NCSX
Specification

Seismic Requirements for NCSX

NCSX-CRIT-SEIS-00

27 Oct. 2004

Signature Not Verified Michael Kalish Digitally signed by Michael Kalish DN: cn=Michael Kalish, o=NCSX, c=US Date: 2004.11.19 09:52:54 -05'00'

Prepared by: ______________________________

M. Kalish

Bob Parsells Digitally signed by Bob Parsells DN: CN = Bob Parsells, C = US Date: 2004.11.19 11:16:10 -05'00'

Concur: ______________________________

R. Parsells

Wayne Reiersen Digitally signed by Wayne Reiersen DN: CN = Wayne Reiersen, C = US, O = PPPL Reason: I have reviewed this document Date: 2004.11.24 09:56:32 -05'00'

Concur: ______________________________

W. Reiersen, Engineering Manager

Jerry Levine 2004.11.19 14:43:30 -05'00'

Concur: ______________________________

J. Levine, ES&H

Hutch Neilson Digitally signed by Hutch Neilson DN: CN = Hutch Neilson, C = US, O = PPPL Date: 2004.11.24 12:50:36 -05'00'

Approved by: ______________________________

G. H. Neilson, NCSX Project Manager

Record of Revisions

Revision	Date	ECP	Description of Change
Rev. 0	10/27/2004	-	Initial Issue

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1 SCOPE

This memo summarizes and interprets the Department of Energy requirements for the NCSX Project with respect to seismic loading. First a simplified static analysis and its applicability is presented for use. Following is a more thorough analysis of the pertinent requirements and how they apply to the design of equipment and components in the NCSX Test Cell.

2 APPLICABLE DOCUMENTS

International Building Code 2000

DOE-STD-1020-2002 Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities

NCSX Structural Design Criteria

C Site Drawing Subgrade Profiles 330-101-1-G3

Soils Foundation Investigation TFTR PPPL, Giffels Associates 12/9/76

3 SUMMARY

Based on applications of DOE Order O420.1A and DOE Guide G420.1-2, PPPL is required by the Department of Energy to meet the seismic requirements of DOE-STD-1020-2002 Performance Category 1 for Seismic Use Group I. Interpretation of these requirements leads to the adoption of the International Building Code, IBC 2000, with 2/3 the Maximum Considered Earthquake (MCE, site specific) as the standard for PPPL.

The primary intent of the IBC 2000 is to provide for the protection of the public in the event of an earthquake. The NCSX facility is not a public facility and as a result interpretation of the IBC 2000 allows for a relaxed seismic requirement for the PPPL / NCSX test cell. Seismic analysis of components and equipment in the test cell if they do not pose a threat to the health and welfare of the public is not required by code (see section 1621.1.1 of IBC 2000). The NCSX project however chooses to as a minimum apply the requirements of IBC 2000 to components and equipment in the test cell which pose a hazard to any personnel (not just the public) in the event of an earthquake.

The analysis technique presented below is the result of discerning from the code the applicable factors and coefficients and distilling the information down to a simple static analysis applicable to the NCSX test cell. This analysis is to be applied when the equipment or component in question can pose a physical hazard to the health and welfare of an employee or the public. For components that do not present a hazard (equipment mounted to the floor with no potential of falling on and injuring an employee is one example) no seismic analysis is required.

This is the minimum standard. Over and above this minimum standard the remaining body of this document interprets the applicable sections of the code for NCSX and may be applied as required by the project to ensure some level of operability of the NCSX device after a seismic event. Section 4.2 of the memo, “Non Buildings Supported by Other Structures” contains the code interpretation from which this simplified static analysis was derived. For complex high value systems a dynamic analysis is recommend to more accurately reflect the seismic loading and provide the basis for a sound structural design.

3.1 Simplified Static Analysis

The following is the static seismic criteria required for components, structures and equipment in the NCSX test cell which pose a moderate to high fire, explosive, or physical, hazard to personnel. The loads prescribed below are to be applied at the center of gravity of the component in question. If stresses and deflections of components are within acceptable limits as described in the “NCSX Structural Design Criteria” document the component is seismically qualified.

For Rigid Equipment and Components in the NCSX Test Cell mounted to the test cell floor and made of steel or other metal material the seismic criteria is:

Fp = .108 x Wp

For Rigid Equipment and Components in the NCSX Test Cell mounted to the test cell floor which contain brittle material such as ceramic or glass in a load bearing path use:

Fp = .128 x Wp

For Non-Rigid (flexible) Equipment and Components in the NCSX Test Cell mounted to the test cell floor and made of steel or other metal material the seismic criteria is:

Fp = .171 x Wp

For Non-Rigid (flexible) Equipment and Components in the NCSX Test Cell mounted to the test cell floor which contain brittle material such as ceramic or glass in a load bearing path use:

Fp = .257 x Wp

If the component in question is not mounted to the test cell floor the seismic load must be adjusted as follows:

Fp (at height) = Fp x (1+.0246*h)

Where h is the height of the mounting location above (or minus the height for below) the test cell floor in Feet.

If the subject component or equipment does not present the potential for a physical hazard during an earthquake but a seismic analysis is performed to meet other project objectives (component survivability) Fp may be reduced by a factor of 2/3rds

Fp(low hazard) = Fp x 2/3

Rigid structures are structures whose natural frequency (Fn) is greater than 16.7 hz

Fn = 1 / (2*p(Wp / K.p *g)^.5)

g = Acceleration of gravity

K.p = Stiffness of the component and attachment in terms of load per unit deflection at the center of gravity

If there is a question as to the rigidity of the component it may be more efficient to use the higher seismic requirement for non-rigid components and avoid calculating the components rigidity

Dynamic analysis is always available and should use the ARS from section 4.5 of this memo applied at the base (ground) level and an amplification factor of **(1 + 2*z/h)=1.48** (see section 4.2) at the test cell floor level

4 DETAILED PPPL CODE INTERPRETATION

DOE requires PPPL to meet the requirements of **DOE-STD-1020-2002**

The laboratory is required to meet **Performance Category 1** (PC-1) and **Seismic Use Group I** per section 2.3.1 of DOE-STD-1020-2002.

Performance Category 1 allows use of the **IBC 2000** with **2/3 the Maximum Considered Earthquake (MCE)**. (2% exceedance probability in 50 years)

IBC 2000

We are **Site Class B** (table 1615.1) based on soil shear wave velocity of 2,500 ft/sec < V.s <5,000 ft/sec. The Site Class B designation is based upon C Site Drawing "Subgrade Profiles 330-101-1-G3" which shows the bottom of the basement slab and piers to be bellow the as measured level of solid rock. In addition the memo entitled Soils Foundation Investigation TFTR PPPL, Giffels Associates 12/9/76 shows shear wave velocities of greater than 2,500 ft/sec for bores at depths similar to and near the C Site Basement foundation and shear wave velocities greater than 2,500 ft/sec for solid rock.

For our longitude and latitude and Site Class B an MCE Ground Motion Curve is generated using the maps in section 1615 of IBC2000

S.s = 36.0% **The mapped spectral acceleration for short periods**

S.1 = 8.5% **The mapped spectral acceleration for a 1 second period**

Now the seismic input is adjusted for Site Coefficients

Fa=1 Site coefficient as a function of site class and mapped acceleration for short periods Table 1615.1.2(1)

Fv=1 Site coefficient as a function of site class and mapped acceleration at 1 sec periods Table 1615.1.2(2)

Sms = Fa * Ss = .36 Adjusted MCE Parameter short periods Equation 16-16

Sm1 = Fv * S1 = .085 Adjusted MCE Parameter 1 sec. period Equation 16-17

Sds = 2/3*Sms = .24 **Five percent damped spectral response acceleration at short periods** Equation 16-18

Sd1 = 2/3*Sms = .057 **Five percent damped spectral response acceleration at short periods** Equation 16-19

We are **Seismic Design Category B** (per Table 1616.3)

The Sds and Sd1 values become the basis for the following analysis:

4.1 Static Analysis of Structures (Buildings)

4.2 Static Analysis of Non Buildings supported by other structures

4.3 Static Analysis of Non Buildings with self supporting structures

4.4 Static Analysis of Rigid Non Building Structures

4.5 Dynamic Analysis

4.1 Structures (Buildings) (Section 1617.4 of IBC 2000 applies)

For Seismic Use Group I and Seismic Design Category B (Sec. 1616.6.2) a static seismic calculation is acceptable for building-structures. This section generally applies to new construction and for NCSX is appropriate for building / additions or the constructions of walls or the addition of rooms.

V= Cs * W Equation 16-34

Cs = Sds / (R / Ie) Equation 16-35

V is the Seismic Base Shear

W is the effective weight of the structure including dead load and other loads as listed in 1617.4.1

Ie = Occupancy Importance Factor per section 1616.2 and Table 1604.5, Ie=1

R = Response modification factor from Table 1617.6

V = (.24 / R) W

Note:

V need not exceed V = (.057* Ie * Wp) / (R * T) Equation 16-36

V shall not be less than V = .011* Ie * Wp Equation 16-37

where T is the fundamental period of the building (section 1617.4.2.1)

For the vertical distribution of the seismic load use Equation 16-41:

Fx=Cvx* V

Fx = The base shear at height

Cvx = (Wx Hx) / Sum (W * H) [The ratio of the weight times the height to the total weight times the total height]

Basement Elevation = 0’

Test Cell Elevation = 13’3”

Top of Steel = 55’

4.2 Non Buildings supported by other structures (Section 1621 of IBC 2000 applies)

A static seismic analysis is acceptable for structures supported by other structures (other structures can mean the building itself) such as piping or HVAC equipment, conduits, cable trays, and pressure vessels. This section is most appropriate for components and equipment installed in the test cell. This section accounts for the height of the component in question within the building or structure. If the non building structure weight exceeds the combined non building structure and building weight by more than 25% than this section does not apply, use section 1622.1.1 (see 4.3) Note: NCSX qualifies as **Design Category B which allows non building structures supported by other structures to be exempt from analysis if they fall within Ip=1 (non-hazardous equipment)** see section 1621.1.1

For hazardous equipment when Ip > 1 use the following

Fp = .4*a.p*Sds*Wp*(1 + 2*z/h) / (Rp / Ip) Equation 16-67

Fp = the seismic force centered at the center of gravity of the component

Wp = component operating weight

a.p = component amplification select from table 1621.2 or 1621.3

For rigid structures whose natural frequency (Fn) is greater than 16.7 hz use a.p = 1

(ref. commentary Figure 1621.1.4)

For non rigid structures use a.p = 2.5

Fn = 1 / (2*p(W.p / K.p *g)^.5) Component Natural Frequency (1621.3.2)

g = Acceleration of gravity

K.p = Stiffnes of the component and attachment in terms of load per unit deflection at the center of gravity

Rp = Component response modification factor select from table 1621.2 or 1621.3,

Represents the ability of a component to sustain permanent deformations without losing strength (= 2.5 for most components includes steel and copper , = 1.25 for low deformability elements such as ceramic, glass, or plain concrete)

z = Height in structure above base at point of attachment of component (height above grade)

h = Average roof height of structure relative to the base elevation

Ip = 1 for non hazardous equipment and 1.5 for hazardous equipment or life safety equipment required to function after an earthquake, from section 1621.1.6

For NCSX we simplify the equation to :

Fp = .096*a.p*Wp*(1 + 2*z/h)*Ip / Rp

With Basement Elevation = 0’

Test Cell Elevation = 13’3”

Top of Steel = 55’

For the Test Cell Floor z/h = .24

Simplified for the Test Cell:

Fp = Sc*Ip*Wp

Where Seismic Coefficient **Sc** Equals:

	Low Deformability Rp=1.25	Limited Deformability Rp=2.5
Rigid Structures a.p = 1 (Fn=16.7 hz)	**.114**	**.072** (Calculated=.057 but reverts to min. value)
Non Rigid Structures a.p = 1.5 (Fn<16.7 hz)	**.171**	**.085**

Adjusting the z/h ration for varying heights and plugging back in to the above equation we ascertain an equation for mounting equipment at varying heights above the test cell floor.

Where h = the mounting location in feet above the Test Cell Floor

Fp = Sc*Ip*(1+.0246*h)*Wp

Note:

Fp shall be no greater than Fp = .38*Ip*Wp

Fp shall not be less than Fp = .072*Ip*Wp

For most applications on NCSX Ip=1. Exceptions include equipment or structures which present a physical hazard to personnel during an earthquake or equipment that holds flammable or explosive materials for which Ip=1.5.

4.3 Buildings with self supporting structures (supported at grade)

A static seismic analysis is acceptable for self supporting components and equipment such as tanks and vessels. This section is appropriate for equipment and structures supported at the ground or fastened to the base foundation (in our case the Test Cell Basement). For equipment, structures or components installed at elevated levels refer to 4.2 **"**Non Buildings supported by other structures". If the structure is rigid it is advantageous to use the exceptions allowed for "Rigid" components to simplify the analysis (see 4.4)

Section 1622.2 of IBC 2000 applies

The basis for this analysis is the same as Section 1617.4.1 (see "4.1" above). It is allowable for self supporting components to divide the shear force V by1.4 if an "allowable stress" criteria is being used for acceptance. For example it is acceptable to use V/1.4 if the acceptance criteria is for the stress not to exceed 2/3 yield.

V= Cs*W Equation 16-34

Cs = Sds / (R / Ie) Equation 16-35

V is the Seismic Base Shear

W is the effective weight of the structure including dead load and other loads as listed in 1617.4.1

I = Importance factor Table 1622.2.5(2)

I=1.00 for low explosion, fire, and physical hazard risk

I=1.25 moderate explosion, fire, and physical hazard risk

I=1.50 high explosion, fire, and physical hazard risk

R = Lesser of Tables 1617.6 and 1622.2.5 but shall not exceed 3

V = (.24 / R)*I*W

Or

V = (.17 / R))*I*W when using allowable stress criteria

Note: V is reduced when the acceptance criteria already accounts for a factor of safety. A higher value for V must be used if for example the acceptance criteria is the yield strength instead of 2/3 yield.

V need not exceed V = (.057*I*Wp) / (R*T) Equation 16-36

V shall not be less than V = .034*I*Wp Equation 16-75

where T is the fundamental period of the building (section 1617.4.2.1)

4.4 Rigid Non Building Structures (supported at grade)

For Rigid Non Building structures supported at grade (Test Cell Basement Floor) a simplified static analysis is allowed. This section is applicable for a wide range of components whose stiffness is such that they will not couple with the low frequency vibrations due to an earthquake. As a result the force applied is much lower and dampening factor R need not be considered. It is allowable for self supporting components to divide the shear force V by1.4 if an “allowable stress” criteria is being used for acceptance. For example it is acceptable to use V/1.4 if the acceptance criteria is for the stress not to exceed 2/3 yield.

Section 1622.2.6 of IBC 2000 applies.

The following criteria apply to components whose natural frequency

is greater than 16.7 hz:

V = .3*Sds*W*I Equation 16-77

V = The total design lateral seismic base shear force applied to the non building structure

W = Operating weight

I = Importance factor Table 1622.2.5(2)

I=1.00 for low explosion, fire, and physical hazard risk

I=1.25 moderate explosion, fire, and physical hazard risk

I=1.50 high explosion, fire, and physical hazard risk

V = .072*I*W

V = .051*I*W when using allowable stress criteria

4.5 Dynamic Analysis

It may be desirable to use a dynamic analysis:

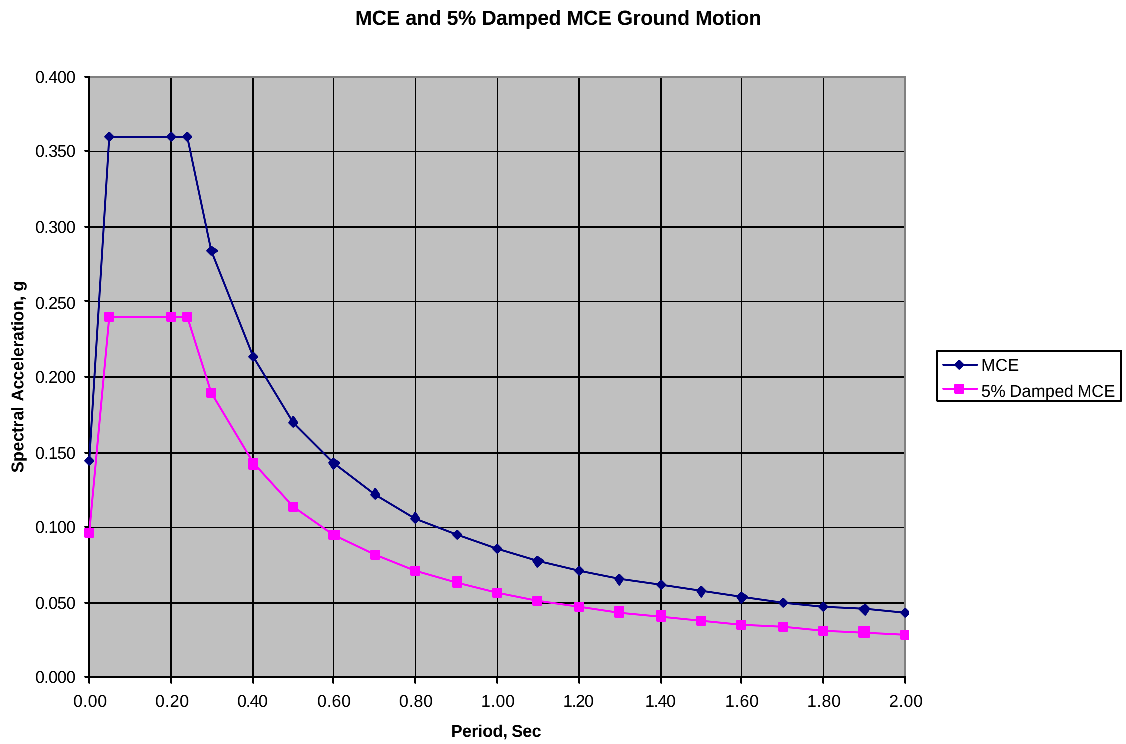
- For components or systems that do not fall into a clear category
- When a dynamic analysis offers relief in lower required seismic inputs

(for example if the component does not fall into a well defined category the selection of most conservative selection of "R" leads to high static base shear inputs)

- For complex systems where a dynamic analysis is necessary for accurately determining failure modes during a seismic event.

The following is the IBC 2000 ground level seismic input for the Maximum Considered Earthquake at PPPL with Site Class Soil considerations taken into account. The input is given with and without 5% dampening. Per DOE STD-1020-2002 we are to use the 5% dampened seismic input (2/3 Sds and 2/3 Sd1). Section 1618 of IBC 2000 applies. An amplification factor of **(1 + 2*z/h)=1.48** can be applied to interpolate the ground level input to the test cell floor level. (see section 4.2)

	Spectral Acceleration, g	
Period, Sec	**MCE**	**5% Damped MCE**
0.00	0.144	0.096
0.05	0.360	0.240
0.20	0.360	0.240
0.24	0.360	0.240
0.30	0.284	0.189
0.40	0.213	0.142
0.50	0.170	0.113
0.60	0.142	0.095
0.70	0.122	0.081
0.80	0.106	0.071
0.90	0.095	0.063
1.00	0.085	0.057
1.10	0.077	0.051
1.20	0.071	0.047
1.30	0.065	0.043
1.40	0.061	0.041
1.50	0.057	0.038
1.60	0.053	0.035
1.70	0.050	0.033
1.80	0.047	0.031
1.90	0.045	0.030
2.00	0.043	0.029


MCE and 5% Damped MCE Ground Motion
Spectral Acceleration, g
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Period, Sec
MCE
5% Damped MCE

APPENDIX A – APPLICABLE TABLES FROM THE IBC 2000

TABLE 1617.6
DESIGN COEFFICIENTS AND FACTORS FOR BASIC SEISMIC-FORCE-RESISTING SYSTEMS

BASIC SEISMIC-FORCE-RESISTING SYSTEM	DETAILING REFERENCE SECTION	RESPONSE MODIFICATION COEFFICIENT, R	SYSTEM OVER-STRENGTH FACTOR, Ω_0^g	DEFLECTION AMPLIFICATION FACTOR, C_d^b	SYSTEM LIMITATIONS AND BUILDING HEIGHT LIMITATIONS (FEET) BY SEISMIC DESIGN CATEGORY[c] AS DETERMINED IN SECTION 1616.3: A or B	C	D[d]	E[e]	F[e]
1. Bearing Wall Systems									
A. Ordinary steel braced frames	(14)[j] 2211	4	2	3½	NL	NL	160	160	160
B. Special reinforced concrete shear walls	1910.2.4	5½	2½	5	NL	NL	160	160	160
C. Ordinary reinforced concrete shear walls	1910.2.3	4½	2½	4	NL	NL	NP	NP	NP
D. Detailed plain concrete shear walls	1910.2.2	2½	2½	2	NL	NP	NP	NP	NP
E. Ordinary plain concrete shear walls	1910.2.1	1½	2½	1½	NL	NP	NP	NP	NP
F. Special reinforced masonry shear walls	2106.1.1.5	5	2½	3½	NL	NL	160	160	100
G. Intermediate reinforced masonry shear walls	2106.1.1.4	3½	2½	2¼	NL	NL	NP	NP	NP
H. Ordinary reinforced masonry shear walls	2106.1.1.2	2½	2½	1¾	NL	160	NP	NP	NP
I. Detailed plain masonry shear walls	2106.1.1.3	2	2½	1¾	NL	NP	NP	NP	NP
J. Ordinary plain masonry shear walls	2106.1.1.1	1½	2½	1¼	NL	NP	NP	NP	NP
K. Light frame walls with shear panels—wood structural panels/sheet steel panels	2306.4.1/ 2211	6	3	4	NL	NL	65	65	65
L. Light frame walls with shear panels—all other materials	2306.4.5	2	2 ½	2	NL	NL	35	NP	NP
2. Building Frame Systems									
A. Steel eccentrically braced frames, moment-resisting, connections at columns away from links	(15)[j]	8	2	4	NL	NL	160	160	100
B. Steel eccentrically braced frames, nonmoment resisting, connections at columns away from links	(15)[j]	7	2	4	NL	NL	160	160	100
C. Special steel concentrically braced frames	(13)[j]	6	2	5	NL	NL	160	160	100
D. Ordinary steel concentrically braced frames	(14)[j]	5	2	4½	NL	NL	160	100	100
E. Special reinforced concrete shear walls	1910.2.4	6	2½	5	NL	NL	160	160	100
F. Ordinary reinforced concrete shear walls	1910.2.3	5	2½	4½	NL	NL	NP	NP	NP
G. Detailed plain concrete shear walls	1910.2.2	3	2½	2½	NL	NP	NP	NP	NP
H. Ordinary plain concrete shear walls	1910.2.1	2	2½	2	NP	NP	NP	NP	NP
I. Composite eccentrically braced frames	(14)[k]	8	2	4	NL	NL	160	160	100

(continued)

TABLE 1617.6—continued
DESIGN COEFFICIENTS AND FACTORS FOR BASIC SEISMIC-FORCE-RESISTING SYSTEMS

BASIC SEISMIC-FORCE-RESISTING SYSTEM	DETAILING REFERENCE SECTION	RESPONSE MODIFICATION COEFFICIENT, R[a]	SYSTEM OVER-STRENGTH FACTOR, Ω_0[g]	DEFLECTION AMPLIFICATION FACTOR, C_d[b]	SYSTEM LIMITATIONS AND BUILDING HEIGHT LIMITATIONS (FEET) BY SEISMIC DESIGN CATEGORY[c] AS DETERMINED IN SECTION 1616.3				
					A or B	C	D[d]	E[e]	F[e]
J. Composite concentrically braced frames	(13)[k]	5	2	4½	NL	NL	160	160	100
K. Ordinary composite braced frames	(12)[k]	3	2	3	NL	NL	NP	NP	NP
L. Composite steel plate shear walls	(17)[k]	6½	2½	5½	NL	NL	160	160	100
M. Special composite reinforced concrete shear walls with steel elements	(16)[k]	6	2½	5	NL	NL	160	160	100
N. Ordinary composite reinforced concrete shear walls with steel elements	(15)[k]	5	2½	4½	NL	NL	NP	NP	NP
O. Special reinforced masonry shear walls	2106.1.1.5	5½	2½	4	NL	NL	160	160	100
P. Intermediate reinforced masonry shear walls	2106.1.1.4	4	2½	2½	NL	NL	NP	NP	NP
Q. Ordinary reinforced masonry shear walls	2106.1.1.2	3	2½	2¼	NL	160	NP	NP	NP
R. Detailed plain masonry shear walls	2106.1.1.3	2½	2½	2¼	NL	NP	NP	NP	NP
S. Ordinary plain masonry shear walls	2106.1.1.1	1½	2½	1¼	NL	NP	NP	NP	NP
T. Light frame walls with shear panels—wood structural panels/sheet steel panels	2306.4.1/ 2211	6½	2½	4½	NL	NL	65	65	65
U. Light frame walls with shear panels—all other materials	2306.4.5	2½	2½	2½	NL	NL	35	NP	NP
3. Moment-resisting Frame Systems									
A. Special steel moment frames	(9)[j]	8	3	5½	NL	NL	NL	NL	NL
B. Special steel truss moment frames	(12)[j]	7	3	5½	NL	NL	160	100	NP
C. Intermediate steel moment frames	(10)[j]	6	3	5	NL	NL	160	100	NP[h]
D. Ordinary steel moment frames	(11)[j]	4	3	3½	NL	NL	35[h]	NP[h,i]	NP[h,i]
E. Special reinforced concrete moment frames	(21.1)[l]	8	3	5½	NL	NL	NL	NL	NL
F. Intermediate reinforced concrete moment frames	(21.1)[l]	5	3	4½	NL	NL	NP	NP	NP
G. Ordinary reinforced concrete moment frames	(21.1)[l]	3	3	2½	NL	NP	NP	NP	NP
H. Special composite moment frames	(9)[k]	8	3	5½	NL	NL	NL	NL	NL
I. Intermediate composite moment frames	(10)[k]	5	3	4½	NL	NL	NP	NP	NP
J. Composite partially restrained moment frames	(8)[k]	6	3	5½	160	160	100	NP	NP
K. Ordinary composite moment frames	(11)[k]	3	3	2½	NL	NP	NP	NP	NP
L. Masonry wall frames	2108.9.6 2106.1.1.6	5½	3	5	NL	NL	160	160	100

(continued)

TABLE 1617.6—continued
DESIGN COEFFICIENTS AND FACTORS FOR BASIC SEISMIC-FORCE-RESISTING SYSTEMS

BASIC SEISMIC-FORCE-RESISTING SYSTEM	DETAILING REFERENCE SECTION	RESPONSE MODIFICATION COEFFICIENT, R^a	SYSTEM OVER-STRENGTH FACTOR, Ω_0^g	DEFLECTION AMPLIFICATION FACTOR, C_d^b	SYSTEM LIMITATIONS AND BUILDING HEIGHT LIMITATIONS (FEET) BY SEISMIC DESIGN CATEGORY[c] AS DETERMINED IN SECTION 1616.3: A or B	C	D[d]	E[e]	F[e]
4. Dual Systems with Special Moment Frames									
A. Steel eccentrically braced frames, moment-resisting connections, at columns away from links	(15)[j]	8	2½	4	NL	NL	NL	NL	NL
B. Steel eccentrically braced frames, nonmoment-resisting connections, at columns away from links	(15)[j]	7	2½	4	NL	NL	NL	NL	NL
C. Special steel concentrically braced frames	(13)[j]	8	2½	6½	NL	NL	NL	NL	NL
D. Ordinary steel concentrically braced frames	(14)[j]	6	2½	5	NL	NL	NL	NL	NL
E. Special reinforced concrete shear walls	1910.2.4	8	2½	6½	NL	NL	NL	NL	NL
F. Ordinary reinforced concrete shear walls	1910.2.3	7	2½	6	NL	NL	NP	NP	NP
G. Composite eccentrically braced frames	(14)[k]	8	2½	4	NL	NL	NL	NL	NL
H. Composite concentrically braced frames	(13)[k]	6	2½	5	NL	NL	NL	NL	NL
I. Composite steel plate shear walls	(17)[k]	8	2½	6½	NL	NL	NL	NL	NL
J. Special composite reinforced concrete shear walls with steel elements	(16)[k]	8	2½	6½	NL	NL	NL	NL	NL
K. Ordinary composite reinforced concrete shear walls with steel elements	(15)[k]	7	2½	6	NL	NL	NP	NP	NP
L. Special reinforced masonry shear walls	2106.1.1.5	7	3	6½	NL	NL	NL	NL	NL
M. Intermediate reinforced masonry shear walls	2106.1.1.4	6½	3	5½	NL	NL	NP	NP	NP
5. Dual Systems with Intermediate Moment Frames									
A. Special steel concentrically braced frames[f]	(13)[j]	6	2½	5	NL	NL	160	100	NP
B. Ordinary steel concentrically braced frames[f]	(14)[j]	5	2½	4½	NL	NL	160	100	NP
C. Special reinforced concrete shear walls	1910.2.4	6	2½	5	NL	NL	160	100	100
D. Ordinary reinforced concrete shear walls	1910.2.3	5½	2½	4½	NL	NL	NP	NP	NP
E. Ordinary reinforced masonry shear walls	2106.1.1.2	3	3	2½	NL	160	NP	NP	NP
F. Intermediate reinforced masonry shear walls	2106.1.1.4	5	3	4½	NL	NL	NP	NP	NP
G. Composite concentrically braced frames	(13)[k]	5	2½	4½	NL	NL	160	100	NP
H. Ordinary composite braced frames	(12)[k]	4	2½	3	NL	NL	NP	NP	NP
I. Ordinary composite reinforced concrete shear walls with steel elements	(15)[k]	5½	2½	4½	NL	NL	NP	NP	NP

(continued)

TABLE 1617.6—continued
DESIGN COEFFICIENTS AND FACTORS FOR BASIC SEISMIC-FORCE-RESISTING SYSTEMS

BASIC SEISMIC-FORCE-RESISTING SYSTEM	DETAILING REFERENCE SECTION	RESPONSE MODIFICATION COEFFICIENT, R^a	SYSTEM OVER-STRENGTH FACTOR, Ω_0^g	DEFLECTION AMPLIFICATION FACTOR, C_d^b	SYSTEM LIMITATIONS AND BUILDING HEIGHT LIMITATIONS (FEET) BY SEISMIC DESIGN CATEGORY[c] AS DETERMINED IN SECTION 1616.3				
					A or B	C	D[d]	E[e]	F[e]
J. Shear wall-frame interactive system with ordinary reinforced concrete moment frames and ordinary reinforced concrete shear walls	21.1[l] 1910.2.3	5½	2½	5	NL	NP	NP	NP	NP
6. Inverted Pendulum Systems									
A. Cantilevered column systems		2½	2	2½	NL	NL	35	35	35
B. Special steel moment frames	(9)[j]	2½	2	2½	NL	NL	NL	NL	NL
C. Ordinary steel moment frames	(11)[j]	1¼	2	2½	NL	NL	NP	NP	NP
D. Special reinforced concrete moment frames	21.1[l]	2½	2	1¼	NL	NL	NL	NL	NL
7. Structural steel systems not specifically detailed for seismic resistance	AISC—ASD AISC—LRFD AISI AISC—HSS	3	3	3	NL	NL	NP	NP	NP

For SI: 1 foot = 304.8 mm, 1 pound per square foot = 0.0479 KN/m^2.

a. Response modification coefficient, R, for use throughout.
b. Deflection amplification factor, C_d.
c. NL = not limited and NP = not permitted.
d. See Section 1617.6.4.1 for a description of building systems limited to buildings with a height of 240 feet or less.
e. See Section 1617.6.4.1 for building systems limited to buildings with a height of 160 feet or less.
f. Ordinary moment frame is permitted to be used in lieu of intermediate moment frame in Seismic Design Categories B and C.
g. The tabulated value of the overstrength factor, Ω_0, may be reduced by subtracting ½ for structures with flexible diaphragms but shall not be taken as less than 2.0 for any structure.
h. Steel ordinary moment frames and intermediate moment frames are permitted in single story buildings up to a height of 60 feet, when the moment joints of field connections are constructed of bolted end plates and the dead load of the roof does not exceed 15 pounds per square foot. The dead weight of the portion of walls more than 35 feet above the base shall not exceed 15 pounds per square foot.
i. Steel ordinary moment frames are permitted in buildings up to a height of 35 feet, where the dead load of the walls, floors and roof does not exceed 15 pounds per square foot.
j. AISC Seismic Part I or Part III, Section number.
k. AISC Seismic Part II, Section number.
l. ACI 318, Section number.

TABLE 1621.2
ARCHITECTURAL COMPONENTS COEFFICIENTS

ARCHITECTURAL COMPONENT OR ELEMENT	COMPONENT AMPLIFICATION FACTOR a_p*	COMPONENT RESPONSE MODIFICATION FACTOR R_p
Interior nonstructural walls and partitions (see also Section 1621.2.7)		
a. Plain (unreinforced) masonry walls	1.0	1.25
b. Other walls and partitions	1.0	2.5
Cantilever elements (unbraced or braced to structural frame below its center of mass)		
a. Parapets and cantilever interior nonstructural walls	2.5	2.5
b. Chimneys and stacks when laterally braced or supported by the structural frame	2.5	2.5
Cantilever elements (braced to structural frame above its center of mass)		
a. Parapets	1.0	2.5
b. Chimneys and stacks	1.0	2.5
c. Exterior nonstructural walls	1.0	2.5
Exterior nonstructural wall elements and connections (see also Section 1621.2.3)		
a. Wall element	1.0	2.5
b. Body of wall panel connections	1.0	2.5
c. Fasteners of the connecting system	1.25	1.0
Veneer		
a. Limited deformability elements and attachments	1.0	2.5
b. Low deformability elements or attachments	1.0	1.25
Penthouses (except when framed by an extension of the building frame)	2.5	3.5
Ceilings (see also Section 1621.2.5)	1.0	2.5
Cabinets		
a. Storage cabinets and laboratory equipment	1.0	2.5
Access floors (see also Section 1621.2.6)		
a. Special access floors (designed in accordance with Section 1621.2.6.1)	1.0	2.5
b. All other	1.0	1.25
Appendages and ornamentations	2.5	2.5
Signs and billboards	2.5	2.5
Other rigid components		
a. High deformability elements and attachments	1.0	3.5
b. Limited deformability elements and attachments	1.0	2.5
c. Low deformability materials and attachments	1.0	1.25
Other flexible components		
a. High deformability elements and attachments	1.0	3.5
b. Limited deformability elements and attachments	2.5	2.5
c. Low deformability materials and attachments	2.5	1.25

*Where justified by detailed dynamic analyses, a lower value for a_p is permitted, but shall not be less than 1. The reduced value of a_p shall be between 2.5, assigned to flexible or flexibly attached equipment, and 1, assigned to rigid or rigidly attached equipment.

TABLE 1621.3
MECHANICAL AND ELECTRICAL COMPONENTS COEFFICIENTS

MECHANICAL AND ELECTRICAL COMPONENT OR ELEMENT	Component Amplification Factor (a_p)[a]	Component Response Modification Factor R_p
1. General mechanical		
a. Boilers and furnaces	1.0	2.5
b. Pressure vessels on skirts and free-standing	2.5	2.5
c. Stacks	2.5	2.5
d. Cantilevered chimneys	2.5	2.5
e. Other	1.0	2.5
2. Manufacturing and process machinery		
a. General	1.0	2.5
b. Conveyors (nonpersonnel)	2.5	2.5
3. Piping systems		
a. High deformability elements and attachments	1.0	3.5
b. Limited deformability elements and attachments	1.0	2.5
c. Low deformability elements or attachments	1.0	1.25
4. HVAC system equipment		
a. Vibration isolated	2.5	2.5
b. Nonvibration isolated	1.0	2.5
c. Mounted in-line with ductwork	1.0	2.5
d. Other	1.0	2.5
5. Elevator components	1.0	2.5
6. Escalator components	1.0	2.5
7. Trussed towers (free-standing or guyed)	2.5	2.5
8. General electrical		
a. Distributed systems (bus ducts, conduit, cable tray)	1.0	3.5
b. Equipment	1.0	2.5

a. Where justified by detailed dynamic analyses, a lower value of a_p is permitted, but shall not be less than 1. The reduced value of a_p shall be between 2.5, assigned to flexible or flexibly attached equipment, and 1, assigned to rigid or rigidly attached equipment.

where:

g = Acceleration of gravity in inches/sec² (mm/s²).

K_p = Stiffness of resilient support system of the component and attachment, determined in terms of load per unit deflection at the center of gravity of the component.

T_p = Component fundamental period.

W_p = Component operating weight.

Alternatively, the fundamental period of the component in seconds, T_p, shall be determined from experimental test data or by analysis.

1621.3.3 Mechanical and electrical component attachments. The stiffness of mechanical and electrical component attachments shall be designed such that the load path for the component performs its intended function.

1621.3.4 Component supports. Mechanical and electrical component supports and the means by which they are attached to the component shall be designed for the forces determined in Section 1621.1.4 and in conformance with the requirements of this code applying to the materials comprising the means of attachment. Such supports include, but are not limited to, structural members, braces, frames, skirts, legs, saddles, pedestals, cables, guys, stays, snubbers and tethers. Component supports are permitted to be forged or cast as a part of the mechanical or electrical component. If standard or proprietary supports are used, they shall be designed by either load rating (i.e., testing) or for the calculated seismic forces. The stiffness of the support shall be designed such that the seismic load path for the component performs its intended function.

Component supports shall be designed to accommodate the seismic relative displacements between points of support determined in accordance with Section 1621.2.5.

The means by which supports are attached to the component, except when integral (i.e., cast or forged), shall be designed to accommodate both the forces and displacements determined in accordance with Sections 1621.1.4 and 1621.1.5. If the value of I_p = 1.5 for the component, the local region of the support attachment point to the component shall be designed to resist the effect of the load transfer on the component wall.

TABLE 1622.2.5(1)
SEISMIC COEFFICIENTS FOR NONBUILDING STRUCTURES

NONBUILDING STRUCTURE TYPE	Response Modification Coefficient R	System Over-Strength Factor Ω_0	Deflection Amplification Factor C_d	STRUCTURAL SYSTEM AND HEIGHT LIMITS[c] (feet) Seismic design category as determined in Section 1616 B	C	D	E or F
1. Nonbuilding frame systems:							
a. Concentric braced frame of steel	See Table 1617.6			NL	NL	NL	NL
b. Special concentric braced frames of steel				NL	NL	NL	NL
2. Moment-resisting frame systems:							
a. Special moment frames of steel	See Table 1617.6			NL	NL	NL	NL
b. Ordinary moment frames of steel				NL	NL	50	50
c. Special moment frames of concrete				NL	NL	NL	NL
d. Intermediate moment frames of concrete				NL	NL	50	50
3. Ordinary moment frames of concrete				NL	50	NP	NP
4. Steel storage racks	4	2	$3\frac{1}{2}$	NL	NL	NL	NL
5. Elevated tanks, vessels, bins or hoppers[a]							
a. On braced legs	3	2	$2\frac{1}{2}$	NL	NL	NL	NL
b. On unbraced legs	3	2	$2\frac{1}{2}$	NL	NL	NL	NL
c. Irregular braced legs single pedestal or skirt supported	2	2	2	NL	NL	NL	NL
d. Welded steel	2	2	2	NL	NL	NL	NL
e. Concrete	2	2	2	NL	NL	NL	NL
6. Horizontal, saddle supported welded steel vessels	3	2	$2\frac{1}{2}$	NL	NL	NL	NL
7. Tanks or vessels supported on structural towers similar to buildings	3	2	2	NL	NL	NL	NL
8. Flat bottom, ground supported tanks, or vessels:							
a. Anchored (welded or bolted steel)	3	2	$2\frac{1}{2}$	NL	NL	NL	NL
b. Unanchored (welded or bolted steel)	$2\frac{1}{2}$	2	2	NL	NL	NL	NL
9. Reinforced or prestressed concrete:							
a. Tanks with reinforced nonsliding base	2	2	2	NL	NL	NL	NL
b. Tanks with anchored flexible base	3	2	2	NL	NL	NL	NL
10. Tanks with unanchored and unconstrained:							
a. Flexible base	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{2}$	NL	NL	NL	NL
b. Other material	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{2}$	NL	NL	NL	NL
11. Cast-in-place concrete silos, stacks and chimneys having walls continuous to the foundation	3	$1\frac{3}{4}$	3	NL	NL	NL	NL
12. Other reinforced masonry structures	3	2	$2\frac{1}{2}$	NL	NL	50	50
13. Other nonreinforced masonry structures	$1\frac{1}{4}$	2	$1\frac{1}{2}$	NL	50	50	50
14. Other steel and reinforced concrete distributed mass cantilever structures not covered herein including stacks, chimneys, silos, and skirt-supported vertical vessels	3	2	$2\frac{1}{2}$	NL	NL	NL	NL
15. Trussed towers (freestanding or guyed), guyed stacks and chimneys	3	2	$2\frac{1}{2}$	NL	NL	NL	NL
16. Cooling towers:							
a. Concrete or steel	$3\frac{1}{2}$	$1\frac{3}{4}$	3	NL	NL	NL	NL
b. Wood frame	$3\frac{1}{2}$	3	3	NL	NL	50	50
17. Telecommunication towers							
a. Truss: Steel	3	$1\frac{1}{2}$	3	NL	NL	NL	NL
b. Pole: Steel	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{2}$	NL	NL	NL	NL
Wood	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{2}$	NL	NL	NL	NL
Concrete	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{2}$	NL	NL	NL	NL
c. Frame: Steel	3	$1\frac{1}{2}$	$1\frac{1}{2}$	NL	NL	NL	NL
Wood	$2\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{2}$	NL	NL	NL	NL
Concrete	2	$1\frac{1}{2}$	$1\frac{1}{2}$	NL	NL	NL	NL
18. Amusement structures and monuments	2	2	2	NL	NL	NL	NL
19. Inverted pendulum-type structures (not elevated tank)[b]	2	2	2	NL	NL	NL	NL
20. Signs and billboards	$3\frac{1}{2}$	$1\frac{3}{4}$	3	NL	NL	NL	NL
21. Other self-supporting structures, tanks or vessels not covered above	$1\frac{1}{4}$	2	$2\frac{1}{2}$	NL	50	50	50

For SI: 1 foot = 304.8 mm.
NL = No limit.
NP = Not permitted.
a. Support towers similar to building-type structures, including those with irregularities (see Section 1616.5 for definition of irregular structures) shall comply with the requirements of Section 1617.6.3 for Seismic Design Category F structures.
b. Light posts, stoplight, etc.
c. Above base.