Computer Applications in Structural Engineering

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Major Steps Needed Towards Earthquake Resistant Design

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- EARTHQUAKE DESIGN PRINCIPLES
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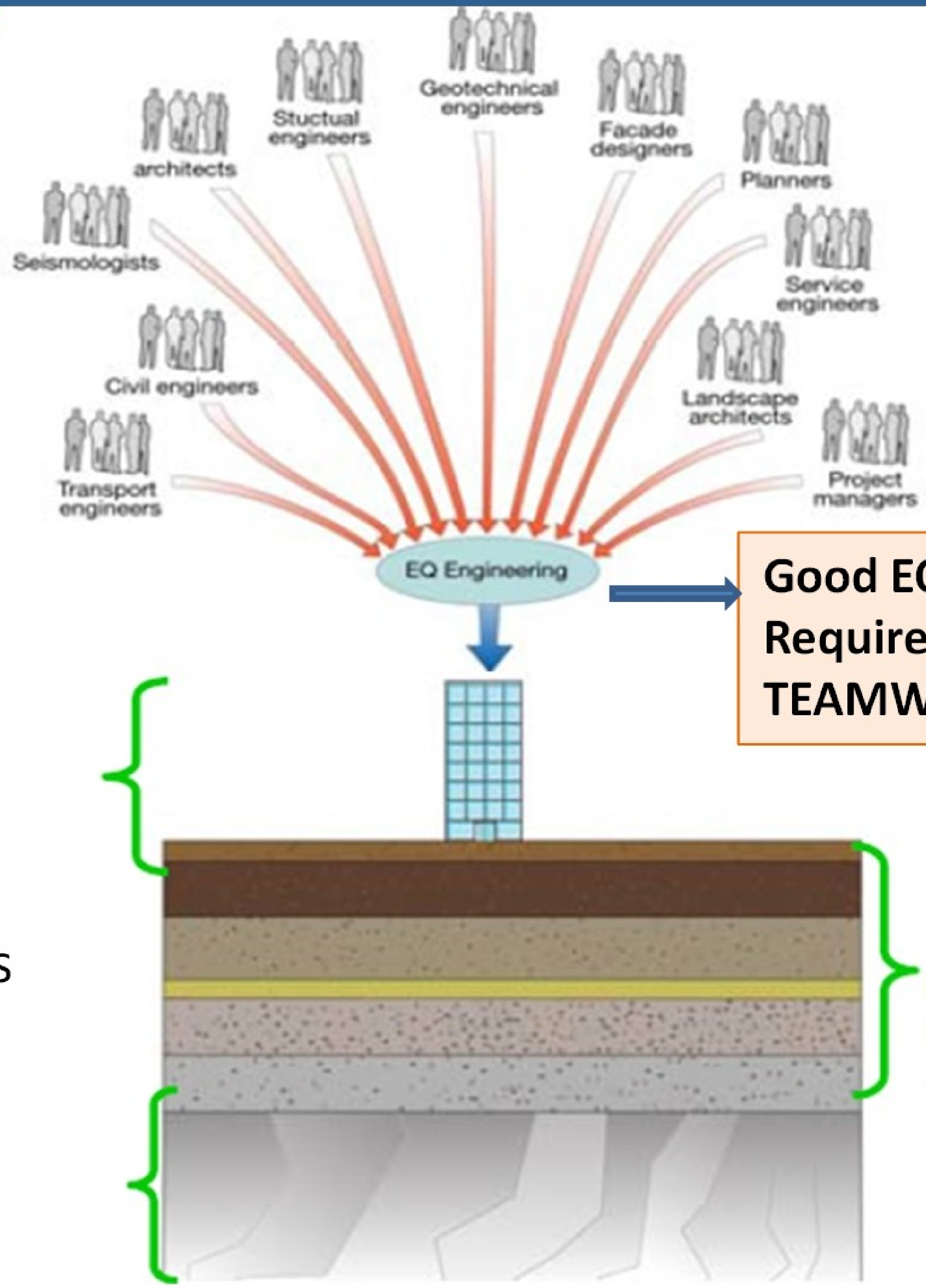
What's Involved?!



Good EQ Engineering Requires good TEAMWORK!

Structures:

- New Buildings & Bridges
- Assessment of historical buildings
- Retrofit of structures
- Risk assessments
- Master Planning
- Management Consultancy

Seismology & Geology

- Probabilistic Hazard Assessment.
- Deterministic Hazard Assessment.
- Geological Studies

Soils:

- Site Classifications.
- Non-linear soil analyses.
- Foundation Design.
- Retaining Wall Design.
- Slope Stability.
- Soil-Structure Interaction.

INTRODUCTION

Pre – 1900: No direct consideration of seismic forces

1900-1940: lateral force = 10% of weight, uniform, (elastic design)

1940-1960: Importance of dynamic, generally not codified

1960-1970: Importance of building period, elastic analysis and design

1970-1990: importance of ductility, soil, zone. Capacity design developed with methods of analysis

1990-2015: Unification between dynamic theory and earthquake codes, importance of 3D dynamic analysis, development of "Displacement-based design" and "Performance based design" (Inelastic analysis, strength design)

INTRODUCTION

Figure 1: A destroyed house in Jerusalem.

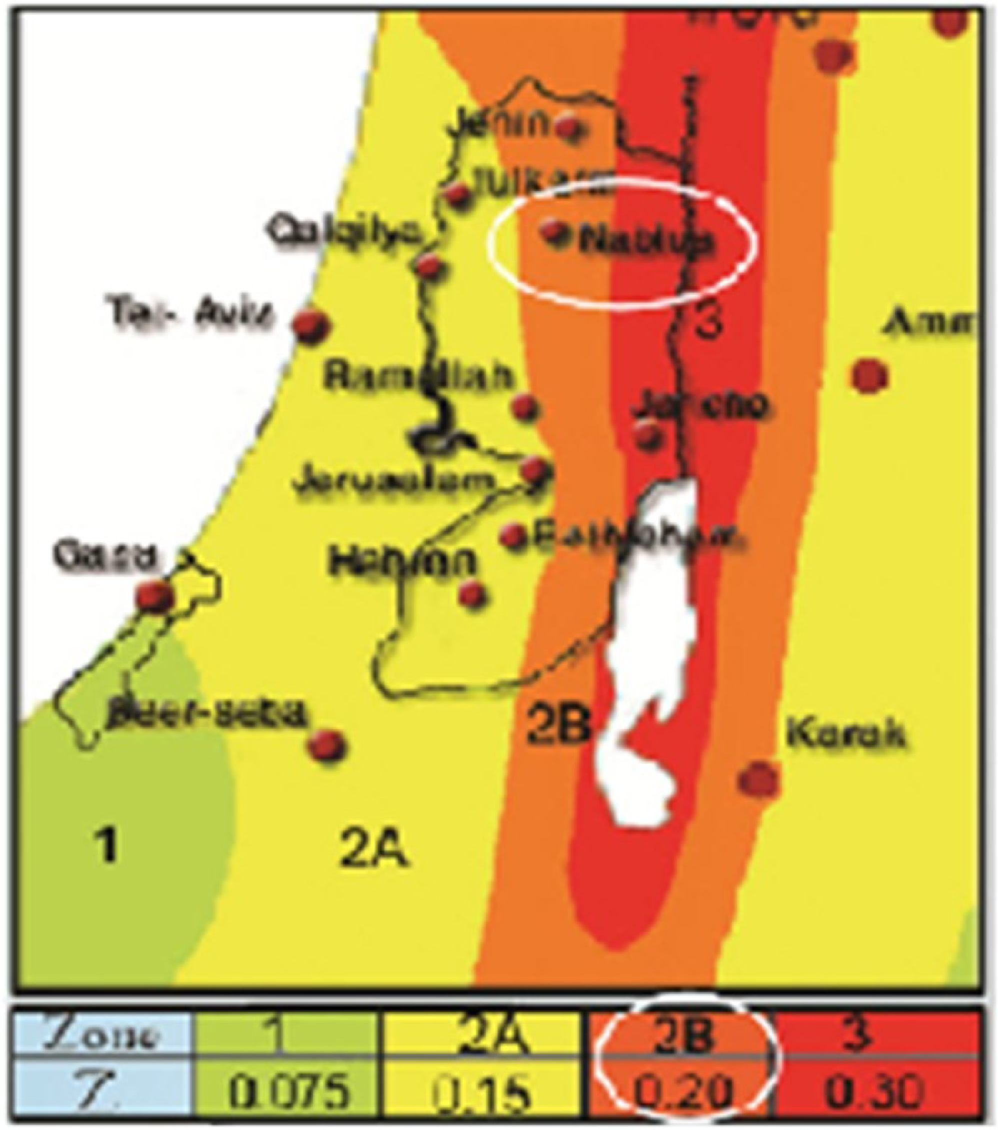


Figure 2: seismic hazard map for Palestine (10% probability of exceedance in 50 years).

INTRODUCTION

Event	Probability of Exceedence	Recurrence Interval
Frequent	50% in 50 years	72 years
Rare	10% in 50 years	475 years
Very rare	2% in 50 years	2,500 years

According to the Poisson model,

$$P = 1 - e^{\frac{-t}{\tau}}$$

INTRODUCTION

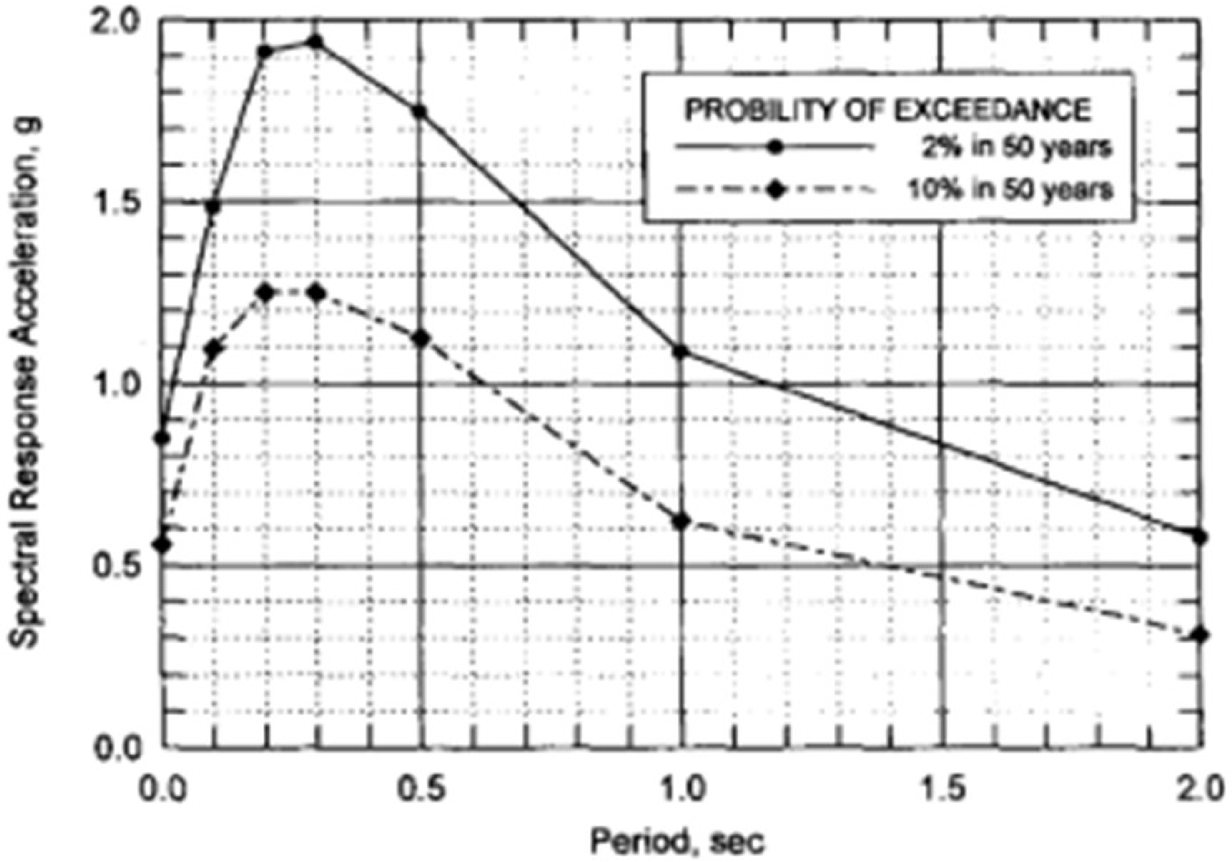


Figure 3: uniform hazard response spectra for 2% and 10% probability of exceedance in 50 years for San Francisco, California. (Active seismic area)

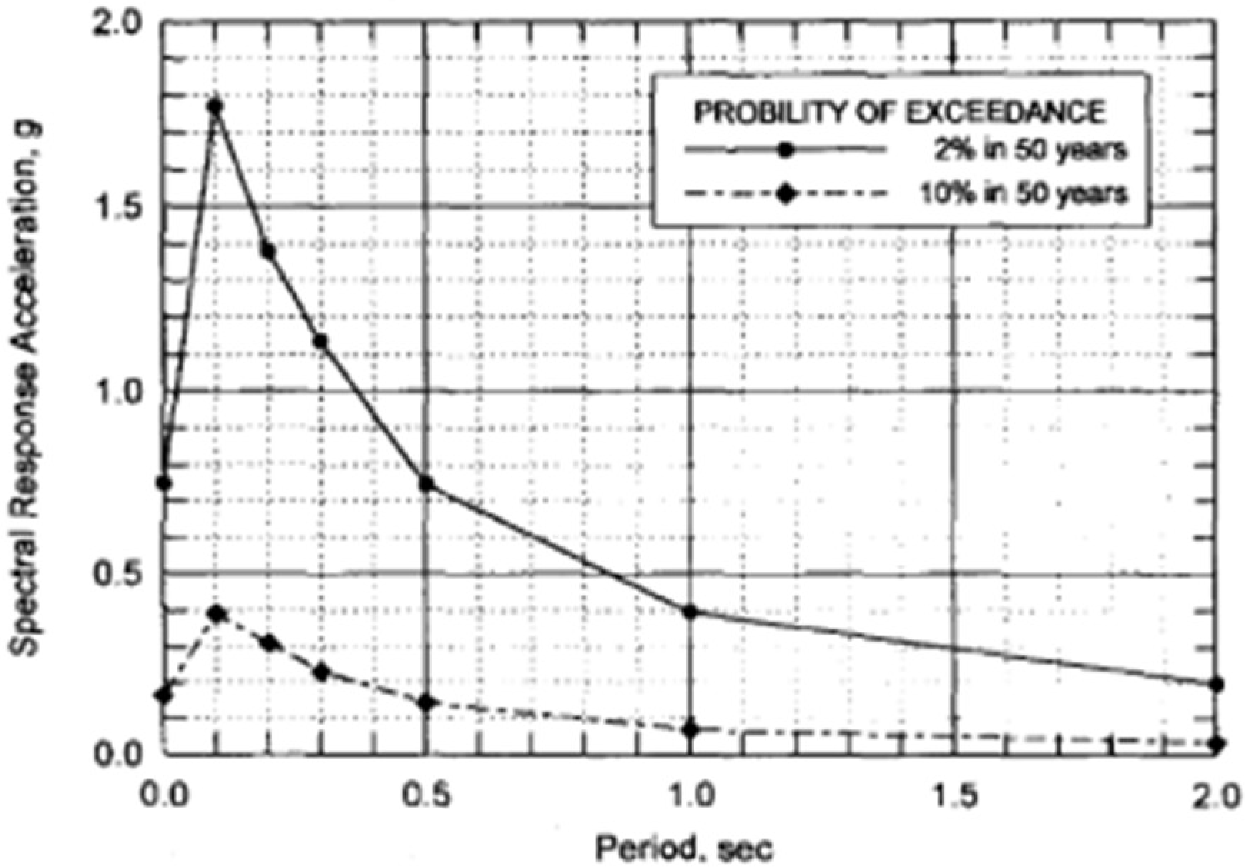


Figure 4: uniform hazard response spectra for 2% and 10% probability of exceedance in 50 years for Charleston, South Carolina. (Less active seismic area)

$$S_{DS} = (2/3)S_{ms}$$

$$S_{D1} = (2/3)S_{M1}$$

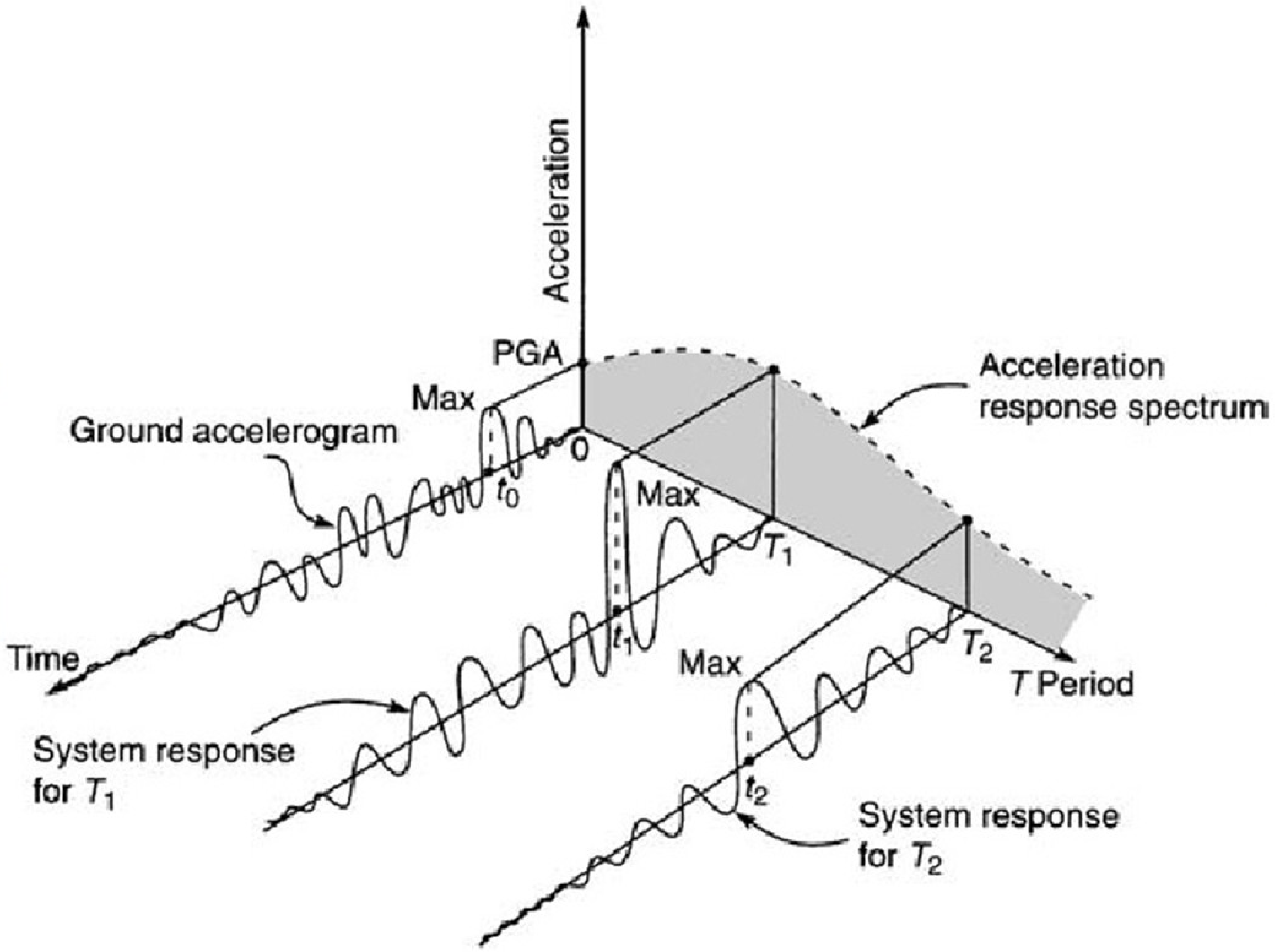
!

Code defined ground motions

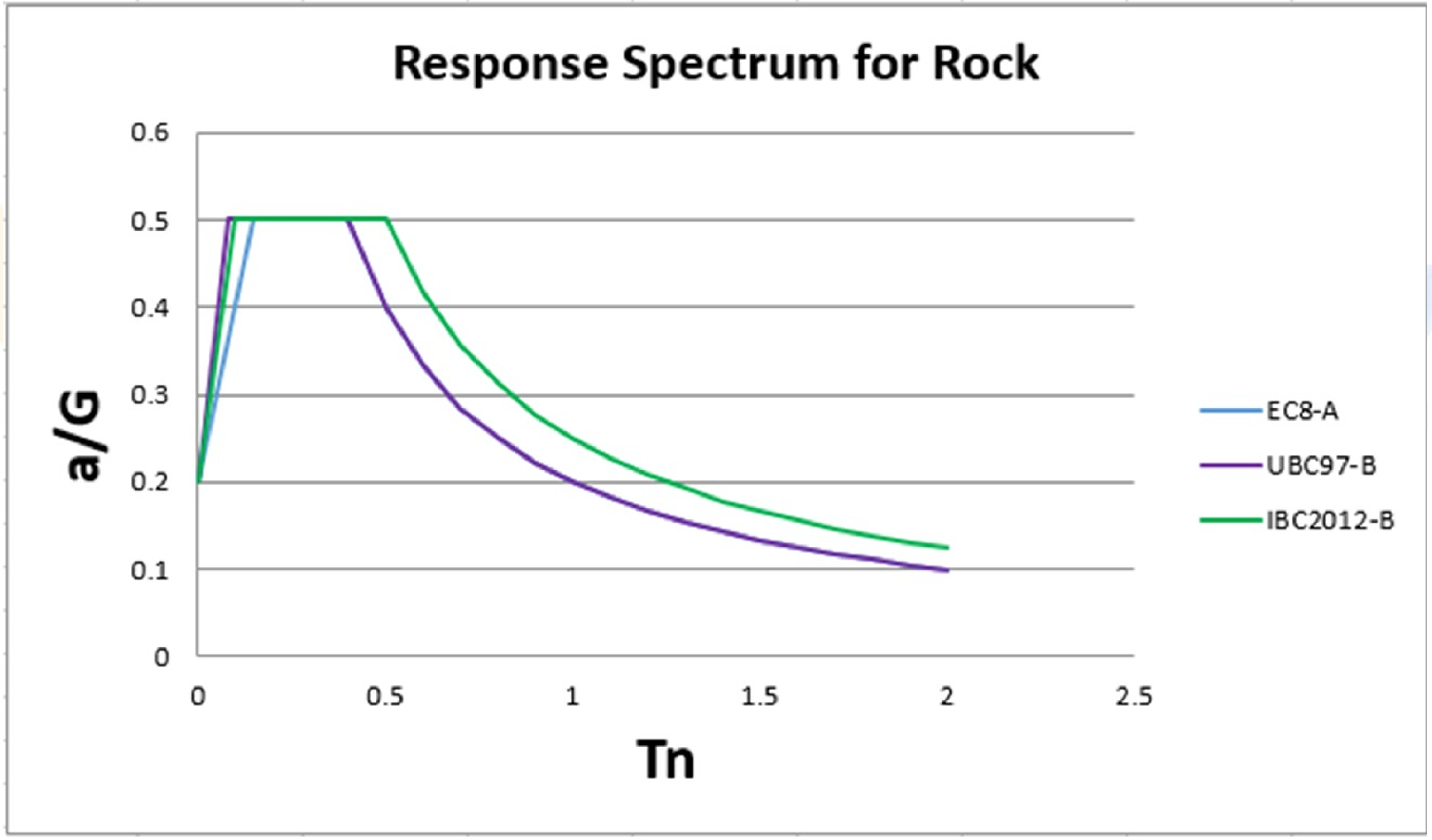
2. Geotechnical Engineers

IBC and UBC		EC8	
Ground type	**Description**	**Ground type**	**Description**
S_A	Hard rock Vs >1500 m/s		
S_B	Rock Vs ≈ 760 – 1500	A	Rock or rock-like geological formation including most 5 m weaker material at the surface Vs,30 >800 m/s
S_C	Very dense soil or soft rock Vs ≈ 360 – 760	B	Deposit of very dense sand, gravel or very stiff clay, at least several tens of m in thicknesses, characterized by a gradual increase of mechanical properties with depth Vs,30 ≈ 360– 800 m/s
S_D	Stiff soil Vs,30 ≈ 180 – 360	C	Deep deposits of dense or medium-dense sand, gravel or stiff clay with thickness from several tens to many hundreds of m Vs ≈ 180 –360 m/s
S_E	Soft soil Vs < 180	D	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil. Vs,30 < 180 m/s
S_F	Soil requiring site specific evaluation. It is more detailed defined in the IBC	E	A soil profile consisting of a surface alluvium layer with Vs,30 values of class C or D and thickness varying between about 5 and 20 m, underlain by stiffer material with Vs,30> 800 m/s
		S1	Deposits consisting or containing a layer at least 10 m thick of soft clays/ silts with high plasticity index (PI > 40) and height water content, Vs,30 < 100 m/s
		S2	Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types A–E or S1

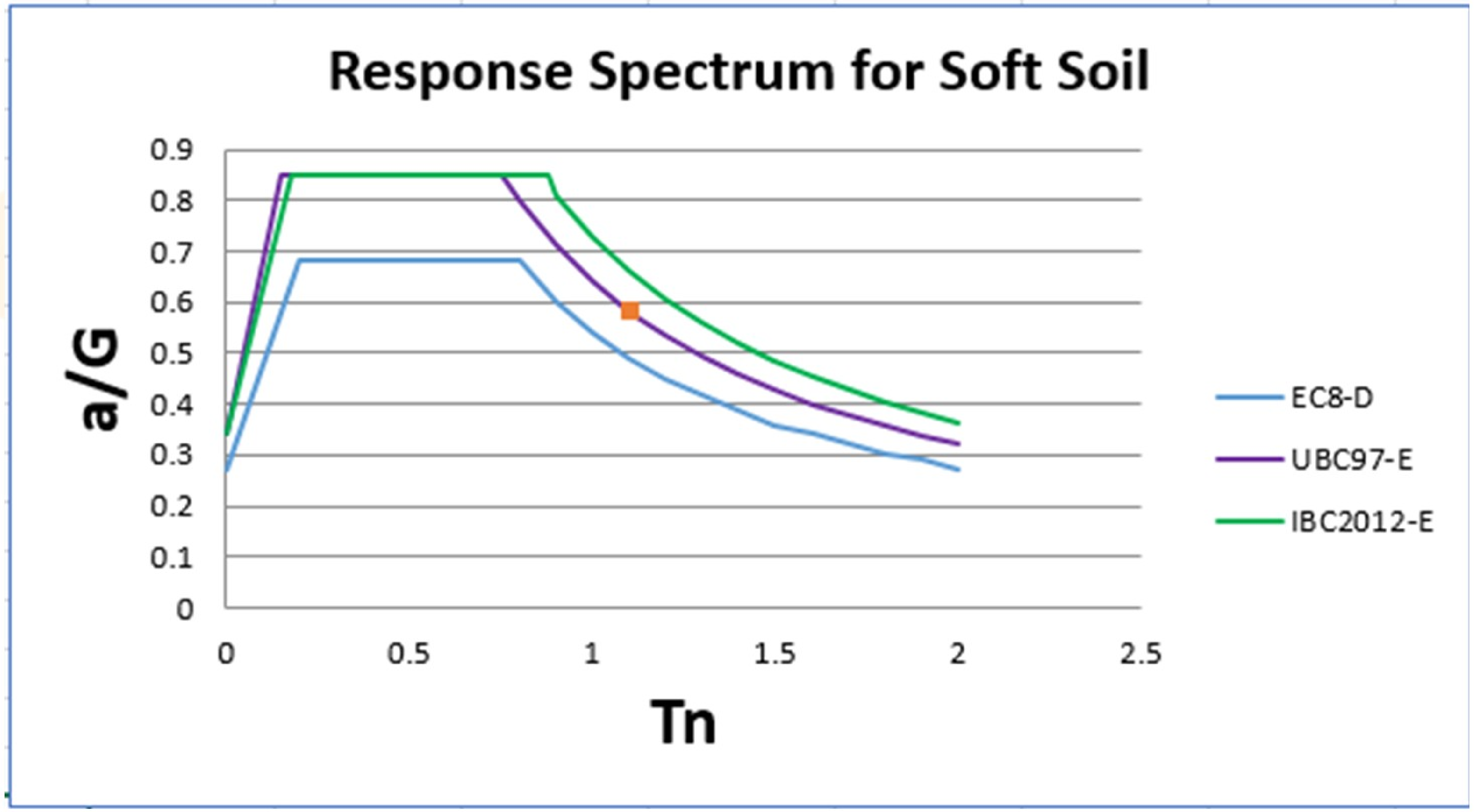
INTRODUCTION



Response Spectrum of Different Codes for zone 2



Response Spectrum of Different Codes for zone 2



Importance of Quality Control

3. Project managers

- Fundamental lesson learned from earthquakes:
  - Necessity of correct matching between mathematical model and reality
  - Necessity of correct matching between earthquake loadings and method of analysis (processing)

INTRODUCTION

-Soil theory is based on assumption of rigid structures built on flexible foundations.

-Structural theory is based on assumption of flexible structures built on rigid foundations.

- Seismic analysis methods
- Fundamental requirements
- Basic Principles of conceptual design
- Importance classes and importance factors
- Capacity design
- Structural materials and types

Seismic Analysis Methods

- Linear
  - Static: ELF method
  - Dynamic: MRS method
- Non-Linear
  - Static: Pushover, Capacity Spectrum
  - Dynamic: NLTH Analyses

Current design:

- Minor damage for moderate earthquakes
- Accepts major damage for severe earthquakes
- Collapse is prevented of severe events (importance of ductility)

Basic Principles of conceptual design

8. Architects + 9. Landscape Architects

Behind Every

unexperiened

Architect,

a civil engineer

is thrown

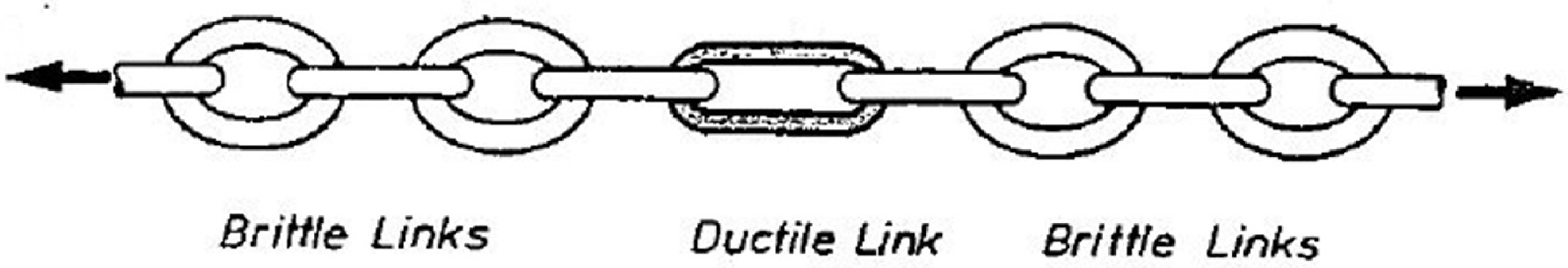
in prison!!!

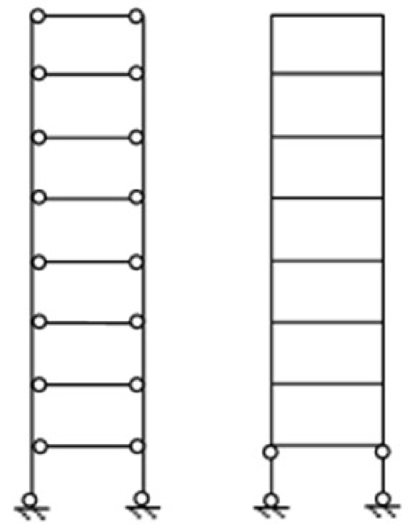
- Buildings should be light (avoid unnecessary masses)
- Structural simplicity, uniformity and symmetry
- Redundancy.
- Bi-directional resistance and stiffness.
- Torsional resistance and stiffness.
- Diaphragmatic behavior at story level.
- Adequate foundation

Importance classes and importance factors

Import. class	Buildings	EC8	IBC	Equiv. UBC
I	Buildings of minor importance for public safety, e.g. agricultural buildings, etc.	0.8	1	1
II	Ordinary buildings, not belonging in the other categories.	1	1	1
III	Buildings whose seismic resistance is of importance in view of the consequences associated with a collapse, e.g. schools, assembly halls, cultural institutions etc.	1.2	1.25	1.25
IV	Buildings whose integrity during earthquakes is of vital importance for civil protection, e.g. hospitals, fire stations, power plants, etc.	1.4	1.5	1.25

EARTHQUAKE DESIGN PRINCIPLES





Structural materials and types

10. Façade Designers

As an example reinforced concrete

- Bearing wall systems
- Building systems
- Frame systems

Design Procedure: for example ELF

- Find T
- Find Cs
- Find base shear V and distribute across height
- Analyze and design the structure to achieve required ductility demands

SUMMARY AND CONCLUSION: اهدِنَا الصِّرَاطَ الْمُسْتَقِيمَ

- **Seismology:** Ground motions having 10% probability of exceedance in 50 years is recommended.

قُلْ هُوَ الْقَادِرُ عَلَى أَن يَبْعَثَ عَلَيْكُمْ عَذَابًا مِّن فَوْقِكُمْ أَوْ مِن تَحْتِ أَرْجُلِكُمْ أَوْ يَلْبِسَكُمْ شِيَعًا وَيُذِيقَ بَعْضَكُم بَأْسَ بَعْضٍ انظُرْ كَيْفَ نُصَرِّفُ الآيَاتِ لَعَلَّهُمْ يَفْقَهُونَ/الأنعام 65

- **Geotechnical:** Avoid contradictory assumptions and avoid odds

وَكَانُواْ يَنْحِتُونَ مِنَ الْجِبَالِ بُيُوتًا آمِنِينَ/الحجر 82

-

Project managers: Importance of quality control

اقْرَأْ بِاسْمِ رَبِّكَ الَّذِي خَلَقَ ...اقْرَأْ وَرَبُّكَ الأَكْرَمُ / العلق 1 و 3

Civil and Structural Engineers: Structural engineers must take part in the initial stages of design

فَخَلَقْنَا الْمُضْغَةَ عِظَامًا فَكَسَوْنَا الْعِظَامَ لَحْمًا / المؤمنون 14

Planners + service engineers: Horizontal expansion in building structures instead of vertical expansion to avoid odds

وَجَعَلْنَا بَيْنَهُمْ وَبَيْنَ الْقُرَى الَّتِي بَارَكْنَا فِيهَا قُرًى ظَاهِرَةً وَقَدَّرْنَا فِيهَا السَّيْرَ سِيرُوا فِيهَا لَيَالِيَ وَأَيَّامًا آمِنِينَ/ سبأ 18

Architects and landscape architects: Structural form: for example a pyramid form is best for both earthquakes and wind

لَكِنِ الَّذِينَ اتَّقَوْا رَبَّهُمْ لَهُمْ غُرَفٌ مِّن فَوْقِهَا غُرَفٌ مَّبْنِيَّةٌ/ الزمر 20

Façade Designers: Dual systems (frames with shear walls or bracing)

اللَّهُ الَّذِي رَفَعَ السَّمَاوَاتِ بِغَيْرِ عَمَدٍ تَرَوْنَهَا/ الرعد 2

- The two extra main parameters for earthquake resistance

-period:

وَاذْكُرُواْ إِذْ جَعَلَكُمْ خُلَفَاء مِن بَعْدِ عَادٍ وَبَوَّأَكُمْ فِي الأَرْضِ تَتَّخِذُونَ مِن سُهُولِهَا قُصُورًا وَتَنْحِتُونَ الْجِبَالَ بُيُوتًا فَاذْكُرُواْ آلاء اللَّهِ وَلاَ تَعْثَوْا فِي الأَرْضِ مُفْسِدِينَ/ الأعراف 74

-ductility

فَاسْتَقِمْ كَمَا أُمِرْتَ وَمَن تَابَ مَعَكَ وَلاَ تَطْغَوْاْ إِنَّهُ بِمَا تَعْمَلُونَ بَصِيرٌ/ هود 112

ألا تطغوا في الميزان/الرحمن 8

End of paper introduction

IBC2012/ ASCE 7-10

- Seismic Performance Objectives
- Seismic design approach
- Earthquake Loads – Equivalent Lateral Force Method
- Determination of response spectrum curve and analysis method
- Equivalent force method
- Examples
- Structural configuration (regular or irregular)

Seismic Performance Objectives

- Current design - minor damage for moderate earthquakes
- Accepts major damage for severe earthquakes
- Collapse is prevented of severe events
- In order to achieve the design objectives, the current code approach requires details capable of undergoing large inelastic deformations for energy dissipation.

Seismic design approach

- Design forces are based on risk

Codes define seismic hazard by seismic zoning maps. Previous codes (UBC 97) are based on 10% chance of exceedance in 50 years. The UBC divides US into four zones with a Z-factor given in UBC Table 16-1.

IBC 2000-2012 codes based on 2% chance of exceedance in 50 years (ASCE 21.2.1, 21.5.1)

Use IBC2012 modified for 10% probability of exceedance in 50 years

Seismic Design Approach

No special requirements for low seismic risk

Chapter 21 requirements for moderate and high seismic risk

Earthquake Loads – ELFM

- Base Shear, V

$$V = C_s \cdot W$$

- Where:

C_s - Seismic Response Coefficient

See ASCE 7-10 12.7.2

W all dead load (all permanent components of the building, including permanent equipment)

- 25% of any design storage floor live loads except for floor live load in public garages and open parking structures.
- If partition loads are considered in floor design, at least $0.5 kN/m^2$ is to be included.
- A portion of the snow load (20% p_f minimum) in regions where the flat roof snow load exceeds $1.5 kN/m^2$

Determination of response spectrum curve and analysis method

Response Spectrum Curve is a function of:

- Spectral response acceleration
- Site soil factors
- Building Period
- Response modification factors
- Importance factor

To find it and determine the proper analysis method follow the steps 1-5:

Step 1 – Determine S_S and S_1

Step 2 - Determine site Soil Classification

Step 3 - Calculate Response Accelerations

Step 4 - Calculate the 5% Damped Design Spectral Response Accelerations

Step 5 - Determine the Seismic Design Category

Step 1 – Determine S_S and S_1 Seismic Ground Motion Values From local building codes or IBC Map

See ASCE 7-10 11.4

- Mapped Acceleration Parameters
  - S_s = Mapped 5% damped, spectral response acceleration parameter at 0.2 sec.≈2.5Z
  - S_1 = Mapped 5% damped spectral response acceleration parameter at a period of 1 sec.≈1.25Z

User Note: Electronic values of mapped acceleration parameters, and other seismic design parameters, are provided at the USGS Web site at http://earthquake.usgs.gov/designmaps, or through the SEI Web site at http://content.seinstitute.org.

Determination of response spectrum curve and analysis method

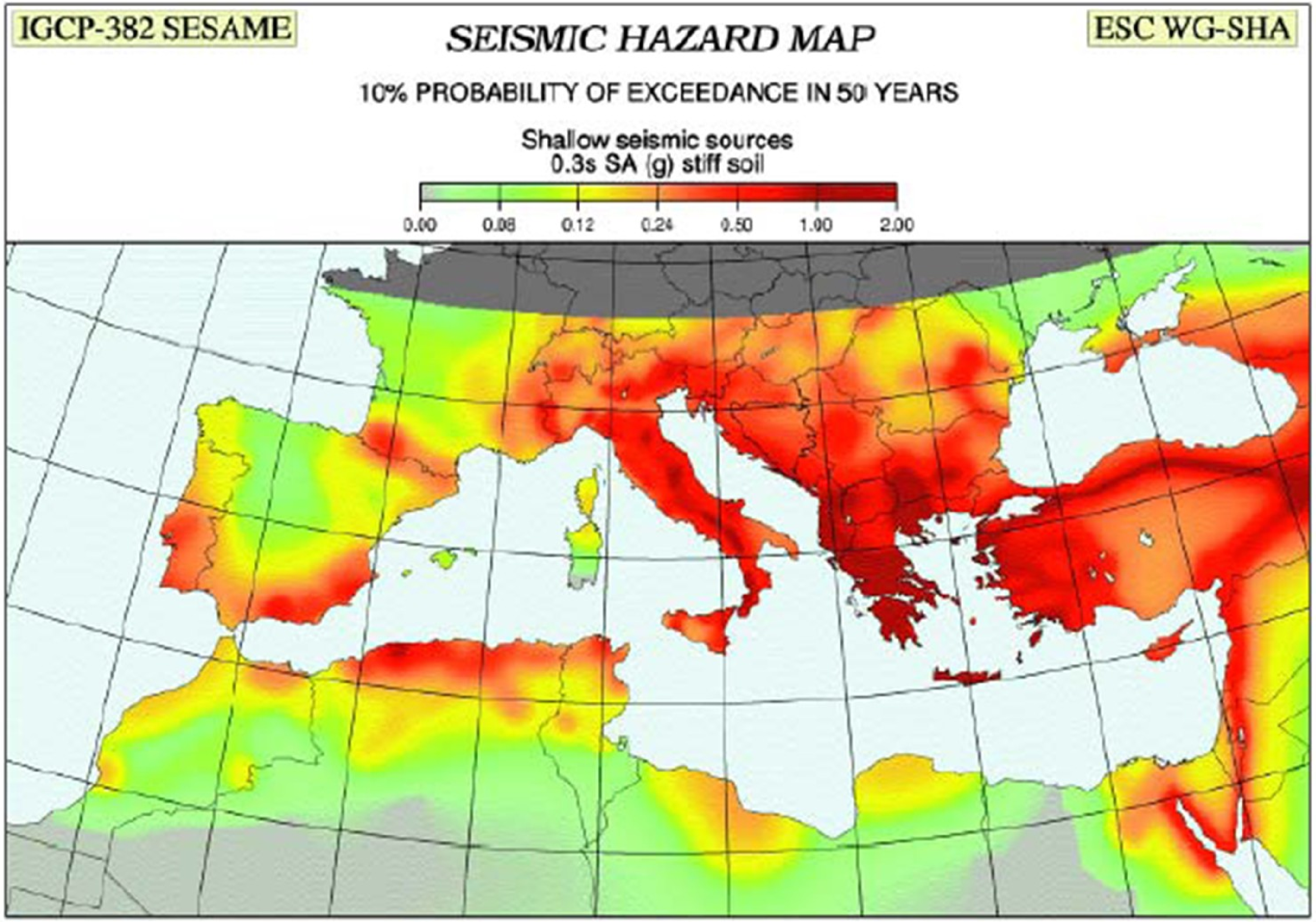


Figure Seismic hazard map of the Mediterranean region depicting 0.3 s SA on stiff soil in g units for a 10% probability of exceedance in 50 years.

Determination of response spectrum curve and analysis method

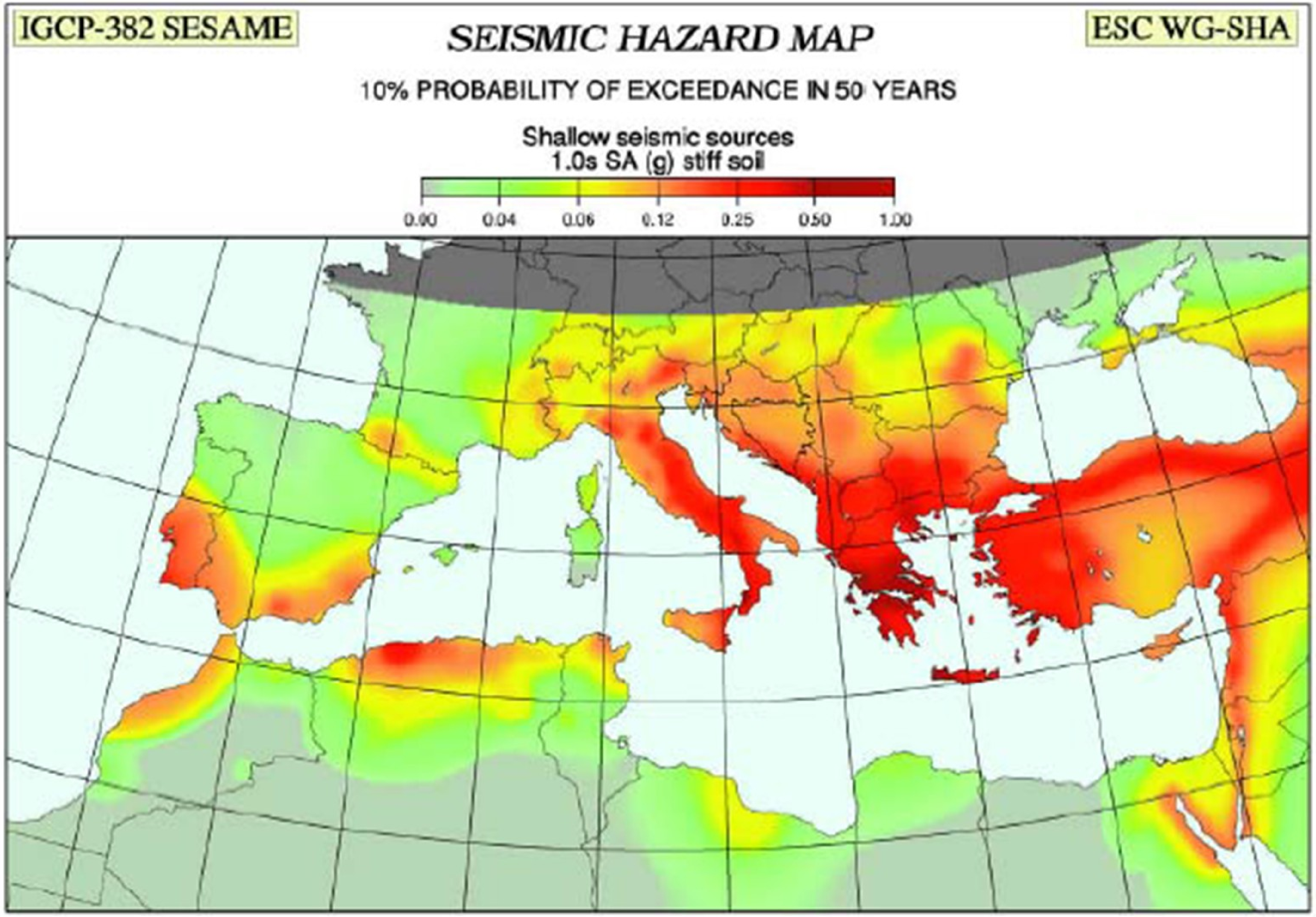


Figure Seismic hazard map of the Mediterranean region depicting 1.0 s SA on stiff soil in g units for a 10% probability of exceedance in 50 years.

See ASCE 7-10 11.4.2, 20

- Site Classes are also labeled A-F
  - A is for hard rock, F for very soft soils
- Choice of site class is based on soil stiffness which is measured in different ways for different types of soil.
- See ASCE 7-10 20 for procedure
- If insufficient data is available, assume Site Class D unless there is a probability of a Site Class F.

Determination of response spectrum curve and analysis method

Table 20.3-1 Site Classification

Site Class	$\bar{v}_s$	$\bar{N}$ or $\bar{N}_{ch}$	$\bar{s}_u$
A. Hard rock	>5,000 ft/s	NA	NA
B. Rock	2,500 to 5,000 ft/s	NA	NA
C. Very dense soil and soft rock	1,200 to 2,500 ft/s	>50	>2,000 psf
D. Stiff soil	600 to 1,200 ft/s	15 to 50	1,000 to 2,000 psf
E. Soft clay soil	<600 ft/s	<15	<1,000 psf
	Any profile with more than 10 ft of soil having the following characteristics: —Plasticity index $PI > 20$, —Moisture content $w \geq 40\%$, —Undrained shear strength $\bar{s}_u < 500$ psf		
F. Soils requiring site response analysis in accordance with Section 21.1	See Section 20.3.1		

For SI: 1 ft/s = 0.3048 m/s; 1 lb/ft^2 = 0.0479 kN/m^2.

Determination of response spectrum curve and analysis method

See ASCE 7-10 11.4.3

- **Step 3 – Calculate Response Accelerations:**

$S_{MS} = F_a \cdot S_S$ $S_{M1} = F_v \cdot S_1$

Where: F_a and F_v are site coefficients

- S_S spectral accelerations for short periods
- S_1 spectral accelerations for 1-second period
- F_a from Table 11.4-1
- F_v from Table 11.4-2

Determination of response spectrum curve and analysis method

Table 11.4-1 Site Coefficient, F_a

Site Class	Mapped Risk-Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameter at Short Period				
	$S_S \le 0.25$	$S_S = 0.5$	$S_S = 0.75$	$S_S = 1.0$	$S_S \ge 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	See Section 11.4.7				

Note: Use straight-line interpolation for intermediate values of S_S.

Table 11.4-2 Site Coefficient, F_v

Site Class	Mapped Risk-Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameter at 1-s Period				
	$S_1 \le 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 \ge 0.5$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	See Section 11.4.7				

Note: Use straight-line interpolation for intermediate values of S_1.

Determination of response spectrum curve and analysis method

See ASCE 7-10 11.4.4

$S_{DS} = S_{MS}$ $S_{D1} = S_{M1}$

- S_{DS} is the design, 5% damped, spectral response acceleration for 0.2sec periods.
- S_{D1} is the design, 5% damped, spectral response acceleration at a period of 1 sec.
- S_{DS} and S_{D1} are used in selecting the Seismic Design Category and in the analysis methods.

Determination of response spectrum curve and analysis method

See ASCE 7-10 11.4.5

- Period Limiting Values
  - $T_0 = .2\ S_{D1}/S_{DS}$
  - $T_S = S_{D1}/S_{DS}$
  - T_L not available
- S_a, design spectral response acceleration
  - S_a is a function of structure period, T_n
  - Four regions, four equations.

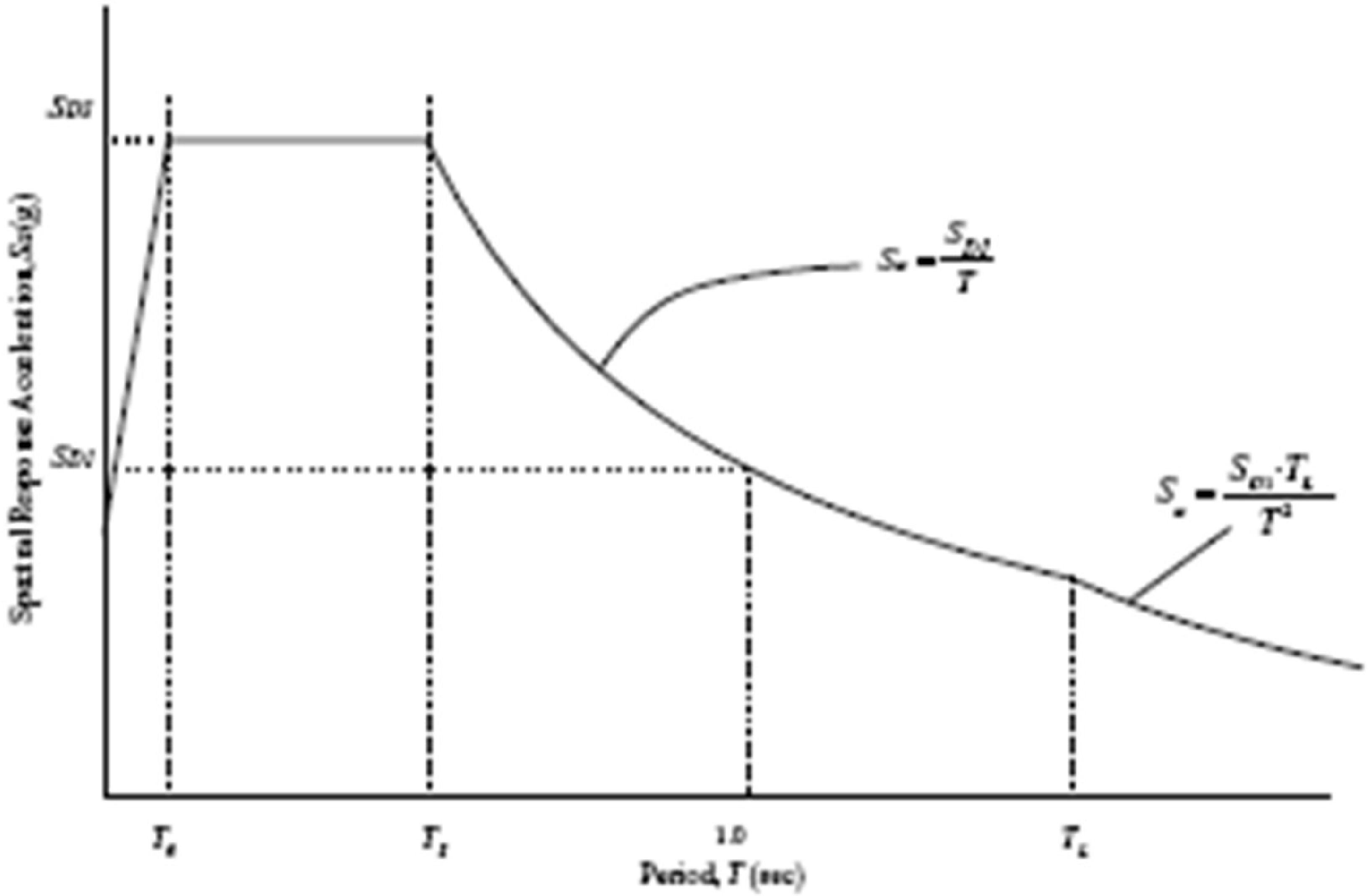


FIGURE 11.4-1 DESIGN RESPONSE SPECTRUM

Importance Factor, I

- See ASCE 7-10 Table 1.5-2

Table 1.5-2 Importance Factors by Risk Category of Buildings and Other Structures for Snow, Ice, and Earthquake Loads[a]

Risk Category from Table 1.5-1	Snow Importance Factor, I_s	Ice Importance Factor—Thickness, I_i	Ice Importance Factor—Wind, I_w	Seismic Importance Factor, I_e
I	0.80	0.80	1.00	1.00
II	1.00	1.00	1.00	1.00
III	1.10	1.25	1.00	1.25
IV	1.20	1.25	1.00	1.50

[a]The component importance factor, I_p, applicable to earthquake loads, is not included in this table because it is dependent on the importance of the individual component rather than that of the building as a whole, or its occupancy. Refer to Section 13.1.3.

Determination of response spectrum curve and analysis method

Use or Occupancy of Buildings and Structures	Risk Category
Buildings and other structures that represent a low risk to human life in the event of failure	I
All buildings and other structures except those listed in Risk Categories I, III, and IV	II
Buildings and other structures, the failure of which could pose a substantial risk to human life.	III
Buildings and other structures, not included in Risk Category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure.	
Buildings and other structures not included in Risk Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing toxic or explosive substances where their quantity exceeds a threshold quantity established by the authority having jurisdiction and is sufficient to pose a threat to the public if released.	
Buildings and other structures designated as essential facilities.	IV
Buildings and other structures, the failure of which could pose a substantial hazard to the community.	
Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, or hazardous waste) containing sufficient quantities of highly toxic substances where the quantity exceeds a threshold quantity established by the authority having jurisdiction to be dangerous to the public if released and is sufficient to pose a threat to the public if released.[a]	
Buildings and other structures required to maintain the functionality of other Risk Category IV structures.	

[a] Buildings and other structures containing toxic, highly toxic, or explosive substances shall be eligible for classification to a lower Risk Category if it can be demonstrated to the satisfaction of the authority having jurisdiction by a hazard assessment as described in Section 1.5.2 that a release of the substances is commensurate with the risk associated with that Risk Category.

Determination of response spectrum curve and analysis method

See ASCE 7-10 11.6

- To be determined for every structure
- function of:
  - Occupancy Category
  - Spectral Response Accelerations S_{DS} and S_{D1}.
- Used to determine analysis options, detailed requirements, height limitations, and other limits on usage.
- Seismic Design Categories labeled A-F

Determination of response spectrum curve and analysis method

Table 11.6-1 Seismic Design Category Based on Short Period Response Acceleration Parameter

Value of S_{DS}	Risk Category: I or II or III	IV
$S_{DS} < 0.167$	A	A
$0.167 \leq S_{DS} < 0.33$	B	C
$0.33 \leq S_{DS} < 0.50$	C	D
$0.50 \leq S_{DS}$	D	D

Table 11.6-2 Seismic Design Category Based on 1-S Period Response Acceleration Parameter

Value of S_{D1}	Risk Category: I or II or III	IV
$S_{D1} < 0.067$	A	A
$0.067 \leq S_{D1} < 0.133$	B	C
$0.133 \leq S_{D1} < 0.20$	C	D
$0.20 \leq S_{D1}$	D	D

Seismic Design Category: summary

- Buildings are classified into three seismic design categories according to their seismic hazard:
- Category A (regions of negligible seismicity: no spectral values are required. Use a minimum lateral force 1% of the dead load.
- Categories B and C (low to moderate seismicity): use S_s and S_1 map values.
- Categories D, E and F (high seismicity): S_s and S_1 should not be less than 1.5g and 0.6g (to be modified for 10%) respectively.

Determination of response spectrum curve and analysis method

Table 12.6-1 Permitted Analytical Procedures

Seismic Design Category	Structural Characteristics	Equivalent Lateral Force Analysis, Section 12.8[a]	Modal Response Spectrum Analysis, Section 12.9[a]	Seismic Response History Procedures, Chapter 16[a]
B, C	All structures	P	P	P
D, E, F	Risk Category I or II buildings not exceeding 2 stories above the base	P	P	P
	Structures of light frame construction	P	P	P
	Structures with no structural irregularities and not exceeding 160 ft in structural height	P	P	P
	Structures exceeding 160 ft in structural height with no structural irregularities and with $T < 3.5T_s$	P	P	P
	Structures not exceeding 160 ft in structural height and having only horizontal irregularities of Type 2, 3, 4, or 5 in Table 12.3-1 or vertical irregularities of Type 4, 5a, or 5b in Table 12.3-2	P	P	P
	All other structures	NP	P	P

[a]P: Permitted; NP: Not Permitted; $T_s = S_{D1}/S_{DS}$.

Determination of response spectrum curve and analysis method

- Category A: regular and irregular structures designed for a minimum lateral force
- Category B & C: regular and irregular structures using any of the three methods
- Category D, E, & F: Table 12.6-1 with some limits on S_{DS} and S_{D1}
  - ELF for regular and some irregular
  - Modal for some irregular
  - Site specific required in Site Classes E or F

Equivalent force method

See ASCE 7-10 12.8.1

Base Shear, $V = C_s W$

Where:

C_s = seismic response coefficient=S_{DS} I/R

S_{DS} = period- dependent coefficient depends on location of structure and site class

I = importance factor (1-1.5)

R=response modification factor=1.5-8

W = the effective seismic weight, including applicable portions of other storage and snow loads (See ASCE 7-10 12.7.2)

Equivalent force method

$C_s = \mathbf{S_{DS}\ I/R}$

See ASCE 7-10 12.8.1.1

C_s need not exceed: $\mathbf{S_{D1}I/(TR))}$ for $T \leq T_L$

$\mathbf{S_{D1}IT_L/(T^2R)}$ for $T > T_L$

C_s shall not be taken less than: $C_s = 0.044\mathbf{S_{DS}I} \geq 0.01$

Also

$\mathbf{0.5S_1I/R}$ for $S_1 \geq 0.6g$ (to be modified)

Equivalent force method

See ASCE 7-10 12.2

The response modification factor, R, accounts for the dynamic characteristics, lateral force resistance, and energy dissipation capacity of the structural system.

Can be different for different directions.

Simplified table shown, better go to Tables 12.2.1

Basic Seismic Force-Resisting System	Response Modification Coefficeint, R^a
Bearing Wall Systems	
Special reinforced concrete shear walls	5
Ordinary reinforced concrete shear walls	4
Detailed plain concrete shear walls	2
Ordinary plain concrete shear walls	1½
Building Frame Systems	
Special reinforced concrete shear walls	6
Ordinary reinforced concrete shear walls	5
Detailed plain concrete shear walls	2
Ordinary plain concrete shear walls	1½
Moment Resisting Frame Systems	
Special reinforced concrete moment frames	8
Intermediate reinforced concrete moment frames[h]	5
Ordinary reinforced concrete moment frames	3

Equivalent force method

May be computed by analytical means:
Rayleigh's formula

$$T = 2\pi \sqrt{\frac{\sum_{i=1}^{n} w_i \delta_i^2}{g \sum_{i=1}^{n} F_i \delta_i}}$$

May be computed by approximate means, T_a
Where analysis is used to compute T: $T \leq C_u T_a$

- C_u is given in Table 12.8-1

Table 12.8-1 Coefficient for Upper Limit on Calculated Period

Design Spectral Response Acceleration Parameter at 1 s, S_{D1}	Coefficient C_u
≥ 0.4	1.4
0.3	1.4
0.2	1.5
0.15	1.6
≤ 0.1	1.7

Equivalent force method

See ASCE 7-10 12.8.2

- An approximate means may be used.

$$T_a = C_T h_n^x$$

Where:

C_T = Building period coefficient.

h_n = height above the base to the highest level of the building

- for moment frames not exceeding 12 stories and having a minimum story height of 3m, T_a may be taken as **0.1N**, where N = number of stories.
- For masonry or concrete shear wall buildings use eq 12.8-9
- T_a may be different in each direction.

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Equivalent force method

See ASCE 7-10 12.8.2

Table 12.8-2 Values of Approximate Period Parameters C_t and x

Structure Type	C_t	x
Moment-resisting frame systems in which the frames resist 100% of the required seismic force and are not enclosed or adjoined by components that are more rigid and will prevent the frames from deflecting where subjected to seismic forces:		
Steel moment-resisting frames	0.028 (0.0724)[a]	0.8
Concrete moment-resisting frames	0.016 (0.0466)[a]	0.9
Steel eccentrically braced frames in accordance with Table 12.2-1 lines B1 or D1	0.03 (0.0731)[a]	0.75
Steel buckling-restrained braced frames	0.03 (0.0731)[a]	0.75
All other structural systems	0.02 (0.0488)[a]	0.75

[a]Metric equivalents are shown in parentheses.

Equivalent force method

$$T_a = C_t h_n^x$$

- Where

C_t =0.047 for moment resisting frame systems of reinforced concrete

= 0.049 for other concrete structural systems

x = 0.9 for concrete moment resisting frames

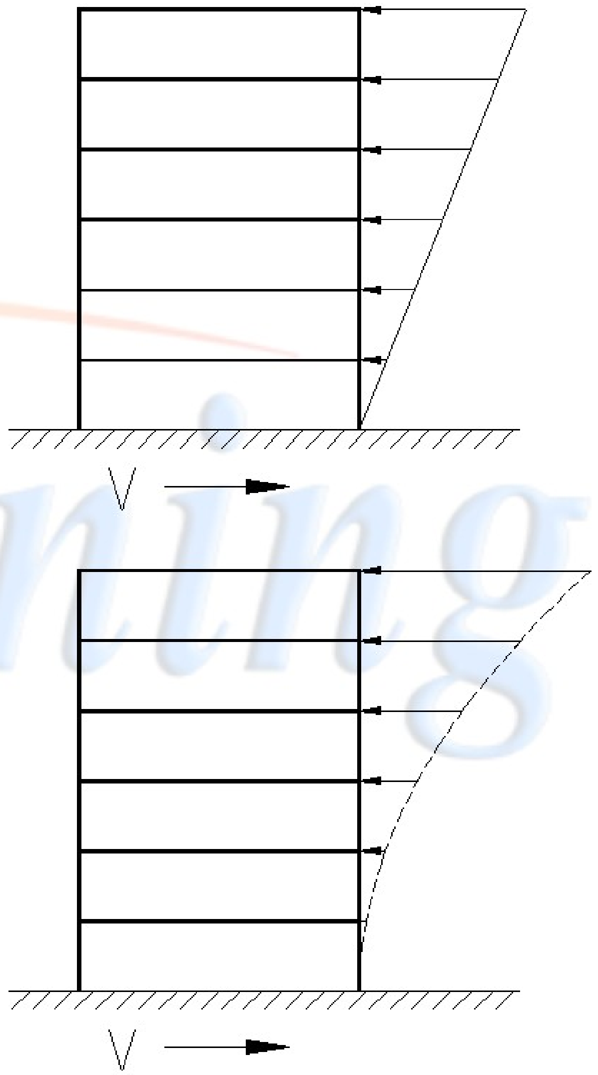
=0.75 for other concrete structural systems

h_n = distance from base to highest level (in m)

Equivalent force method

See ASCE 7-10 12.8.3

- For short period buildings the vertical distribution follows generally the first mode of vibration in which the force increases linearly with height for evenly distributed mass.
- For long period buildings the force is shifted upwards to account for the whipping action associated with increased flexibility



Equivalent force method

$F_x = C_{vx}V$

Where C_{vx} = Vertical Distribution Factor

$$C_{vx} := \frac{W_x \left(h_x\right)^k}{\sum_{i=1}^{n} W_i \left(h_i\right)^k}$$

W_x = Weight at level x

h_x = elevation of level x above the base

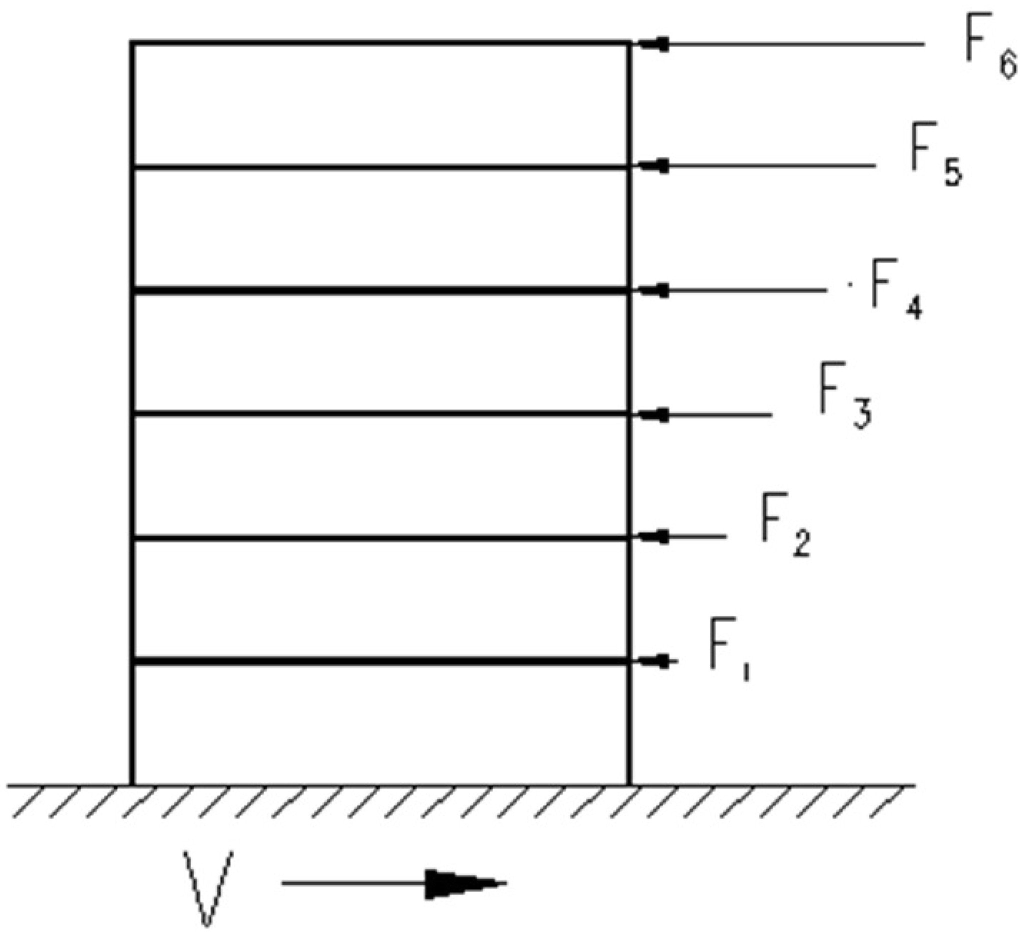
k = exponent related to structure period

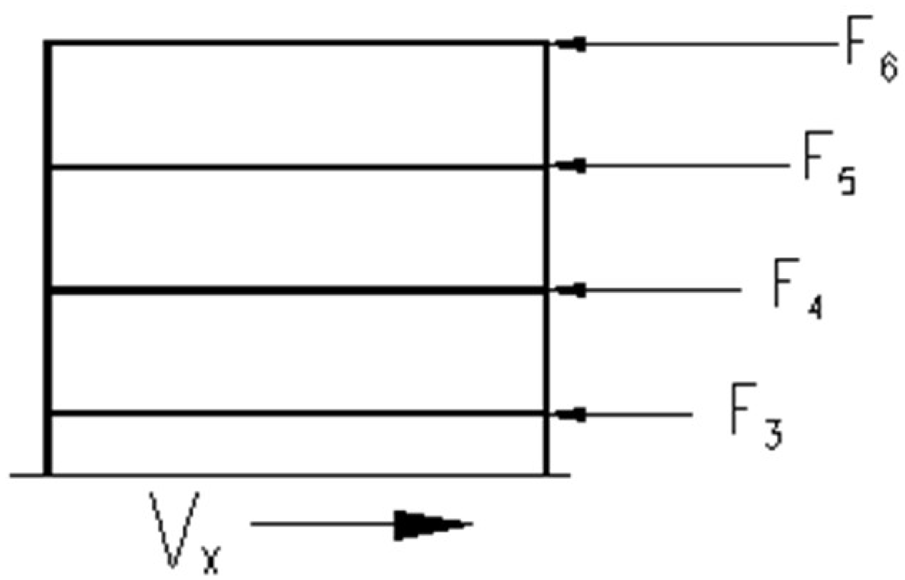
When $T < 0.5$sec, $k = 1$, When $T > 2.5$sec, $k = 2$,

Linearly interpolate when $0.5 < T < 2.5$sec

Equivalent force method

- Story shear, V_x, is the shear force at a given story level
- V_x is the sum of all the forces above that level.





Equivalent force method

Horizontal Distribution

See ASCE 7-10 12.8.4

- Being an inertial force, the Story Force, F_x, is distributed in accordance with the distribution of the mass at each level.

- The Story Shear, V_x, is distributed to the vertical lateral force resisting elements based on the relative lateral stiffnesses of the vertical resisting elements and the diaphragm.

Equivalent force method

Torsion

See ASCE 7-10 12.8.4.1-3

- The analysis must take into account any torsional effects resulting from the location of the masses relative to the centers of resistance.
- In addition to the predicted torsion, accidental torsion must be applied for structures with rigid diaphragms by assuming the center of mass at each level is moved from its actual location a distance equal to 5% the building dimension perpendicular to the direction of motion.
- Buildings of Seismic Design Categories C, D, E, and F with torsional irregularities are to have torsional moments magnified.

Equivalent force method

Load Combinations

"The effects on the structure and its components due to gravity loads and seismic forces shall be combined in accordance with the factored load combinations as presented in ASCE 7 except that the effect of seismic loads, E, shall be as defined herein."

Equivalent force method

See ASCE 7-10 12.4

- When Seismic effects and Dead Load effects are additive:

$$E = E_h + E_v = \rho Q_E + 0.2 S_{DS} D$$

- When Seismic effects and Dead Load effects counteract:

$$E = E_h - E_v = \rho Q_E - 0.2 S_{DS} D$$

- Q_E = Effect of horizontal seismic forces

- ρ = the reliability factor

See ASCE 7-10 12.3.4

- The reliability factor is intended to account for redundancy in the structure.
- The factor, ρ, may be taken as 1.0 for eight cases listed in ASCE 7-05 12.3.4.1, including Seismic Design Categories A-C.
- For structures of Seismic Design Categories D-F:

$$\rho = 1.3$$

With listed exceptions (ASCE 7-10 12.3.4.2)