
Type	Height (inches)						Slight		Moderate		Extensive		Complete	
	Roof	Modal	Slight	Moderate	Extensive	Complete	Median	Beta	Median	Beta	Median	Beta	Median	Beta
W1	168	126	0.0050	0.0124	0.0383	0.0937	0.63	0.80	1.56	0.81	4.82	0.88	11.81	1.01
W2	288	216	0.0050	0.0124	0.0383	0.0938	1.08	0.89	2.68	0.89	8.27	0.86	20.25	0.97
S1L	288	216	0.0075	0.0119	0.0253	0.0625	1.62	0.73	2.58	0.73	5.47	0.75	13.50	0.93
S1M	720	540	0.0050	0.0080	0.0169	0.0417	2.70	0.66	4.30	0.70	9.12	0.78	22.50	0.91
S1H	1872	1123	0.0037	0.0060	0.0127	0.0313	4.21	0.64	6.72	0.66	14.23	0.68	35.10	0.86
S2L	288	216	0.0063	0.0100	0.0250	0.0625	1.35	0.89	2.16	0.89	5.40	0.88	13.50	0.97
S2M	720	540	0.0042	0.0067	0.0167	0.0417	2.25	0.67	3.60	0.68	9.00	0.74	22.50	0.92
S2H	1872	1123	0.0031	0.0050	0.0125	0.0313	3.51	0.62	5.62	0.63	14.04	0.68	35.10	0.84
S3	180	135	0.0050	0.0080	0.0201	0.0547	0.68	0.89	1.08	0.90	2.71	0.98	7.38	0.85
S4L	288	216	0.0050	0.0080	0.0200	0.0547	1.08	0.98	1.73	0.95	4.33	0.97	11.81	0.98
S4M	720	540	0.0033	0.0053	0.0134	0.0364	1.80	0.69	2.88	0.72	7.22	0.81	19.68	0.98
S4H	1872	1123	0.0025	0.0040	0.0100	0.0273	2.81	0.66	4.50	0.67	11.26	0.78	30.71	0.93
S5L	288	216	0.0038	0.0075	0.0188	0.0438	0.81	1.00	1.62	1.00	4.05	1.03	9.45	0.91
S5M	720	540	0.0025	0.0050	0.0125	0.0292	1.35	0.74	2.70	0.72	6.75	0.78	15.75	0.94
S5H	1872	1123	0.0019	0.0037	0.0094	0.0219	2.11	0.67	4.21	0.69	10.53	0.74	24.57	0.90
C1L	240	180	0.0063	0.0100	0.0250	0.0625	1.13	0.85	1.80	0.85	4.50	0.88	11.25	0.95
C1M	600	450	0.0042	0.0067	0.0167	0.0417	1.87	0.70	3.00	0.69	7.50	0.75	18.75	0.95
C1H	1440	864	0.0031	0.0050	0.0125	0.0313	2.70	0.66	4.32	0.71	10.80	0.79	27.00	0.95
C2L	240	180	0.0050	0.0096	0.0247	0.0625	0.90	0.91	1.72	0.94	4.44	1.01	11.25	0.90
C2M	600	450	0.0033	0.0064	0.0164	0.0417	1.50	0.76	2.86	0.74	7.40	0.74	18.75	0.94
C2H	1440	864	0.0025	0.0048	0.0123	0.0313	2.16	0.66	4.12	0.67	10.66	0.74	27.00	0.91
C3L	240	180	0.0038	0.0075	0.0188	0.0438	0.68	0.92	1.35	0.99	3.38	1.04	7.88	0.88
C3M	600	450	0.0025	0.0050	0.0125	0.0292	1.12	0.77	2.25	0.79	5.62	0.78	13.12	0.93
C3H	1440	864	0.0019	0.0038	0.0094	0.0219	1.62	0.68	3.24	0.69	8.10	0.70	18.90	0.88
PC1	180	135	0.0050	0.0080	0.0201	0.0547	0.68	0.89	1.08	0.95	2.71	1.00	7.38	0.96
PC2L	240	180	0.0050	0.0080	0.0201	0.0547	0.90	0.98	1.44	0.98	3.61	1.02	9.84	0.91
PC2M	600	450	0.0033	0.0053	0.0134	0.0364	1.50	0.76	2.40	0.75	6.02	0.75	16.40	0.94
PC2H	1440	864	0.0025	0.0040	0.0100	0.0273	2.16	0.66	3.46	0.68	8.66	0.73	23.63	0.92
RM1L	240	180	0.0050	0.0080	0.0201	0.0547	0.90	0.97	1.44	1.01	3.61	1.07	9.84	0.88
RM1M	600	450	0.0033	0.0053	0.0134	0.0364	1.50	0.78	2.40	0.78	6.02	0.78	16.40	0.94
RM2L	240	180	0.0050	0.0080	0.0201	0.0547	0.90	0.94	1.44	0.98	3.61	1.05	9.84	0.89
RM2M	600	450	0.0033	0.0053	0.0134	0.0364	1.50	0.76	2.40	0.75	6.02	0.75	16.40	0.92
RM2H	1440	864	0.0025	0.0040	0.0100	0.0273	2.16	0.66	3.46	0.67	8.66	0.80	23.63	0.89
URML	180	135	0.0038	0.0075	0.0187	0.0438	0.51	0.89	1.01	0.91	2.53	0.96	5.91	1.09
URMM	420	315	0.0025	0.0050	0.0125	0.0292	0.79	0.81	1.57	0.84	3.94	0.87	9.19	0.82
MH	120	120	0.0050	0.0100	0.0300	0.0875	0.60	0.81	1.20	0.89	3.60	0.97	10.50	0.86

6.4.3.3 Nonstructural Damage - Drift-Sensitive

Damage states of nonstructural drift-sensitive components of Special buildings are based on the same drift ratios as those of Code buildings (Table 5.10). Even for essential facilities, nonstructural components are typically not designed or detailed for special earthquake displacements. Improvement in the performance of drift-sensitive components of Special buildings is assumed to be entirely a function of drift reduction due to the increased stiffness and strength of the structures of these buildings.

Median values of drift-sensitive nonstructural fragility curves are based on global building displacement (in inches), calculated as the product of: (1) drift ratio, (2) building height and (3) the fraction of building height at the location of push-over mode displacement (α_2).

The total variability of each nonstructural drift-sensitive damage state, β_{NSDds}, is modeled by the combination of following three contributors to damage variability:

- uncertainty in the damage state threshold of nonstructural components ($\beta_{M(NSDds)}$ = 0.5, for all structural damage states and building types,
- variability in capacity (response) properties of the model building type that contains the nonstructural components of interest ($\beta_{C(Au)}$ = 0.15 for Special buildings, and

- variability in response of the model building type due to the spatial variability of ground motion demand ($\beta_{D(A)}$ = 0.45 and $\beta_{C(V)}$ = 0.50).

Each of these three contributors to damage state variability are assumed to be lognormally distributed random variables. Capacity and demand are dependent parameters and a convolution process is used to derive combined capacity/demand variability of each nonstructural damage state. Capacity/demand variability is then combined with damage state uncertainty, as described in Section 5.4.3.3.

Tables 6.5a, 6.5b and 6.5c summarize median and lognormal standard deviation (β_{NSDds}) values for Slight, Moderate, Extensive and Complete damage states of nonstructural drift-sensitive components of Special buildings for High-Code, Moderate-Code and Low-Code seismic design levels, respectively. Note that for the following tables, shaded boxes indicate types that are not permitted by current seismic codes.

Table 6.5a Special Building Nonstructural Drift-Sensitive Fragility - High-Code Seismic Design Level

Building Type	Median Spectral Displacement (inches) and Logstandard Deviation (Beta)							
	Slight		Moderate		Extensive		Complete	
	Median	Beta	Median	Beta	Median	Beta	Median	Beta
W1	0.50	0.74	1.01	0.77	3.15	0.79	6.30	0.78
W2	0.86	0.76	1.73	0.77	5.40	0.88	10.80	0.93
S1L	0.86	0.72	1.73	0.76	5.40	0.75	10.80	0.74
S1M	2.16	0.68	4.32	0.68	13.50	0.70	27.00	0.73
S1H	4.49	0.70	8.99	0.69	28.08	0.69	56.16	0.70
S2L	0.86	0.74	1.73	0.77	5.40	0.90	10.80	0.95
S2M	2.16	0.70	4.32	0.72	13.50	0.73	27.00	0.72
S2H	4.49	0.71	8.99	0.69	28.08	0.70	56.16	0.73
S3	0.54	0.70	1.08	0.76	3.38	0.83	6.75	0.93
S4L	0.86	0.81	1.73	0.84	5.40	0.93	10.80	1.00
S4M	2.16	0.76	4.32	0.74	13.50	0.75	27.00	0.82
S4H	4.49	0.70	8.99	0.71	28.08	0.72	56.16	0.80
S5L								
S5M								
S5H								
C1L	0.72	0.77	1.44	0.76	4.50	0.84	9.00	0.88
C1M	1.80	0.71	3.60	0.71	11.25	0.72	22.50	0.71
C1H	3.46	0.70	6.91	0.69	21.60	0.71	43.20	0.75
C2L	0.72	0.76	1.44	0.76	4.50	0.80	9.00	0.94
C2M	1.80	0.74	3.60	0.76	11.25	0.73	22.50	0.74
C2H	3.46	0.69	6.91	0.69	21.60	0.71	43.20	0.75
C3L								
C3M								
C3H								
PC1	0.54	0.69	1.08	0.78	3.38	0.85	6.75	0.88
PC2L	0.72	0.80	1.44	0.83	4.50	0.90	9.00	1.03
PC2M	1.80	0.75	3.60	0.80	11.25	0.77	22.50	0.77
PC2H	3.46	0.70	6.91	0.71	21.60	0.73	43.20	0.82
RM1L	0.72	0.74	1.44	0.80	4.50	0.80	9.00	0.94
RM1M	1.80	0.70	3.60	0.77	11.25	0.77	22.50	0.77
RM2L	0.72	0.74	1.44	0.76	4.50	0.78	9.00	0.96
RM2M	1.80	0.71	3.60	0.78	11.25	0.74	22.50	0.74
RM2H	3.46	0.69	6.91	0.69	21.60	0.71	43.20	0.74
URML								
URMM								
MH	0.48	0.85	0.96	0.92	3.00	0.98	6.00	0.99

Table 6.5b Special Building Nonstructural Drift-Sensitive Fragility - Moderate-Code Seismic Design Level

Building Type	Median Spectral Displacement (inches) and Logstandard Deviation (Beta)							
	Slight		Moderate		Extensive		Complete	
	Median	Beta	Median	Beta	Median	Beta	Median	Beta
W1	0.50	0.77	1.01	0.82	3.15	0.84	6.30	0.87
W2	0.86	0.84	1.73	0.88	5.40	0.93	10.80	0.93
S1L	0.86	0.78	1.73	0.78	5.40	0.78	10.80	0.76
S1M	2.16	0.71	4.32	0.71	13.50	0.73	27.00	0.81
S1H	4.49	0.69	8.99	0.69	28.08	0.72	56.16	0.82
S2L	0.86	0.81	1.73	0.91	5.40	0.96	10.80	0.89
S2M	2.16	0.73	4.32	0.74	13.50	0.73	27.00	0.87
S2H	4.49	0.69	8.99	0.70	28.08	0.74	56.16	0.84
S3	0.54	0.82	1.08	0.86	3.38	0.97	6.75	0.95
S4L	0.86	0.89	1.73	0.97	5.40	1.02	10.80	0.94
S4M	2.16	0.76	4.32	0.74	13.50	0.84	27.00	0.97
S4H	4.49	0.71	8.99	0.73	28.08	0.83	56.16	0.94
S5L								
S5M								
S5H								
C1L	0.72	0.80	1.44	0.86	4.50	0.88	9.00	0.88
C1M	1.80	0.73	3.60	0.72	11.25	0.74	22.50	0.89
C1H	3.46	0.71	6.91	0.71	21.60	0.79	43.20	0.93
C2L	0.72	0.84	1.44	0.87	4.50	0.95	9.00	1.00
C2M	1.80	0.79	3.60	0.76	11.25	0.76	22.50	0.88
C2H	3.46	0.70	6.91	0.71	21.60	0.77	43.20	0.87
C3L								
C3M								
C3H								
PC1	0.54	0.82	1.08	0.87	3.38	0.93	6.75	1.02
PC2L	0.72	0.88	1.44	0.95	4.50	1.03	9.00	0.99
PC2M	1.80	0.84	3.60	0.77	11.25	0.79	22.50	0.95
PC2H	3.46	0.72	6.91	0.74	21.60	0.84	43.20	0.94
RM1L	0.72	0.86	1.44	0.88	4.50	0.99	9.00	1.04
RM1M	1.80	0.80	3.60	0.79	11.25	0.79	22.50	0.88
RM2L	0.72	0.81	1.44	0.86	4.50	0.97	9.00	1.03
RM2M	1.80	0.78	3.60	0.77	11.25	0.77	22.50	0.88
RM2H	3.46	0.71	6.91	0.71	21.60	0.74	43.20	0.87
URML								
URMM								
MH	0.48	0.85	0.96	0.92	3.00	0.98	6.00	0.99

Table 6.5c Special Building Nonstructural Drift-Sensitive Fragility - Low-Code Seismic Design Level

Building Type	Median Spectral Displacement (inches) and Logstandard Deviation (Beta)							
	Slight		Moderate		Extensive		Complete	
	Median	Beta	Median	Beta	Median	Beta	Median	Beta
W1	0.50	0.83	1.01	0.86	3.15	0.88	6.30	1.00
W2	0.86	0.93	1.73	0.94	5.40	0.99	10.80	0.93
S1L	0.86	0.81	1.73	0.80	5.40	0.80	10.80	0.94
S1M	2.16	0.73	4.32	0.76	13.50	0.86	27.00	0.98
S1H	4.49	0.71	8.99	0.74	28.08	0.87	56.16	0.98
S2L	0.86	0.94	1.73	0.93	5.40	0.93	10.80	0.98
S2M	2.16	0.73	4.32	0.76	13.50	0.91	27.00	0.99
S2H	4.49	0.71	8.99	0.74	28.08	0.85	56.16	0.96
S3	0.54	0.89	1.08	0.96	3.38	1.01	6.75	0.90
S4L	0.86	1.02	1.73	0.99	5.40	0.95	10.80	1.01
S4M	2.16	0.76	4.32	0.84	13.50	0.95	27.00	1.04
S4H	4.49	0.74	8.99	0.87	28.08	0.96	56.16	1.03
S5L	0.86	1.04	1.73	1.04	5.40	1.00	10.80	0.99
S5M	2.16	0.78	4.32	0.84	13.50	0.97	27.00	1.04
S5H	4.49	0.76	8.99	0.87	28.08	0.96	56.16	1.03
C1L	0.72	0.90	1.44	0.92	4.50	0.93	9.00	0.93
C1M	1.80	0.74	3.60	0.77	11.25	0.94	22.50	1.00
C1H	3.46	0.75	6.91	0.86	21.60	0.97	43.20	1.03
C2L	0.72	0.93	1.44	0.99	4.50	1.06	9.00	0.92
C2M	1.80	0.80	3.60	0.80	11.25	0.91	22.50	1.00
C2H	3.46	0.73	6.91	0.80	21.60	0.93	43.20	1.01
C3L	0.72	0.99	1.44	1.05	4.50	1.06	9.00	0.93
C3M	1.80	0.84	3.60	0.83	11.25	0.95	22.50	1.01
C3H	3.46	0.76	6.91	0.84	21.60	0.96	43.20	1.03
PC1	0.54	0.92	1.08	0.99	3.38	1.07	6.75	1.02
PC2L	0.72	0.99	1.44	1.02	4.50	1.02	9.00	0.95
PC2M	1.80	0.81	3.60	0.82	11.25	0.95	22.50	1.02
PC2H	3.46	0.74	6.91	0.86	21.60	0.96	43.20	1.02
RM1L	0.72	0.98	1.44	1.06	4.50	1.08	9.00	0.94
RM1M	1.80	0.83	3.60	0.84	11.25	0.91	22.50	0.99
RM2L	0.72	0.94	1.44	1.03	4.50	1.07	9.00	0.92
RM2M	1.80	0.81	3.60	0.80	11.25	0.91	22.50	0.99
RM2H	3.46	0.74	6.91	0.79	21.60	0.92	43.20	1.01
URML	0.54	0.93	1.08	0.98	3.38	1.05	6.75	1.11
URMM	1.26	0.89	2.52	0.88	7.88	0.87	15.75	0.99
MH	0.48	0.85	0.96	0.92	3.00	0.98	6.00	0.99

6.4.3.4 Nonstructural Damage - Acceleration-Sensitive Components

Damage states of nonstructural acceleration-sensitive components of Special buildings are based on the peak floor accelerations of Code buildings of seismic design level (Table 5.12) increased by a factor of 1.5. A factor of 1.5 on damage-state acceleration reflects increased anchorage strength of nonstructural acceleration-sensitive components of Special buildings.

The floor acceleration values are used directly as median values, assuming average upper-floor demand is represented by response at the point of the push-over mode displacement.

The total variability of each damage state, β_{NSAds}, is modeled by the combination of following three contributors to nonstructural acceleration-sensitive damage variability:

- uncertainty in the damage state threshold of nonstructural components ($\beta_{M(NSAds)}$ = 0.6, for all structural damage states and building types,

- variability in capacity (response) properties of the model building type that contains the nonstructural components of interest ($\beta_{C(Au)}$ = 0.15 for Special buildings, and

- variability in response of the model building type due to the spatial variability of ground motion demand ($\beta_{D(A)}$ = 0.45 and $\beta_{C(V)}$ = 0.50).

Each of these three contributors to damage state variability are assumed to be lognormally distributed random variables. Capacity and demand are dependent parameters and a convolution process is used to derive combined capacity/demand variability of each nonstructural damage state. Capacity/demand variability is then combined with damage state uncertainty, as described in Section 5.4.3.3.

Tables 6.6a, 6.6b and 6.6c summarize median and lognormal standard deviation (β_{NSAds}) values for Slight, Moderate, Extensive and Complete damage states of nonstructural acceleration-sensitive components of Special buildings for High-Code, Moderate-Code and Low-Code seismic design levels, respectively.

Table 6.6a Special Building Nonstructural Acceleration-Sensitive Fragility - High-Code Seismic Design Level

Building Type	Median Spectral Acceleration (g) and Logstandard Deviation (Beta)							
	Slight		Moderate		Extensive		Complete	
	Median	Beta	Median	Beta	Median	Beta	Median	Beta
W1	0.45	0.72	0.90	0.68	1.80	0.68	3.60	0.68
W2	0.45	0.69	0.90	0.67	1.80	0.68	3.60	0.68
S1L	0.45	0.66	0.90	0.67	1.80	0.67	3.60	0.67
S1M	0.45	0.66	0.90	0.67	1.80	0.68	3.60	0.68
S1H	0.45	0.67	0.90	0.66	1.80	0.66	3.60	0.66
S2L	0.45	0.66	0.90	0.67	1.80	0.66	3.60	0.66
S2M	0.45	0.68	0.90	0.65	1.80	0.65	3.60	0.65
S2H	0.45	0.67	0.90	0.65	1.80	0.65	3.60	0.65
S3	0.45	0.68	0.90	0.67	1.80	0.66	3.60	0.66
S4L	0.45	0.67	0.90	0.67	1.80	0.67	3.60	0.67
S4M	0.45	0.66	0.90	0.65	1.80	0.66	3.60	0.66
S4H	0.45	0.66	0.90	0.65	1.80	0.63	3.60	0.63
S5L								
S5M								
S5H								
C1L	0.45	0.67	0.90	0.68	1.80	0.67	3.60	0.67
C1M	0.45	0.66	0.90	0.66	1.80	0.66	3.60	0.66
C1H	0.45	0.67	0.90	0.65	1.80	0.65	3.60	0.65
C2L	0.45	0.68	0.90	0.67	1.80	0.67	3.60	0.63
C2M	0.45	0.68	0.90	0.65	1.80	0.64	3.60	0.64
C2H	0.45	0.68	0.90	0.65	1.80	0.64	3.60	0.64
C3L								
C3M								
C3H								
PC1	0.45	0.72	0.90	0.66	1.80	0.67	3.60	0.63
PC2L	0.45	0.68	0.90	0.67	1.80	0.66	3.60	0.66
PC2M	0.45	0.67	0.90	0.64	1.80	0.65	3.60	0.65
PC2H	0.45	0.66	0.90	0.64	1.80	0.63	3.60	0.63
RM1L	0.45	0.73	0.90	0.66	1.80	0.68	3.60	0.64
RM1M	0.45	0.69	0.90	0.65	1.80	0.64	3.60	0.64
RM2L	0.45	0.71	0.90	0.66	1.80	0.67	3.60	0.63
RM2M	0.45	0.70	0.90	0.65	1.80	0.64	3.60	0.64
RM2H	0.45	0.69	0.90	0.65	1.80	0.64	3.60	0.64
URML								
URMM								
MH	0.38	0.66	0.75	0.67	1.50	0.67	3.00	0.67

Table 6.6b Special Building Nonstructural Acceleration-Sensitive Fragility - Moderate-Code Seismic Design Level

Building Type	Median Spectral Acceleration (g) and Logstandard Deviation (Beta)							
	Slight		Moderate		Extensive		Complete	
	Median	Beta	Median	Beta	Median	Beta	Median	Beta
W1	0.38	0.71	0.75	0.68	1.50	0.68	3.00	0.65
W2	0.38	0.67	0.75	0.68	1.50	0.68	3.00	0.68
S1L	0.38	0.67	0.75	0.67	1.50	0.68	3.00	0.68
S1M	0.38	0.67	0.75	0.67	1.50	0.67	3.00	0.67
S1H	0.38	0.67	0.75	0.66	1.50	0.66	3.00	0.66
S2L	0.38	0.66	0.75	0.66	1.50	0.68	3.00	0.68
S2M	0.38	0.65	0.75	0.65	1.50	0.64	3.00	0.64
S2H	0.38	0.65	0.75	0.65	1.50	0.65	3.00	0.65
S3	0.38	0.66	0.75	0.66	1.50	0.66	3.00	0.66
S4L	0.38	0.67	0.75	0.66	1.50	0.65	3.00	0.65
S4M	0.38	0.65	0.75	0.65	1.50	0.65	3.00	0.65
S4H	0.38	0.65	0.75	0.65	1.50	0.65	3.00	0.65
S5L								
S5M								
S5H								
C1L	0.38	0.68	0.75	0.66	1.50	0.68	3.00	0.68
C1M	0.38	0.66	0.75	0.65	1.50	0.65	3.00	0.65
C1H	0.38	0.65	0.75	0.65	1.50	0.65	3.00	0.65
C2L	0.38	0.67	0.75	0.67	1.50	0.67	3.00	0.67
C2M	0.38	0.65	0.75	0.64	1.50	0.66	3.00	0.66
C2H	0.38	0.65	0.75	0.64	1.50	0.64	3.00	0.64
C3L								
C3M								
C3H								
PC1	0.38	0.67	0.75	0.67	1.50	0.65	3.00	0.65
PC2L	0.38	0.66	0.75	0.66	1.50	0.64	3.00	0.64
PC2M	0.38	0.64	0.75	0.64	1.50	0.64	3.00	0.64
PC2H	0.38	0.64	0.75	0.65	1.50	0.65	3.00	0.65
RM1L	0.38	0.67	0.75	0.67	1.50	0.67	3.00	0.67
RM1M	0.38	0.65	0.75	0.64	1.50	0.66	3.00	0.66
RM2L	0.38	0.67	0.75	0.67	1.50	0.67	3.00	0.67
RM2M	0.38	0.65	0.75	0.64	1.50	0.66	3.00	0.66
RM2H	0.38	0.65	0.75	0.64	1.50	0.64	3.00	0.64
URML								
URMM								
MH	0.38	0.66	0.75	0.67	1.50	0.67	3.00	0.67

Table 6.6c Special Building Nonstructural Acceleration-Sensitive Fragility - Low-Code Seismic Design Level

Building Type	Median Spectral Acceleration (g) and Logstandard Deviation (Beta)							
	Slight		Moderate		Extensive		Complete	
	Median	Beta	Median	Beta	Median	Beta	Median	Beta
W1	0.30	0.71	0.60	0.68	1.20	0.66	2.40	0.65
W2	0.30	0.66	0.60	0.66	1.20	0.69	2.40	0.69
S1L	0.30	0.66	0.60	0.68	1.20	0.68	2.40	0.68
S1M	0.30	0.66	0.60	0.68	1.20	0.68	2.40	0.68
S1H	0.30	0.67	0.60	0.67	1.20	0.67	2.40	0.67
S2L	0.30	0.65	0.60	0.68	1.20	0.68	2.40	0.68
S2M	0.30	0.65	0.60	0.67	1.20	0.67	2.40	0.67
S2H	0.30	0.64	0.60	0.67	1.20	0.67	2.40	0.67
S3	0.30	0.65	0.60	0.67	1.20	0.67	2.40	0.67
S4L	0.30	0.65	0.60	0.68	1.20	0.68	2.40	0.68
S4M	0.30	0.64	0.60	0.68	1.20	0.68	2.40	0.68
S4H	0.30	0.64	0.60	0.67	1.20	0.67	2.40	0.67
S5L	0.30	0.65	0.60	0.68	1.20	0.68	2.40	0.68
S5M	0.30	0.64	0.60	0.67	1.20	0.67	2.40	0.67
S5H	0.30	0.64	0.60	0.67	1.20	0.67	2.40	0.67
C1L	0.30	0.65	0.60	0.68	1.20	0.68	2.40	0.68
C1M	0.30	0.64	0.60	0.67	1.20	0.67	2.40	0.67
C1H	0.30	0.67	0.60	0.67	1.20	0.67	2.40	0.67
C2L	0.30	0.66	0.60	0.66	1.20	0.65	2.40	0.65
C2M	0.30	0.63	0.60	0.65	1.20	0.65	2.40	0.65
C2H	0.30	0.63	0.60	0.66	1.20	0.66	2.40	0.66
C3L	0.30	0.65	0.60	0.67	1.20	0.67	2.40	0.67
C3M	0.30	0.63	0.60	0.66	1.20	0.66	2.40	0.66
C3H	0.30	0.63	0.60	0.67	1.20	0.67	2.40	0.67
PC1	0.30	0.66	0.60	0.65	1.20	0.65	2.40	0.65
PC2L	0.30	0.65	0.60	0.68	1.20	0.68	2.40	0.68
PC2M	0.30	0.63	0.60	0.67	1.20	0.67	2.40	0.67
PC2H	0.30	0.64	0.60	0.66	1.20	0.66	2.40	0.66
RM1L	0.30	0.66	0.60	0.66	1.20	0.65	2.40	0.65
RM1M	0.30	0.64	0.60	0.65	1.20	0.65	2.40	0.65
RM2L	0.30	0.66	0.60	0.66	1.20	0.66	2.40	0.66
RM2M	0.30	0.64	0.60	0.65	1.20	0.65	2.40	0.65
RM2H	0.30	0.63	0.60	0.65	1.20	0.65	2.40	0.65
URML	0.30	0.68	0.60	0.66	1.20	0.64	2.40	0.64
URMM	0.30	0.64	0.60	0.65	1.20	0.65	2.40	0.65
MH	0.38	0.66	0.75	0.67	1.50	0.67	3.00	0.67

6.4.4 Structural Fragility Curves - Equivalent Peak Ground Acceleration

Structural damage fragility curves are expressed in terms of an equivalent value of PGA (rather than spectral displacement) for evaluation of Special buildings that are components of lifelines. Only structural damage functions are developed based on PGA, since structural damage is considered the most appropriate measure of damage for lifeline facilities. Similar methods could be used to develop nonstructural damage functions based on PGA. In this case, capacity curves are not necessary to estimate building response and PGA is used directly as the PESH input to building fragility curves.

This section provides equivalent-PGA fragility curves for Special buildings based on the structural damage functions of Tables 6.4a - 6.4c and standard spectrum shape properties of Chapter 4. These functions have the same format and are based on the same approach and assumptions as those described in Section 5.4.4 for development equivalent-PGA fragility curves for Code buildings.

The values given in Tables 6.7a through 6.7c are appropriate for use in the evaluation of scenario earthquakes whose demand spectrum shape is based on, or similar to, large-magnitude, WUS ground shaking at soil sites (reference spectrum shape). For evaluation of building damage due to scenario earthquakes whose spectra are not similar to the reference spectrum shape, damage-state median parameters may be adjusted to better represent equivalent-PGA structural fragility for the spectrum shape of interest.

Median values of equivalent-PGA are adjusted for: (1) the site condition (if different from Site Class D) and (2) the ratio of long-period spectral response (i.e., S_{A1}) to PGA (if different from a value of 1.5, the ratio of S_{A1} to PGA of the reference spectrum shape). Damage-state variability is not adjusted assuming that the variability associated with ground shaking (although different for different source/site conditions) when combined with the uncertainty in damage-state threshold, is approximately the same for all demand spectrum shapes.

Equivalent-PGA medians, given in Tables 6.7a through 6.7c for the reference spectrum shape, are adjusted to represent other spectrum shapes using the spectrum shape ratios of Tables 5.14 and 5.15, the soil amplification factor, F_V, and Equation (5-6). In general, implementation of Equation (5-6) requires information on earthquake magnitude and source-to-site distance to estimate the spectrum shape ratio for rock sites, and 1-second period spectral acceleration at the site (to estimate the soil amplification factor). Note that for the following tables, shaded boxes indicate types that are not permitted by current seismic codes.

Table 6.7a Equivalent-PGA Structural Fragility - Special High-Code Seismic Design Level

Building Type	Median Equivalent-PGA (g) and Logstandard Deviation (Beta)							
	Slight		Moderate		Extensive		Complete	
	Median	Beta	Median	Beta	Median	Beta	Median	Beta
W1	0.32	0.64	0.78	0.64	2.00	0.64	3.22	0.64
W2	0.35	0.64	0.82	0.64	1.76	0.64	3.13	0.64
S1L	0.25	0.64	0.44	0.64	0.92	0.64	2.17	0.64
S1M	0.17	0.64	0.34	0.64	0.85	0.64	2.10	0.64
S1H	0.13	0.64	0.26	0.64	0.65	0.64	1.73	0.64
S2L	0.33	0.64	0.58	0.64	1.10	0.64	2.07	0.64
S2M	0.18	0.64	0.35	0.64	0.97	0.64	2.34	0.64
S2H	0.14	0.64	0.27	0.64	0.81	0.64	2.13	0.64
S3	0.19	0.64	0.36	0.64	0.79	0.64	1.44	0.64
S4L	0.34	0.64	0.54	0.64	1.04	0.64	1.91	0.64
S4M	0.21	0.64	0.37	0.64	0.98	0.64	2.27	0.64
S4H	0.16	0.64	0.32	0.64	0.90	0.64	2.29	0.64
S5L								
S5M								
S5H								
C1L	0.29	0.64	0.51	0.64	1.07	0.64	2.06	0.64
C1M	0.19	0.64	0.36	0.64	1.02	0.64	2.48	0.64
C1H	0.14	0.64	0.28	0.64	0.83	0.64	2.03	0.64
C2L	0.33	0.64	0.66	0.64	1.42	0.64	2.40	0.64
C2M	0.22	0.64	0.49	0.64	1.24	0.64	2.97	0.64
C2H	0.15	0.64	0.37	0.64	1.11	0.64	2.80	0.64
C3L								
C3M								
C3H								
PC1	0.25	0.64	0.48	0.64	1.02	0.64	1.86	0.64
PC2L	0.32	0.64	0.51	0.64	1.03	0.64	1.78	0.64
PC2M	0.22	0.64	0.40	0.64	0.92	0.64	2.25	0.64
PC2H	0.15	0.64	0.30	0.64	0.83	0.64	2.13	0.64
RM1L	0.39	0.64	0.65	0.64	1.52	0.64	2.53	0.64
RM1M	0.25	0.64	0.50	0.64	1.15	0.64	2.76	0.64
RM2L	0.34	0.64	0.59	0.64	1.41	0.64	2.36	0.64
RM2M	0.22	0.64	0.43	0.64	1.05	0.64	2.65	0.64
RM2H	0.15	0.64	0.30	0.64	0.89	0.64	2.58	0.64
URML								
URMM								
MH	0.16	0.64	0.26	0.64	0.45	0.64	0.88	0.64

Table 6.7b Equivalent-PGA Structural Fragility - Special Moderate-Code Seismic Design Level

Building Type	Median Equivalent-PGA (g) and Logstandard Deviation (Beta)							
	Slight		Moderate		Extensive		Complete	
	Median	Beta	Median	Beta	Median	Beta	Median	Beta
W1	0.32	0.64	0.59	0.64	1.32	0.64	2.08	0.64
W2	0.28	0.64	0.51	0.64	1.00	0.64	1.83	0.64
S1L	0.20	0.64	0.31	0.64	0.60	0.64	1.29	0.64
S1M	0.16	0.64	0.28	0.64	0.60	0.64	1.27	0.64
S1H	0.13	0.64	0.22	0.64	0.51	0.64	1.17	0.64
S2L	0.27	0.64	0.37	0.64	0.67	0.64	1.27	0.64
S2M	0.17	0.64	0.28	0.64	0.69	0.64	1.40	0.64
S2H	0.14	0.64	0.23	0.64	0.63	0.64	1.44	0.64
S3	0.18	0.64	0.26	0.64	0.46	0.64	0.86	0.64
S4L	0.26	0.64	0.36	0.64	0.61	0.64	1.17	0.64
S4M	0.18	0.64	0.29	0.64	0.69	0.64	1.33	0.64
S4H	0.16	0.64	0.26	0.64	0.66	0.64	1.42	0.64
S5L								
S5M								
S5H								
C1L	0.23	0.64	0.33	0.64	0.63	0.64	1.22	0.64
C1M	0.17	0.64	0.28	0.64	0.70	0.64	1.38	0.64
C1H	0.14	0.64	0.23	0.64	0.59	0.64	1.15	0.64
C2L	0.26	0.64	0.44	0.64	0.77	0.64	1.34	0.64
C2M	0.20	0.64	0.35	0.64	0.81	0.64	1.63	0.64
C2H	0.15	0.64	0.30	0.64	0.78	0.64	1.63	0.64
C3L								
C3M								
C3H								
PC1	0.24	0.64	0.33	0.64	0.63	0.64	1.05	0.64
PC2L	0.24	0.64	0.35	0.64	0.59	0.64	1.06	0.64
PC2M	0.19	0.64	0.29	0.64	0.62	0.64	1.27	0.64
PC2H	0.15	0.64	0.25	0.64	0.60	0.64	1.30	0.64
RM1L	0.31	0.64	0.44	0.64	0.79	0.64	1.33	0.64
RM1M	0.24	0.64	0.36	0.64	0.74	0.64	1.65	0.64
RM2L	0.28	0.64	0.41	0.64	0.74	0.64	1.27	0.64
RM2M	0.21	0.64	0.32	0.64	0.69	0.64	1.58	0.64
RM2H	0.15	0.64	0.25	0.64	0.64	0.64	1.53	0.64
URML								
URMM								
MH	0.16	0.64	0.26	0.64	0.45	0.64	0.88	0.64

Table 6.7c Equivalent-PGA Structural Fragility - Special Low-Code Seismic Design Level

Building Type	Median Equivalent-PGA (g) and Logstandard Deviation (Beta)							
	Slight		Moderate		Extensive		Complete	
	Median	Beta	Median	Beta	Median	Beta	Median	Beta
W1	0.28	0.64	0.50	0.64	1.00	0.64	1.51	0.64
W2	0.21	0.64	0.34	0.64	0.68	0.64	1.10	0.64
S1L	0.16	0.64	0.23	0.64	0.42	0.64	0.71	0.64
S1M	0.15	0.64	0.23	0.64	0.42	0.64	0.73	0.64
S1H	0.13	0.64	0.20	0.64	0.40	0.64	0.71	0.64
S2L	0.19	0.64	0.25	0.64	0.44	0.64	0.74	0.64
S2M	0.16	0.64	0.24	0.64	0.52	0.64	0.88	0.64
S2H	0.14	0.64	0.21	0.64	0.50	0.64	0.93	0.64
S3	0.14	0.64	0.18	0.64	0.30	0.64	0.57	0.64
S4L	0.19	0.64	0.23	0.64	0.38	0.64	0.68	0.64
S4M	0.16	0.64	0.23	0.64	0.47	0.64	0.81	0.64
S4H	0.15	0.64	0.23	0.64	0.48	0.64	0.87	0.64
S5L	0.18	0.64	0.26	0.64	0.41	0.64	0.68	0.64
S5M	0.14	0.64	0.24	0.64	0.50	0.64	0.80	0.64
S5H	0.13	0.64	0.24	0.64	0.51	0.64	0.84	0.64
C1L	0.17	0.64	0.22	0.64	0.39	0.64	0.67	0.64
C1M	0.15	0.64	0.23	0.64	0.48	0.64	0.80	0.64
C1H	0.13	0.64	0.20	0.64	0.39	0.64	0.66	0.64
C2L	0.19	0.64	0.27	0.64	0.44	0.64	0.79	0.64
C2M	0.16	0.64	0.26	0.64	0.56	0.64	0.93	0.64
C2H	0.14	0.64	0.25	0.64	0.56	0.64	0.96	0.64
C3L	0.17	0.64	0.25	0.64	0.39	0.64	0.65	0.64
C3M	0.14	0.64	0.23	0.64	0.46	0.64	0.75	0.64
C3H	0.12	0.64	0.22	0.64	0.48	0.64	0.79	0.64
PC1	0.18	0.64	0.24	0.64	0.38	0.64	0.65	0.64
PC2L	0.18	0.64	0.23	0.64	0.36	0.64	0.66	0.64
PC2M	0.16	0.64	0.22	0.64	0.45	0.64	0.79	0.64
PC2H	0.14	0.64	0.21	0.64	0.45	0.64	0.81	0.64
RM1L	0.22	0.64	0.29	0.64	0.44	0.64	0.80	0.64
RM1M	0.19	0.64	0.26	0.64	0.50	0.64	0.92	0.64
RM2L	0.20	0.64	0.27	0.64	0.41	0.64	0.77	0.64
RM2M	0.17	0.64	0.24	0.64	0.47	0.64	0.88	0.64
RM2H	0.14	0.64	0.22	0.64	0.49	0.64	0.92	0.64
URML	0.19	0.64	0.28	0.64	0.47	0.64	0.68	0.64
URMM	0.14	0.64	0.22	0.64	0.38	0.64	0.70	0.64
MH	0.16	0.64	0.26	0.64	0.45	0.64	0.88	0.64

6.5 Damage Due to Ground Failure - Special Buildings

Damage to Special buildings due to ground failure is assumed to be the same as the damage to Code buildings for the same amount of permanent ground deformation (PGD). Fragility curves developed in Section 5.5 for Code buildings are also appropriate for prediction of damage to Special buildings due to ground failure.

6.6 Evaluation of Building Damage - Essential Facilities

6.6.1 Overview

Special building capacity and fragility curves for structural and nonstructural systems are used to predict essential facility damage when the user is able to determine that the essential facility is superior to a typical building of the model building type and design level of interest. If such a determination cannot be made by the user, then the Code building functions of Chapter 5 are used to evaluate essential building damage. These criteria are summarized in Table 6.8.

Table 6.8 Criteria for Evaluating Essential Facility Damage

Evaluate Essential Facility Using:	User Deems Essential Facility to be:
Code building damage functions (High-Code, Moderate-Code, Low-Code and Pre-Code functions of Chapter 5)	Typical of the model building type and seismic design level of interest (i.e., no special seismic protection of components)
Special building damage functions (High-Code, Moderate-Code and Low-Code functions of Chapter 6)	Superior to the model building type and seismic design level of interest (e.g., 50 percent stronger lateral-force-resisting structural system, and special anchorage and bracing of nonstructural components)

During an earthquake, the essential facilities may be damaged either by ground shaking, ground failure, or both. Essential facilities are evaluated separately for the two modes of, ground shaking and ground failure, and the resulting damage-state probabilities combined for evaluation of loss.

6.6.2 Damage Due to Ground Shaking

Damage to essential facilities due to ground shaking uses the same methods as those described in Section 5.6.2 for Code buildings, with the exception that Special buildings are assumed to have less degradation and greater effective damping than Code buildings.

6.6.2.1 Demand Spectrum Reduction for Effective Damping - Special Buildings

Demand spectra for evaluation of damage to Special buildings are constructed using the same approach, assumptions and formulas as those described in Section 5.6.2.1 for Code buildings, except values of the degradation factor, κ, that defines the effective amount of hysteretic damping as a function of duration are different for Special buildings. Degradation factors for Special buildings are given in Table 6.9.

Figure 6.5 shows typical demand spectra (spectral acceleration plotted as a function of spectral displacement) for three demand levels. These three demand levels represent Short (κ = 0.90), Moderate (κ = 0.60) and Long (κ = 0.40) duration ground shaking, respectively. Also shown in the figure is the building capacity curve of a low-rise Special building (Moderate-Code seismic design) that was used to estimate effective damping. The intersection of the capacity curve with each of the three demand spectra illustrates the significance of duration (damping) on building response.

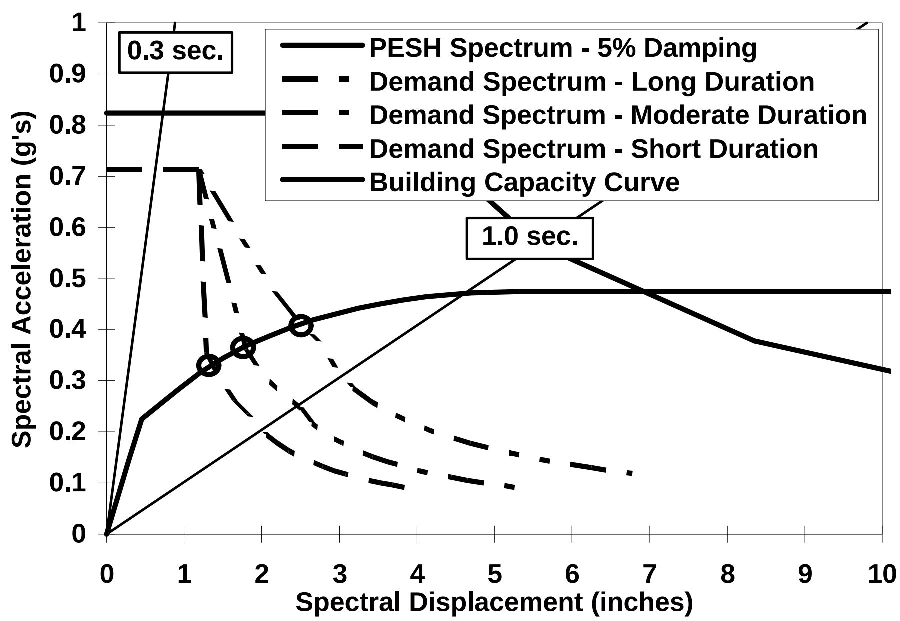


Figure 6.5 Example Demand Spectra - Special Building (M = 7.0 at 20 km, WUS, Site Class E).

Comparison of Figure 6.5 with Figure 5.7 (same example building and PESH demand, except capacity curve and damping represents Code building properties) illustrates the significance of increased strength and damping (reduced degradation) of Special buildings on the reduction of building displacement. In this case, the Special building displaces only about one-half as much as a comparable Code building for the same level of PESH demand. Forces on nonstructural acceleration-sensitive components are not reduced, but are slightly increased due to the higher strength of the Special building.

Table 6.9 Special Building Degradation Factor (κ) as a Function of Short, Moderate and Long Earthquake Duration

Building Type		High-Code Design			Moderate-Code Design			Low-Code Design		
No.	Label	Short	Moderate	Long	Short	Moderate	Long	Short	Moderate	Long
1	W1	1.0	1.0	0.7	1.0	0.8	0.5	0.9	0.6	0.3
2	W2	1.0	0.8	0.6	0.9	0.6	0.4	0.8	0.4	0.2
3	S1L	1.0	0.8	0.6	0.9	0.6	0.4	0.8	0.4	0.2
4	S1M	1.0	0.8	0.6	0.9	0.6	0.4	0.8	0.4	0.2
5	S1H	1.0	0.8	0.6	0.9	0.6	0.4	0.8	0.4	0.2
6	S2L	0.8	0.6	0.4	0.7	0.5	0.3	0.6	0.4	0.2
7	S2M	0.8	0.6	0.4	0.7	0.5	0.3	0.6	0.4	0.2
8	S2H	0.8	0.6	0.4	0.7	0.5	0.3	0.6	0.4	0.2
9	S3	0.8	0.6	0.4	0.7	0.5	0.3	0.6	0.4	0.2
10	S4L	0.8	0.6	0.4	0.7	0.5	0.3	0.6	0.4	0.2
11	S4M	0.8	0.6	0.4	0.7	0.5	0.3	0.6	0.4	0.2
12	S4H	0.8	0.6	0.4	0.7	0.5	0.3	0.6	0.4	0.2
13	S5L	0.6	0.4	0.2	0.6	0.4	0.2	0.6	0.4	0.2
14	S5M	0.6	0.4	0.2	0.6	0.4	0.2	0.6	0.4	0.2
15	S5H	0.6	0.4	0.2	0.6	0.4	0.2	0.6	0.4	0.2
16	C1L	1.0	0.8	0.6	0.9	0.6	0.4	0.8	0.4	0.2
17	C1M	1.0	0.8	0.6	0.9	0.6	0.4	0.8	0.4	0.2
18	C1H	1.0	0.8	0.6	0.9	0.6	0.4	0.8	0.4	0.2
19	C2L	1.0	0.8	0.6	0.9	0.6	0.4	0.8	0.4	0.2
20	C2M	1.0	0.8	0.6	0.9	0.6	0.4	0.8	0.4	0.2
21	C2H	1.0	0.8	0.6	0.9	0.6	0.4	0.8	0.4	0.2
22	C3L	0.6	0.4	0.2	0.6	0.4	0.2	0.6	0.4	0.2
23	C3M	0.6	0.4	0.2	0.6	0.4	0.2	0.6	0.4	0.2
24	C3H	0.6	0.4	0.2	0.6	0.4	0.2	0.6	0.4	0.2
25	PC1	0.8	0.6	0.4	0.7	0.5	0.3	0.6	0.4	0.2
26	PC2L	0.8	0.6	0.4	0.7	0.5	0.3	0.6	0.4	0.2
27	PC2M	0.8	0.6	0.4	0.7	0.5	0.3	0.6	0.4	0.2
28	PC2H	0.8	0.6	0.4	0.7	0.5	0.3	0.6	0.4	0.2
29	RM1L	1.0	0.8	0.6	0.9	0.6	0.4	0.8	0.4	0.2
30	RM1M	1.0	0.8	0.6	0.9	0.6	0.4	0.8	0.4	0.2
31	RM2L	1.0	0.8	0.6	0.9	0.6	0.4	0.8	0.4	0.2
32	RM2M	1.0	0.8	0.6	0.9	0.6	0.4	0.8	0.4	0.2
33	RM2H	1.0	0.8	0.6	0.9	0.6	0.4	0.8	0.4	0.2
34	URML	0.6	0.4	0.2	0.6	0.4	0.2	0.6	0.4	0.2
35	URMM	0.6	0.4	0.2	0.6	0.4	0.2	0.6	0.4	0.2
36	MH	0.9	0.6	0.4	0.9	0.6	0.4	0.9	0.6	0.4

6.6.2.2 Damage State Probability

Structural and nonstructural fragility curves of essential facilities are evaluated for spectral displacement and spectral acceleration defined by the intersection of the capacity and demand curves. Each of these curves describe the cumulative probability of being in or exceeding, a particular damage state. Nonstructural components (both drift- and acceleration-sensitive components) may, in some cases, be dependent on the structural damage state (e.g., Complete structural damage may cause Complete nonstructural damage). The Methodology assumes nonstructural damage states to be independent of structural damage states. Cumulative probabilities are differenced to obtain discrete probabilities of being in each of the five damage states. This process is shown schematically in Figure 6.6.

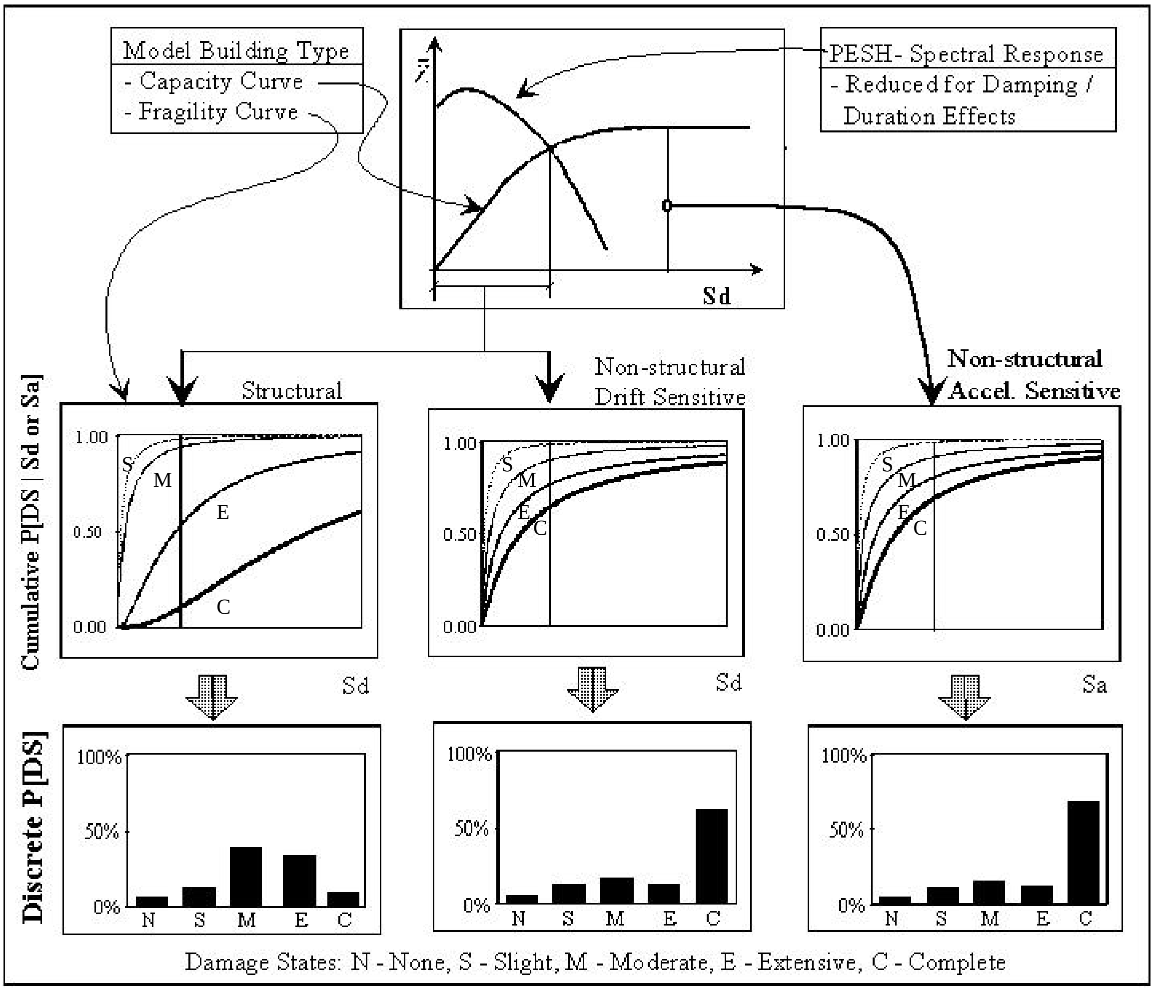


Figure 6.6 Example Essential Facility Damage Estimation Process.

6.6.3 Combined Damage Due to Ground Failure and Ground Shaking

Damage to essential facilities is based either on Code building damage functions or Special building damage functions. Code building damage due to ground shaking is combined with damage due to ground shaking as specified in Section 5.6.3. Special building damage due to ground failure (Section 6.5.2) is combined with damage due to ground shaking (Section 6.6.2.2) using the same approach, assumptions and formulas as those given in Section 5.6.3 for Code buildings.

6.6.4 Combined Damage to Essential Facilities

Combined ground shaking/ground failure damage to the model building type and design level of interest (either a Special or a Code building) represents combined damage to the essential facility.

6.7 Guidance for Expert Users

This section provides guidance for users who are seismic/structural experts interested in modifying essential facility damage functions supplied with the methodology. This section also provides the expert user with guidance regarding the selection of the appropriate mix of design levels for the region of interest.

6.7.1 Selection of Representative Seismic Design Level

The methodology permits the user to select the seismic design level considered appropriate for each essential facility and to designate the facility as a Special building, when designed and constructed to above-Code standards. In general, performance of essential facilities is not expected to be better than the typical (Code) building of the representative model building type. Exceptions to this generalization include California hospitals of recent (post-1973) construction. If the user is not able to determine that the essential facility is significantly better than average, then the facility should be modeled using Code building damage functions (i.e., same methods as those developed in Chapter 5 for general building stock).

Table 6.10 provides guidance for selecting appropriate building damage functions for essential facilities based on design vintage. These guidelines are applicable to the following facilities:

1. hospitals and other medical facilities having surgery or emergency treatment areas,
2. fire and police stations, and
3. municipal government disaster operation and communication centers deemed (for design) to be vital in emergencies,

provided that seismic codes (e.g., *Uniform Building Code*) were adopted and enforced in the study area of interest. Such adoption and enforcement is generally true for jurisdictions of California, but may not be true other areas.

Table 6.10 Guidelines for Selection of Damage Functions for Essential Facilities Based on *UBC* Seismic Zone and Building Age

***UBC* Seismic Zone (NEHRP Map Area)**	**Post-1973**	**1941 - 1973**	**Pre-1941**
Zone 4 (Map Area 7)	Special High-Code	Moderate-Code	Pre-Code (W1 = Moderate-Code)
Zone 3 (Map Area 6)	Special Moderate-Code	Moderate-Code	Pre-Code (W1 = Moderate-Code)
Zone 2B (Map Area 5)	Moderate-Code	Low-Code	Pre-Code (W1 = Low-Code)
Zone 2A (Map Area 4)	Low-Code	Low-Code	Pre-Code (W1 = Low-Code)
Zone 1 Map Area 2/3)	Low-Code	Pre-Code (W1 = Low-Code)	Pre-Code (W1 = Low-Code)
Zone 0 (Map Area 1)	Pre-Code (W1 = Low-Code)	Pre-Code (W1 = Low-Code)	Pre-Code (W1 = Low-Code)

The guidelines given in Table 6.1 assume that essential buildings in the study region are not designed for wind. The user should consider the possibility that mid-rise and high-rise facilities could be designed for wind and may have considerable lateral strength, even if not designed for earthquake. Users must be knowledgeable about the type and history of construction in the study region of interest and apply engineering judgment in assigning essential facilities to a building type and seismic design level.

6.7.2 High Potential Loss Facilities

6.7.2.1 Introduction

This section describes damage evaluation of high potential loss (HPL) facilities. HPL facilities are likely to cause heavy earthquake losses, if significantly damaged. Examples of such facilities include nuclear power plants, certain military and industrial facilities, dams, etc.

6.7.2.2 Input Requirements and Output Information

The importance of these facilities (in terms of potential earthquake losses) suggests that damage assessment be done in a special way as compared to ordinary buildings. Each HPL facility should be treated on an individual basis by users who have sufficient expertise to evaluate damage to such facilities. Required input to the damage evaluation module includes the following items:

- capacity curves that represents median (typical) properties of the HPL facility structure, or a related set of engineering parameters, such as period, yield strength, and ultimate capacity, that may be used by seismic/structural engineering experts with the methods of Chapter 5 to select representative damage functions,

- fragility curves for the HPL facility under consideration, or related set engineering parameters, that can be used by seismic/structural engineering experts with the methods of Chapter 5 to select appropriate damage functions.

The direct output (damage estimate) from implementation of the fragility curves is an estimate of the probability of being in, or exceeding, each damage state for the given level of ground shaking. This output is used directly as an input to other damage or loss estimation methods or combined with inventory information to predict the distribution of damage as a function of facility type, and geographical location. In the latter case, the number and geographical location of facilities of interest would be a required input to the damage estimation method.

6.7.2.3 Form of Damage Functions and Damage Evaluation

The form of user-supplied HPL facility damage functions should be the same as that of buildings (Chapter 5) and their use in the methodology would be similar to that of essential facilities.

6.8 Essential Facility and HPL Damage References

Refer to Section 5.8 for building damage references.