Seismic Design Using the 2006 IBC and ASCE 7-05

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Overview

Seismic Design Using the 2006 IBC and ASCE 7-05

2006 *International Building Code*

- Uses ASCE 7-05 as primary structural reference
  - No required modifications to ASCE 7
  - A few alternates to ASCE 7
- References materials standards for structural design
- Contains geotechnical investigation requirements
- Contains analysis, design, detailing, and installation requirements for foundations
- Contains detailed inspection, testing, and observation requirements for structural and nonstructural systems

ASCE 7-05: Significant Changes

- Completely reorganized
- Updated seismic hazard maps (available online)
- Seismic Use Group eliminated
  (Occupancy Category used directly)
- Revised structural systems and limitations
- New redundancy factor
- New simplified design procedure--not covered in this presentation
- http://content.seinstitute.org/publications/errata.html

Seismic Hazard Maps Online

- S_s and S_1, Hazard Curves, Uniform Hazard Spectra
  - Location-specific values for various building codes
  - Hazard curves and uniform hazard spectra by location
- http://earthquake.usgs.gov/research/hazmaps/

Seismic Design Criteria

Seismic Design Using the 2006 IBC and ASCE 7-05

Seismic Design Options

- 2003 IBC
  - IBC Sections 1614 through 1623 based on and referring to ASCE 7-02, with several modifications

    or
  - ASCE 7-02 Sections 9.1 through 9.6, 9.13, and 9.14 without IBC modifications to ASCE 7-02
- 2006 IBC
  - IBC Section 1613 based on and referring to ASCE 7-05, with several alternates
  - SDC permitted to be determined based on IBC or ASCE 7 (same procedure for both)

IBC Alternates to ASCE 7 Provisions

- No IBC modifications to ASCE 7, just alternates
  - Section 1613.6.1 Flexible diaphragm assumptions
  - Section 1613.6.2 Additional seismic-force-resisting systems for seismically isolated structures
- Otherwise, use ASCE 7-05
- Use IBC for modifications to materials standards (IBC Chapters 19-23)

ASCE 7-05 Seismic Reorganization – Goals

1. Improve clarity and use
2. Reduce depth of section numbering from 6 max typical to 4 max typical

   (i.e., Sec. 9.5.2.5.2.2 is now Sec. 12.5.3)
3. Simplify table and figure numbering

   (i.e., Table 9.5.2.5.1 is now Table 12.6-1)
4. Create logical sequence of provisions aim at the structural engineering community
5. Improve headings and clarify ambiguous provisions

ASCE 7-05 Reorganization

1. Changed major subjects to Chapters rather than Sections (similar to the IBC)
2. Replaced Chapter 9 with Chapters 11-23
3. Incorporated detailing references into system table
4. Put the chapters into a logical sequence
5. Rewrote ambiguous headings
6. Rewrote sections to eliminate ambiguity
7. Provided Cross Reference Table C11-1…02 to 05

Seismic Design Criteria

ASCE 7-05 Section 11.1 Purpose

"…specified earthquake loads are based upon post-elastic energy dissipation in the structure, and because of this fact, the requirements for design, detailing, and construction shall be satisfied even for structures and members for which *load combos w/o EQ exceed those with EQ*…"

Chapter 11 Seismic Design Criteria

11.1 General
11.2 Definitions
11.3 Notation
11.4* Seismic Ground Motion Values
11.5* Importance Factor
11.6* Seismic Design Category
11.7 Design Requirements for Category A
11.8** Geologic Hazards & Geotechnical Investigation

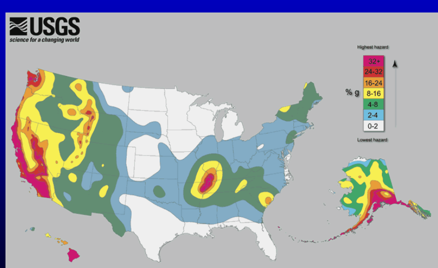
*Use ASCE 7 or IBC Section 1613
**Don't use; use IBC Chapter 18 instead

Seismic Hazard

- Same method as 2003 IBC
  - Response spectrum ordinates are mapped
  - Near-fault effects are included in basic maps
  - Data is "location-specific"
  - Soil effects still handled separately
- Updated – 2002 USGS Seismic Hazard Maps
  - Minor differences, depending on location
- Soil factors same as 2003 IBC

Seismic Hazard Maps

- MCE Spectral Accelerations: S_S, S_1



http://eqhazmaps.usgs.gov

What is MCE?

- Maximum <u>Considered</u> Earthquake
  - (**NOT** maximum <u>credible</u> earthquake OR maximum <u>capable</u> earthquake)
- Ground motion that is the lesser of:
  - 2% probability of exceedance in 50 years (2475 yr m.r.i.)
  - 150% of median acceleration from characteristic earthquakes on known faults, but only if this is greater than 150% of "zone 4" (no consistent m.r.i.)

Summary of Ground Motion

- Maps → S_S, S_1
- Site class, S_S, and S_1 → F_a, F_v
- $S_{MS} = F_a S_S$ $S_{M1} = F_v S_1$
- $S_{DS} = 2/3\, S_{MS}$ $S_{D1} = 2/3\, S_{M1}$ → **Design**

Design Response Spectrum

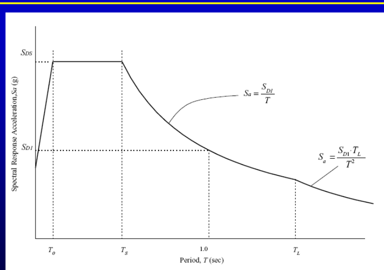


FIGURE 11.4-1 DESIGN RESPONSE SPECTRUM

ASCE 7-05 Figure 11.4-1

Geotechnical Considerations

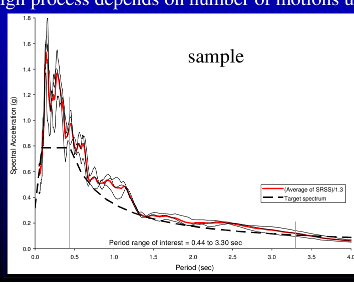
- Site Class (IBC Sec. 1613.5.5 or ASCE 7 Ch. 20)
  - Based on shear wave velocity, SPT blow count, or shear strength
- Identify site hazards (Sec. 1802.2.6)
  - SDC ≥ C
  - Surface faulting
  - Liquefaction, slope instability
- Seismic wall pressures (Sec. 1802.2.7)
  - SDC ≥ D
  - For design purposes treat these loads as “E” not “H”

Site-Specific Ground Motion

- Site response analysis (ASCE 7 Chapter 21)
  - Required for determining F_a and F_v in Site Class F
  - Soil layers above rock modeled and analyzed to quantify amplification of rock motion
- Ground motion hazard analysis
  - Required for seismically isolated structures with large ground motion

Time Histories

- Rules in ASCE 7-05 Section 16.1.3.2
  - Address selection, scaling, period range
  - Design process depends on number of motions used



Occupancy Category and Importance Factors

Occupancy Category	Description	Importance Factor
I	Agricultural, temporary, storage	I_E = 1.0
II	Not Occupancy Category I, III or IV	
III	Substantial hazard to human life: > 300 people in "covered structures whose primary occupancy is public assembly" > 250-person school or day care > 500-person college > 50-resident health care (no surgery) > 5,000 occupants jail, detention	I_E = 1.25
IV	Essential facilities: surgery or emergency health care; fire, rescue, police; emergency vehicle, shelters; aviation control towers; etc.	I_E = 1.50

Drift Limits

Depend on:

- Occupancy category
- Structural system (masonry or not masonry)
- Building height and nonstructural component design

TABLE 12.12-1 ALLOWABLE STORY DRIFT, Δ_a[a,b]

Structure	Occupancy Category		
	I or II	III	IV
Structures, other than masonry shear wall structures, 4 stories or less with interior walls, partitions, ceilings and exterior wall systems that have been designed to accommodate the story drifts.	$0.025h_{sx}$[c]	$0.020h_{sx}$	$0.015h_{sx}$
Masonry cantilever shear wall structures [d]	$0.010h_{sx}$	$0.010h_{sx}$	$0.010h_{sx}$
Other masonry shear wall structures	$0.007h_{sx}$	$0.007h_{sx}$	$0.007h_{sx}$
All other structures	$0.020h_{sx}$	$0.015h_{sx}$	$0.010h_{sx}$

Impact of Occupancy (strength and drift)

OC (I_E)	Description	$F/F_{typical}$	$\Delta/\Delta_{typical}$
II (**I_E = 1.0**)	Not III or IV ***("typical")***	1.0	1.0
III (**I_E = 1.25**)	Substantial hazard to human life: >300 people in "covered structures whose primary occupancy is public assembly" > 250-person school or day care > 500-person college > 50-resident health care (no surgery) > 5,000 occupants jail, detention	1.25	0.75
IV (**I_E = 1.50**)	Essential facilities: surgery or emergency health care; fire, rescue, police; emergency vehicle, shelters; aviation control towers; etc.	1.5	0.5

Seismic Design Category (SDC)

- IBC Tables 1613.5.6(1) and 1613.5.6(2)
- Function of seismic hazard, site class, and occupancy category
- Controls system selection, analysis, design, and detailing
- Can be based just on S_{DS} in certain conditions
  - *IBC Section 1613.5.6.1*
  - *Short period for analysis and design*
  - *Rigid diaphragm or short diaphragm span*

Seismic Design Category

TABLE 1613.5.6(1)
SEISMIC DESIGN CATEGORY BASED ON SHORT-PERIOD RESPONSE ACCELERATIONS

VALUE OF S_{DS}	OCCUPANCY CATEGORY		
	I or II	III	IV
$S_{DS} < 0.167g$	A	A	A
$0.167g \leq S_{DS} < 0.33g$	B	B	C
$0.33g \leq S_{DS} < 0.50g$	C	C	D
$0.50g \leq S_{DS}$	D	D	D

TABLE 1613.5.6(2)
SEISMIC DESIGN CATEGORY BASED ON 1-SECOND PERIOD RESPONSE ACCELERATION

VALUE OF S_{D1}	OCCUPANCY CATEGORY		
	I or II	III	IV
$S_{D1} < 0.067g$	A	A	A
$0.067g \leq S_{D1} < 0.133g$	B	B	C
$0.133g \leq S_{D1} < 0.20g$	C	C	D
$0.20g \leq S_{D1}$	D	D	D

- SDC E: OC I, II, III where $S_1 \geq 0.75$
- SDC F: OC IV where $S_1 \geq 0.75$

Seismic Design Category A

- Minimum lateral force for integrity/stability
- Lateral load path (connections between parts)
- Anchorage of concrete/masonry walls

- ALL requirements appear in ASCE 7-05 Section 11.7 – no other seismic requirements apply

Load Combinations

- IBC addresses:
  - D, L, L_r, S, R, H, F, T
  - W, E
- Don't use ASCE 7 Chapter 2 or Section 12.4.2.3
- ASCE 7 referenced for:
  - P (ponding), F_a (flood)
- Recognize that not all loads are maximum simultaneously

Seismic Load Combination
Complications

- Strength design v. ASD
- ASD: basic v. alternative

- Redundancy factor, ρ
- Overstrength factor, Ω_0
- Vertical EQ effects, $0.2S_{DS}D$

Redundancy Factor

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Redundancy Defined

- *Unnecessary repetition*
  - For the sake of "engineering economy," some designers have used fewer, larger elements
  - At times this has resulted in poor seismic performance; the repetition was necessary
- *Duplication or repetition of elements … to provide alternative functional channels in case of failure*

American Heritage Dictionary

Advice for Investment (and structures)

- Conventional wisdom:
  "Diversify; don't put all your eggs in one basket."
- Andrew Carnegie:
  "Concentrate; put all your eggs in one basket, and watch that basket."

1997 UBC – 2003 IBC: Questions

- Redundancy or reliability?
- What degree of redundancy? (How many baskets do you have?)
- How big is the building? (Is your basket big or small?)

$$\rho_x = 2 - \frac{20}{r_{max_x}\sqrt{A_x}}$$

ASCE 7-05: Answers

- We want redundancy (multiple elements)
  - Use multiple smaller baskets

    or

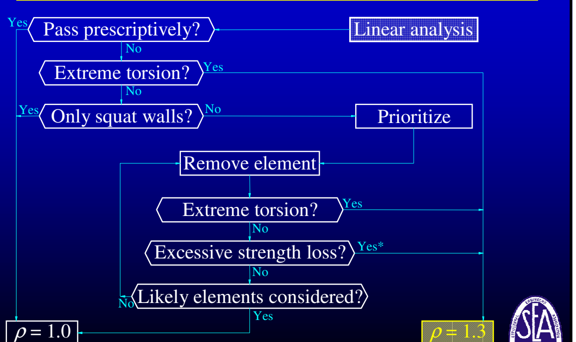
  - Make the basket stronger

- Either a building is redundant or it is not:
  ρ = 1.0 or 1.3
- Building size doesn't matter

Where Does Redundancy Matter?

- Seismic-force-resisting system strength for buildings
- So, ρ = 1.0 for:
  - Seismic Design Category B or C
  - Drift and P-delta effects
  - Nonstructural components
  - Most nonbuilding structures
  - Members designed for Ω_0 forces
  - Prescriptive diaphragm loads
  - Structures with damping systems

Determining the Redundancy Factor

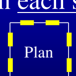


See appendix flowchart

Redundancy: Prescriptive (ρ = 1.0)

(ASCE 7-05 Section 12.3.4.2, item b)

- Regular in plan at all levels
- At least **two bays** of SFR framing at perimeter on each side in each direction (where V_{story} > 0.35V)

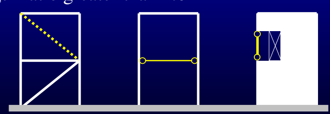


- Count shear wall "bays" as L/h (2L/h for light-framed)

Redundancy: By Calculation

(ASCE 7-05 Section 12.3.4.2, item a)

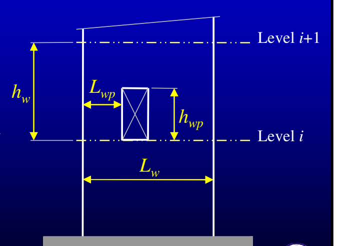
- Where $V_{story} > 0.35\ V$, consider loss of seismic resistance:
  - Braced frames: lose any single brace
  - Moment frames: lose moment resistance at both ends of any single beam (or base of any single cantilever column)
  - Shear walls: lose any single wall or wall pier with height-to-length ratio greater than 1.0



- Criteria:
  - No extreme torsion; reduction in story strength ≤ 33%

Wall Height-to-Length Ratios

- Shear wall
  - h_w/L_w
- Wall pier
  - h_{wp}/L_{wp}
- Consider loss where
  - $h_w/L_w > 1.0$
  - $h_{wp}/L_{wp} > 1.0$



System and Analysis Requirements

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Systems Factor Table (ASCE 7-05)

- 83 choices for systems
- Systems added
  - Precast Shear Walls
  - Buckling-restrained Braced Frames
  - Steel Plate Shear Walls
- Systems deleted
  - Ordinary Steel CBFs (from Bearing Wall and Dual Systems groups)
- Systems renamed
  - Inverted Pendulum Systems and Cantilevered Column Systems → Cantilevered Column Systems
  - Added additional system types in Cantilevered Column Systems group (e.g., Timber Frames)

Systems Factor Table (ASCE 7-05)

TABLE 12.2-1 DESIGN COEFFICIENTS AND FACTORS FOR SEISMIC FORCE–RESISTING SYSTEMS

Seismic Force–Resisting System	ASCE 7 Section where Detailing Requirements are Specified	Response Modification Coefficient, R^a	System Overstrength Factor, $\Omega_0{}^g$	Deflection Amplification Factor, $C_d{}^b$	Structural System Limitations and Building Height (ft) Limit[c] — Seismic Design Category: B	C	D^d	E^d	F^e
A. BEARING WALL SYSTEMS									
1. Special reinforced concrete shear walls	14.2 and 14.2.3.6	5	2½	5	NL	NL	160	160	100
2. Ordinary reinforced concrete shear walls	14.2 and 14.2.3.4	4	2½	4	NL	NL	NP	NP	NP
3. Detailed plain concrete shear walls	14.2 and 14.2.3.2	2	2½	2	NL	NP	NP	NP	NP
4. Ordinary plain concrete shear walls	14.2 and 14.2.3.1	1½	2½	1½	NL	NP	NP	NP	NP
5. Intermediate precast shear walls	14.2 and 14.2.3.5	4	2½	4	NL	NL	40^k	40^k	40^k
6. Ordinary precast shear walls	14.2 and 14.2.3.3	3	2½	3	NL	NP	NP	NP	NP
7. Special reinforced masonry shear walls	14.4 and 14.4.3	5	2½	3½	NL	NL	160	160	100
8. Intermediate reinforced masonry shear walls	14.4 and 14.4.3	3½	2½	2¼	NL	NL	NP	NP	NP
9. Ordinary reinforced masonry shear walls	14.4	2	2½	1¾	NL	160	NP	NP	NP
10. Detailed plain masonry shear walls	14.4	2	2½	1¾	NL	NP	NP	NP	NP
11. Ordinary plain masonry shear walls	14.4	1½	2½	1¼	NL	NP	NP	NP	NP
12. Prestressed masonry shear walls	14.4	1½	2½	1¾	NL	NP	NP	NP	NP
13. Light-framed walls sheathed with wood structural panels rated for shear resistance or steel sheets	14.1, 14.1.4.2, and 14.5	6½	3	4	NL	NL	65	65	65
14. Light-framed walls with shear panels of all other materials	14.1, 14.1.4.2, and 14.5	2	2½	2	NL	NL	35	NP	NP
15. Light-framed wall systems using flat strap bracing	14.1, 14.1.4.2, and 14.5	4	2	3½	NL	NL	65	65	65

Systems Factor Table (ASCE 7-05)

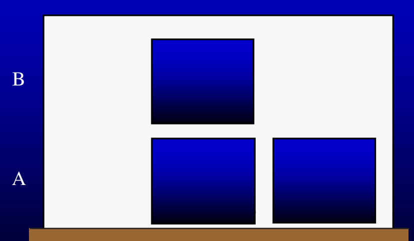
- Column added for detailing requirements section references
- 2006 IBC adds exception to relax limitations for ordinary steel CBFs and MFs for some seismically isolated structures
- Miscellaneous changes to factors and footnotes

Irregularities

- Only 1 change to irregularity types
  - Extreme Weak Story vertical irregularity added

Vertical Structural Irregularities

Weak Story: Strength A < 80% Strength B
Extreme Weak Story: Strength A < 65% Strength B



Weak Story

Irregularities

Additional reference sections have been added to tables. Some do not change provisions and simply provide additional clarity. Some are references to new requirements (e.g. the Horizontal Irregularity Type 1a reference to 12.7.3).

TABLE 12.3-1 HORIZONTAL STRUCTURAL IRREGULARITIES

	Irregularity Type and Description	Reference Section	Seismic Design Category Application
1a.	**Torsional Irregularity** is defined to exist where the maximum story drift, computed including accidental torsion, at one end of the structure transverse to an axis is more than 1.2 times the average of the story drifts at the two ends of the structure. Torsional irregularity requirements in the reference sections apply only to structures in which the diaphragms are rigid or semirigid.	12.3.3.4 12.8.4.3 12.7.3 12.12.1 Table 12.6-1 Section 16.2.2	D, E, and F C, D, E, and F B, C, D, E, and F C, D, E, and F D, E, and F B, C, D, E, and F
1b.	**Extreme Torsional Irregularity** is defined to exist where the maximum story drift, computed including accidental torsion, at one end of the structure transverse to an axis is more than 1.4 times the average of the story drifts at the two ends of the structure. Extreme torsional irregularity requirements in the reference sections apply only to structures in which the diaphragms are rigid or semirigid.	12.3.3.1 12.3.3.4 12.7.3 12.8.4.3 12.12.1 Table 12.6-1 Section 16.2.2	E and F D B, C, and D C and D C and D D B, C, and D
2.	**Reentrant Corner Irregularity** is defined to exist where both plan projections of the structure beyond a reentrant corner are greater than 15% of the plan dimension of the structure in the given direction.	12.3.3.4 Table 12.6-1	D, E, and F D, E, and F
3.	**Diaphragm Discontinuity Irregularity** is defined to exist where there are diaphragms with abrupt discontinuities or variations in stiffness, including those having cutout or open areas greater than 50% of the gross enclosed diaphragm area, or changes in effective diaphragm stiffness of more than 50% from one story to the next.	12.3.3.4 Table 12.6-1	D, E, and F D, E, and F
4.	**Out-of-Plane Offsets Irregularity** is defined to exist where there are discontinuities in a lateral force-resistance path, such as out-of-plane offsets of the vertical elements.	12.3.3.4 12.3.3.3 12.7.3 Table 12.6-1 16.2.2	D, E, and F B, C, D, E, and F B, C, D, E, and F D, E, and F B, C, D, E, and F
5.	**Nonparallel Systems-Irregularity** is defined to exist where the vertical lateral force-resisting elements are not parallel to or symmetric about the major orthogonal axes of the seismic force–resisting system.	12.5.3 12.7.3 Table 12.6-1 Section 16.2.2	C, D, E, and F B, C, D, E, and F D, E, and F B, C, D, E, and F

Analysis Procedures

TABLE 9.5.2.5.1
PERMITTED ANALYTICAL PROCEDURES

Seismic Design Category	Structural Characteristics	Index Force Analysis Section 9.5.3	Simplified Analysis Section 9.5.4	Equivalent Lateral Force Analysis Section 9.5.5	Modal Response Spectrum Analysis Section 9.5.6	Linear Response History Analysis Section 9.5.7	Nonlinear Response History Analysis Section 9.5.8
A	All structures	P	P	P	P	P	P
B, C	SUG-1 buildings of light-framed construction not exceeding three stories in height	NP	P	P	P	P	P
	Other SUG-1 buildings not exceeding two stories in height	NP	P	P	P	P	P
	All other structures	NP	NP	P	P	P	P
D, E, F	SUG-1 buildings of light-framed construction not exceeding three stories in height	NP	P	P	P	P	
	Other SUG-1 buildings not exceeding two stories in height	NP	P	P	P	P	P
	Regular structures with $T < 3.5 T_s$ and all structures of light-frame construction	NP	NP	P	P	P	P
	Irregular structures with $T < 3.5 T_s$ and having only plan irregularities type 2, 3, 4, or 5 of Table 9.5.2.3.2 or vertical irregularities type 4 or 5 of Table 9.5.2.3.3	NP	NP	P	P	P	P
	All other structures	NP	NP	NP	P	P	P

Notes: P — indicates permitted, NP — indicates not permitted

ASCE 7-02

TABLE 12.6-1 PERMITTED ANALYTICAL PROCEDURES

Seismic Design Category	Structural Characteristics	Equivalent Lateral Force Analysis Section 12.8	Modal Response Spectrum Analysis Section 12.9	Seismic Response History Procedures Chapter 16
B, C	Occupancy Category I or II buildings of light-framed construction not exceeding 3 stories in height	P	P	P
	Other Occupancy Category I or II buildings not exceeding 2 stories in height	P	P	P
	All other structures	P	P	P
D, E, F	Occupancy Category I or II buildings of light-framed construction not exceeding 3 stories in height	P	P	P
	Other Occupancy Category I or II buildings not exceeding 2 stories in height	P	P	P
	Regular structures with $T < 3.5T_s$ and all structures of light frame construction	P	P	P
	Irregular structures with $T < 3.5T_s$ and having only horizontal irregularities Type 2, 3, 4, or 5 of Table 12.2-1 or vertical irregularities Type 4, 5a, or 5b of Table 12.3-1	P	P	P
	All other structures	NP	P	P

NOTE: P: Permitted; NP: Not Permitted

ASCE 7-05

Analysis Procedures

- Modal Response Spectrum Analysis Procedure
  - Provisions reduced in extent by deleting most of the mathematics from provisions
  - Provisions revised to indicate that resulting forces, not drifts, are subject to 85% of ELF procedure lower bound

ASCE 7-05 Base Shear Equations

$$V = C_S W$$

Where C_s = seismic response coefficient

ASCE 7-02 Base Shear Equations

$$C_s = \frac{S_{DS}}{R/I}$$
$$\le \frac{S_{D1}}{T(R/I)}$$
$$\ge 0.044 S_{DS} I$$
$$\ge \frac{0.5 S_1}{R/I} \text{ for SDC E and F}$$

Also, for regular structures with ≤ 5 stories and with $T \le 0.5$ seconds, C_s may be based on $S_s = 1.5$g and $S_1 = 0.6$g.

ASCE 7-05 Base Shear Equations

$$C_s = \frac{S_{DS}}{R/I}$$
$$\le \frac{S_{D1}}{T(R/I)} \text{ for } T \le T_L$$
$$\le \frac{S_{D1} T_L}{T^2(R/I)} \text{ for } T > T_L$$
$$\ge 0.01$$
$$\ge \frac{0.5 S_1}{R/I} \text{ for } S_1 \ge 0.6g$$

→ $\ge 0.044 S_{DS} I \ge 0.01$
WA emergency change (app);
ASCE 7-05 Supplement No. 2

Also, for regular structures with ≤ 5 stories and with $T \le 0.5$ seconds, C_s may be based on $S_s = 1.5$g.

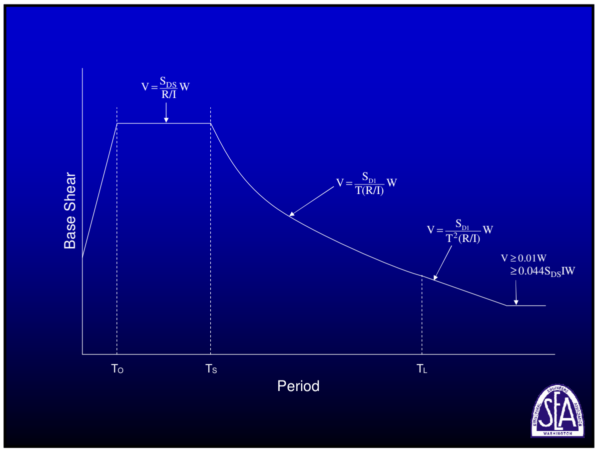
ASCE 7-02 vs. ASCE 7-05

ASCE 7-02

$$C_S = \frac{S_{DS}}{R/I}$$
$$\le \frac{S_{D1}}{T(R/I)}$$
$$\ge 0.044 S_{DS} I$$
$$\ge \frac{0.5 S_1}{R/I} \text{ for SDC E \& F}$$

ASCE 7-05

$$C_S = \frac{S_{DS}}{R/I}$$
$$\le \frac{S_{D1}}{T(R/I)} \text{ for } T \le T_L$$
$$\le \frac{S_{D1} T_L}{T^2(R/I)} \text{ for } T > T_L$$
$$\ge 0.01 \quad \boxed{\ge 0.044 S_{DS} I \ge 0.01}$$
$$\ge \frac{0.5 S_1}{R/I} \text{ for } S_1 \ge 0.6g$$



Combinations of Framing Systems

- Provisions reformatted and expanded
- Separate subsections for:
  - Combinations of framing systems in different directions
  - Combinations of framing systems in same direction

Combinations of Framing Systems

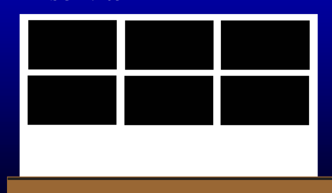
- Systems in Different Directions
  - No real changes
  - Clarifies that individual system factors apply in their respective directions

Combinations of Framing Systems

- Systems in Same Direction
  - Provisions split into those for vertical and horizontal combinations

Combinations of Framing Systems

- Systems in Same Direction – Vertical Combinations
  - Two-stage equivalent lateral force procedure for vertical combinations in 2003 IBC now included in ASCE 7-05



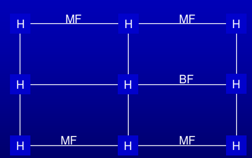
Combinations of Framing Systems

- Systems in Same Direction – Vertical Combinations

  Two-stage equivalent lateral force procedure
  - No longer required that both flexible upper portion and the rigid lower portion be regular structures
  - For the requirement that lower portion be at least 10 times stiffer than upper portion, stiffness no longer specified as “average story” stiffness

Combinations of Framing Systems

- Systems in Same Direction – Horizontal Combinations



Plan View

In ASCE 7-05, possible to have different values of *R* on independent lines in the same direction providing:

- Occupancy Category I or II
- ≤ 2 stories
- Light-frame construction or flexible diaphragms

Diaphragms, Drift and Deformation

Seismic Design Using the 2006 IBC and ASCE 7-05

Diaphragm Flexibility

- Important for the purposes of distribution of story shear and torsional moment, affecting design displacements
- Where diaphragms are *not flexible*,
  - the distribution of lateral forces shall consider the effect of the inherent torsional moment (M_t) (12.8.4.1)
  - the design shall include the inherent torsional moment (M_t) plus the accidental torsional moments (M_{ta}) (12.8.4.2)
  - structures assigned to SDC - C,D,E,F with Type 1a or 1b torsional irregularity shall account effect by multiplying (M_{ta}) with the torsional amplification factor (A_x) (12.8.4.3)

Diagrammatic Flexibility

- Torsional Amplification Factor, A_x (Figure 12.8-1)

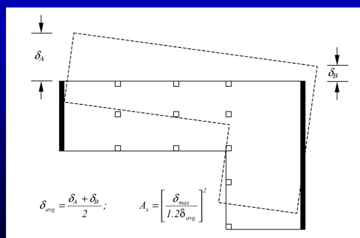


FIGURE 12.8-1 TORSIONAL AMPLIFICATION FACTOR, A_x

Diaphragm Flexibility

(12.3.1)

- Structural analysis shall explicitly consider stiffness of the diaphragm unless idealized as *flexible* or *rigid*
  - Flexible Diaphragm (12.3.1.1)
  - Rigid Diaphragm (12.3.1.2)
  - Calculated Flexible Diaphragm (12.3.1.3)

Diaphragm Flexibility

(12.3.1)

- *Flexible* Diaphragm (12.3.1.1)
  - Constructed of wood structural panels or untopped steel deck
  - Vertical elements are steel or composite steel and concrete braced frames, or concrete, masonry, steel, or composite shear walls.
  - Wood structural panels or untopped steel decks in one- and two-family residential buildings of light-frame construction
  - *Note*: *2006 IBC – 1613.6.1 Alternatives* provides an option

Diaphragm Flexibility
(12.3.1)

- *Rigid* Diaphragm (12.3.1.2)
  - Concrete slab or concrete filled metal deck
  - Span / Depth ≤ 3
  - No horizontal irregularities

Diaphragm Flexibility
(12.3.1)

- Calculated *Flexible* Diaphragm (12.3.1.3)
  - Maximum in-plane deflection is more than twice the average story drift of vertical elements

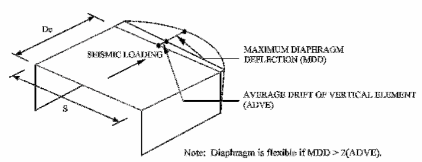


FIGURE 12.3-1 FLEXIBLE DIAPHRAGM

Story Drift Limit
(12.12.1)

- $\Delta \leq \Delta_a$ (Table 12.12-1)
  - Story Drift Determination
    - 12.8.6 – Equivalent Lateral Force (ELF)
    - 12.9.2 – Modal Analysis
    - 16.1 – Linear Response History
- SDC – C,D,E,F with *horizontal torsional irregularity* (1a or 1b), story *drift* (Δ) must be computed using deflections along *edges* of structure

Allowable Story Drift, Δ_a

(Table 12.12-1)

TABLE 12.12-1 ALLOWABLE STORY DRIFT, Δ_a[a,b]

Structure	Occupancy Category		
	I or II	III	IV
Structures, other than masonry shear wall structures, 4 stories or less with interior walls, partitions, ceilings and exterior wall systems that have been designed to accommodate the story drifts.	$0.025h_{sx}$[c]	$0.020h_{sx}$	$0.015h_{sx}$
Masonry cantilever shear wall structures[d]	$0.010h_{sx}$	$0.010h_{sx}$	$0.010h_{sx}$
Other masonry shear wall structures	$0.007h_{sx}$	$0.007h_{sx}$	$0.007h_{sx}$
All other structures	$0.020h_{sx}$	$0.015h_{sx}$	$0.010h_{sx}$

[a] h_{sx} is the story height below Level x.
[b] For seismic force–resisting systems comprised solely of moment frames in Seismic Design Categories D, E, and F, the allowable story drift shall comply with the requirements of Section 12.12.1.1.
[c] There shall be no drift limit for single-story structures with interior walls, partitions, ceilings, and exterior wall systems that have been designed to accommodate the story drifts. The structure separation requirement of Section 12.12.3 is not waived.
[d] Structures in which the basic structural system consists of masonry shear walls designed as vertical elements cantilevered from their base or foundation support which are so constructed that moment transfer between shear walls (coupling) is negligible.

Moment Frames in SDC: D - F

(12.12.1.1)

- Design story drift (Δ)
  - $\Delta \leq \Delta_a/\rho$
  - ρ = Redundancy Factor = 1.0 or 1.3 (12.3.4.2)
- *Reason:* Redundancy helps a moment frame structure to attain comparatively large deflection without significant strength loss. Therefore, penalty should not be confined to design *strength* only, but also to *drift* allowances.

Story Drift Determination

(12.8.6)

- *Deflections* of level x, δ_x, to be used for Δ, are determined by:

$$\delta_x = C_d\, \delta_{xe} / I$$

C_d : deflection amplification factor (Table 12.2-1)
δ_{xe} : deflections determined by elastic analysis
I : importance factor (11.5.1)

Story Drift Determination

(Figure 12.8-2)

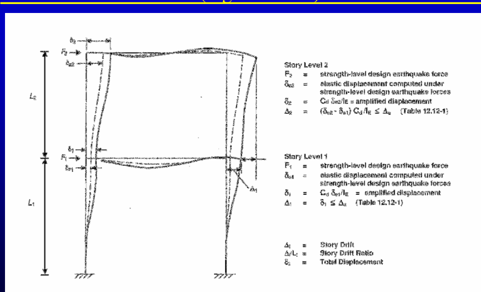


FIGURE 12.8-2 STORY DRIFT DETERMINATION

Story Drift Determination

- Modal Response Parameters (12.9.2)
  - The value for story drifts shall be computed using properties of each mode and the response spectra defined in code ***divided*** by the quantity ***R / I***. The value for ***displacement and drift*** quantities shall be ***multiplied*** by the quantity C_d / I.

$$\frac{I}{R} \times \frac{C_d}{I} = \frac{C_d}{R}$$

Story Drift Determination

- Scaling Values of Combined Response (12.9.4)
  - Where the combined response for the modal base shear (V_t) is less than 85% of the calculated base shear (V) using the ELF procedure, the forces, *but not the drifts*, shall be multiplied by:

$$0.85\frac{V}{V_t}$$

Building Separations?
(12.12.3)

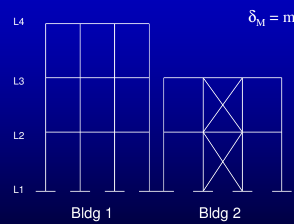
12.12.3 Building Separation. All portions of the structure shall be designed and constructed to act as an integral unit in resisting seismic forces unless separated structurally by a distance sufficient to avoid damaging contact under total deflection (δ_x) as determined in Section 12.8.6.

- "Portions of the structure" ?
- "Avoid damaging contact" ?
- "Total deflection (δ_x)" ?

Building Separations? - Examples
(12.12.3)

$\delta_M = (\delta_x)_{max} = C_d\delta_{xe} / I$ [Eqn. 12.8-15]

δ_M = maximum inelastic displacement



Maximum Inelastic Displacements		
	Bldg 1	Bldg 2
Level x	δ_{M1} (in.)	δ_{M2} (in.)
4	7.60	----
3	5.50	3.75
2	2.60	1.75
1	0	

Source: 2006 IBC Structural/Seismic Design Manual - Volume 1, SEAOC, ICC

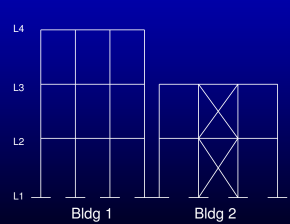
Building Separations? - Example 1
(12.12.3)

Ex 1) Separation within the ***same*** Structure

$\delta_{MT} = \delta_{M13} + \delta_{M23}$

δ_M = maximum inelastic displacement

$\delta_{MT} = 5.50 + 3.75 =$ **9.25 in.**



Maximum Inelastic Displacements		
	Bldg 1	Bldg 2
Level x	δ_{M1} (in.)	δ_{M2} (in.)
4	7.60	----
3	5.50	3.75
2	2.60	1.75
1	0	

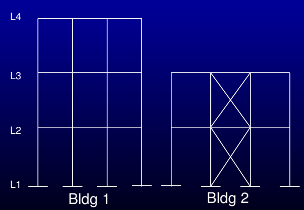
Source: 2006 IBC Structural/Seismic Design Manual - Volume 1, SEAOC, ICC

Building Separations? - Example 2

(12.12.3)

Ex 2) Separation from an adjacent building on the ***same*** property

- *2006 IBC and ASCE 7 - 05 makes no distinction between an "internal" separation in the same building and the separation between two "adjacent" buildings on the same property. It is silent with respect to separation between adjacent buildings.*



Maximum Inelastic Displacements		
	Bldg 1	Bldg 2
Level x	$\delta_{M1\ (in.)}$	$\delta_{M2\ (in.)}$
4	7.60	----
3	5.50	3.75
2	2.60	1.75
1	0	

Source: 2006 IBC Structural/Seismic Design Manual - Volume 1, SEAOC, ICC

Building Separations? - Example 2

(12.12.3)

Ex 2) Separation from an adjacent building on the ***same*** property

2a) 2006 IBC and ASCE 7-05

$$\delta_{MT} = \delta_{M13} + \delta_{M23}$$

$$\delta_{MT} = 5.50 + 3.75 = 9.25\text{in.}$$

2b) 2003 IBC – 1620.4.5

$$\delta_{MT} = \sqrt{(\delta_{M13})^2 + (\delta_{M23})^2}$$ [2003 IBC - Eqn. 16-64]

$$\delta_{MT} = \sqrt{(5.50)^2 + (3.75)^2} = 6.66\text{ in.}$$

- **Exception**: Smaller separations shall be permitted when justified by rational analyses based on maximum expected ground motions.

Summary

- Diaphragm Flexibility
  - Flexible or Rigid Idealization, *Semi-rigid*
  - Can impact many of the design and detailing requirements
- Drift and Displacements
  - Allowable Drifts
  - Building Separations
  - Moment Frames in SDC - D,E,F → $\Delta \le \Delta_a/\rho$
- Diaphragm Forces
  - Horizontal and vertical irregularities can impact diaphragm connection forces
  - Clearer format
- Collector elements and connections (SDC – C,D,E,F)
  - Designed for the load combinations with overstrength factor (Ω_0) *[with exception]*
- Structural walls and their anchorage
  - Dependant on SDC's and diaphragm flexibility
  - Wall material