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Course Description

Seismic Design for Non-West Coast Engineers – Part 1

August 10, 2017

This introductory, two-part webinar will address basic concepts of seismic design.

Part 1 of the webinar will start with a brief historical perspective of earthquakes and will then discuss the basics of earthquake loading and building dynamic response, and the use of ductility in resisting earthquakes.

Learning Objectives

- Describe the impact of major historical earthquakes
- Define key components of force on buildings caused by earthquakes
- Identify philosophy behind earthquake resistant design
- Describe the roll of ductility in earthquake resistant design

There's always a solution in steel.

Seismic Design for Non-West Coast Engineers – Part 1

Presented by
Michael D. Engelhardt, PhD, PE
Professor
The University of Texas at Austin

Seismic Design for Non-West Coast Engineers

Part 1 (August 10, 2017)

- **Causes, Location, and Impact of Earthquakes**
- **EQ Forces on Buildings**
- **Overall Philosophy and Approach for EQ-Resistant Design**
- **Role of Ductility in EQ-Resistant Design**

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Seismic Design for Non-West Coast Engineers

Part 2 (August 17, 2017)

- **Steel Structures: Performance in Past EQs**
- **EQ Resistant Design per ASCE 7-10**
- **Structural Steel Seismic Force-Resisting Systems in the AISC *Seismic Provisions***
- **References for Further Learning**

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Seismic Design for Non-West Coast Engineers

Part 1

- **Causes, Location, and Impact of Earthquakes**
- **EQ Forces on Buildings**
- **Overall Philosophy and Approach for EQ-Resistant Design**
- **Role of Ductility in EQ-Resistant Design**

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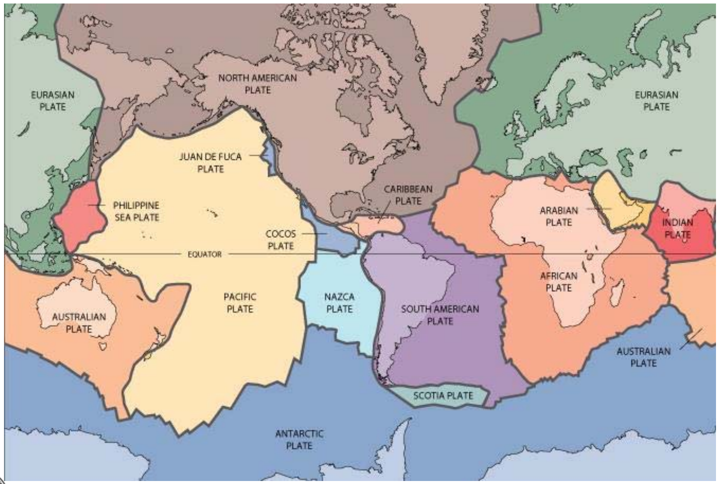
Cause and Location of Earthquakes



Source: USGS

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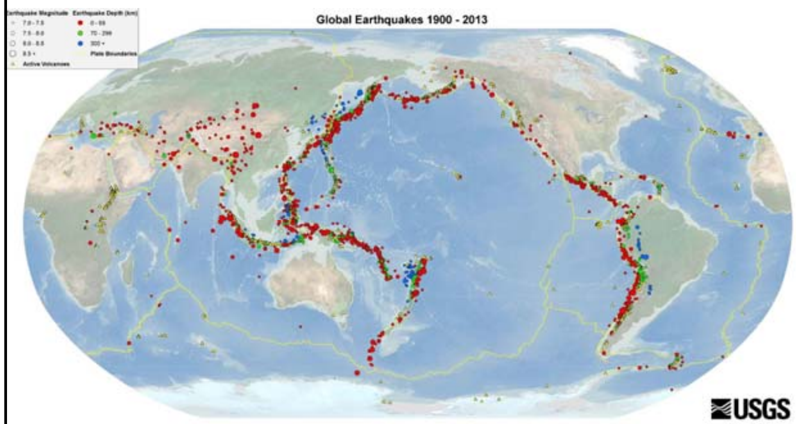

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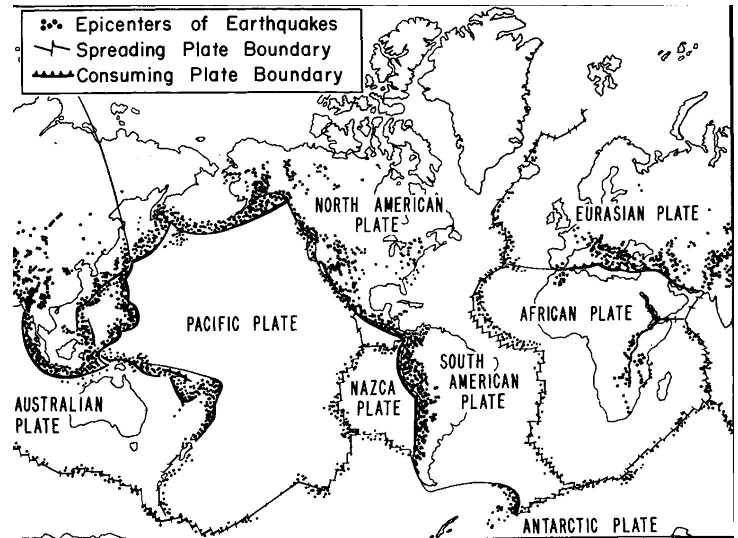

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Source: USGS

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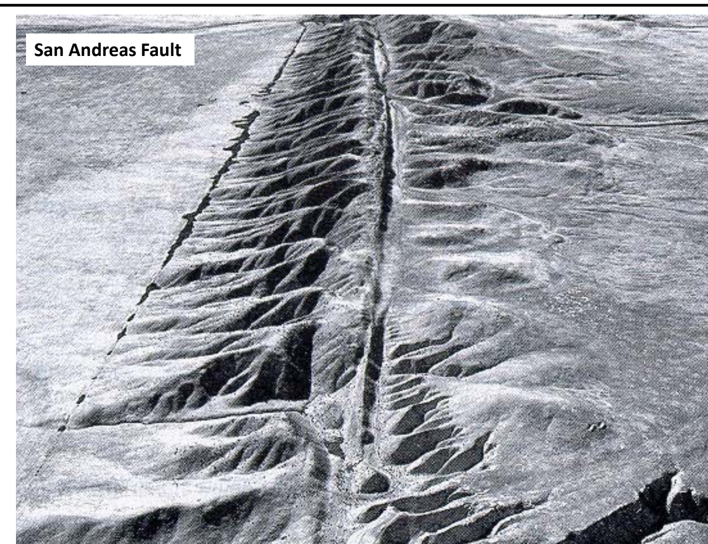

Source: USGS

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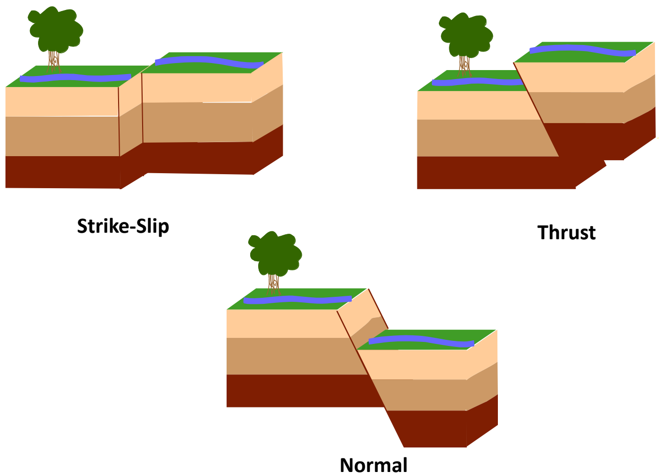

Source: USGS

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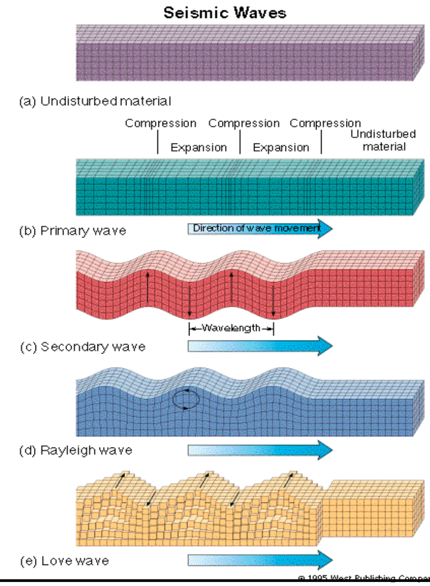

Source: USGS

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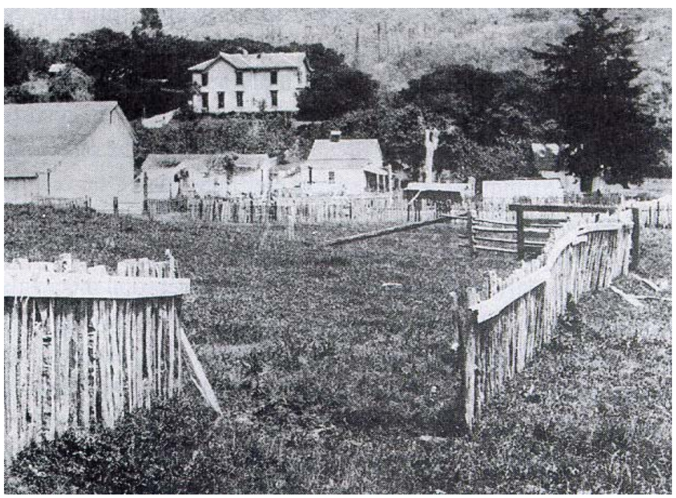
1906 San Francisco Earthquake



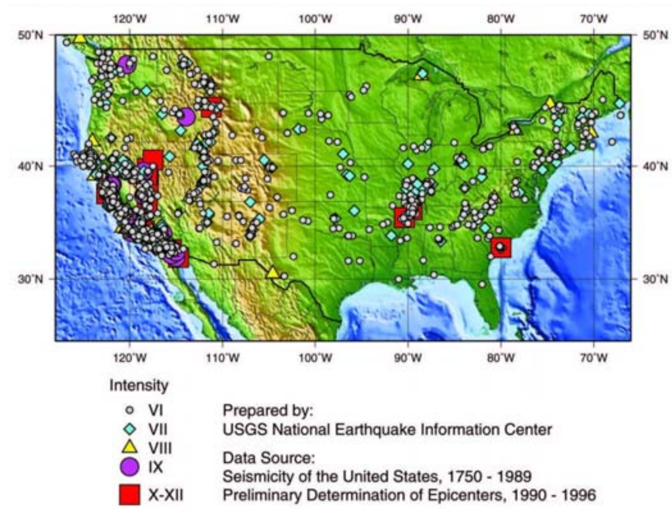
Source: USGS

19

2010 Darfield New Zealand Earthquake

Source: www.gns.cri.nz

20

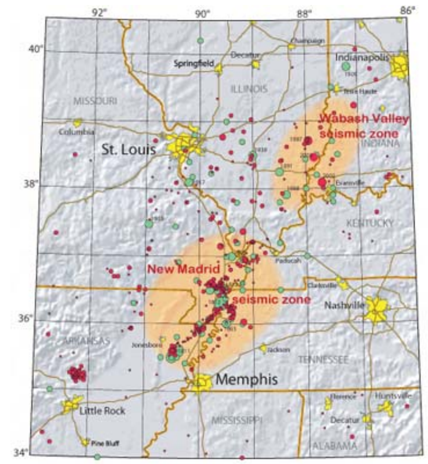


Earthquakes in the Continental United States: 1750 - 1996

Source: FEMA P-749 *Earthquake Resistant Design Concepts* 21

New Madrid 1811-12 Earthquakes

Dec. 16, 1811	Mag. ~7.5
Jan 23, 1812	Mag. ~7.3
Feb. 7, 1812	Mag. ~7.5

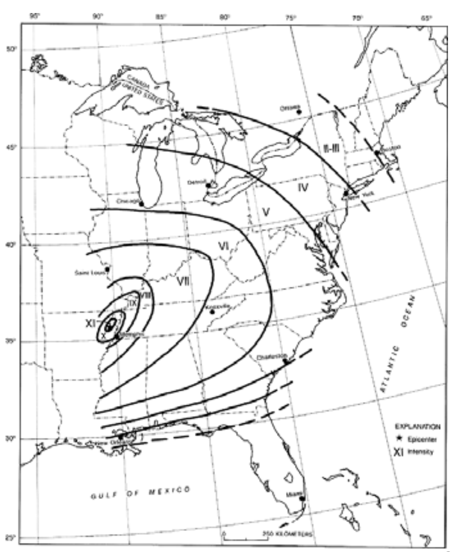


EQ's with Mag. ≥ 2.5: 1974-2002

EQ's prior to 1974

Source: USGS 22

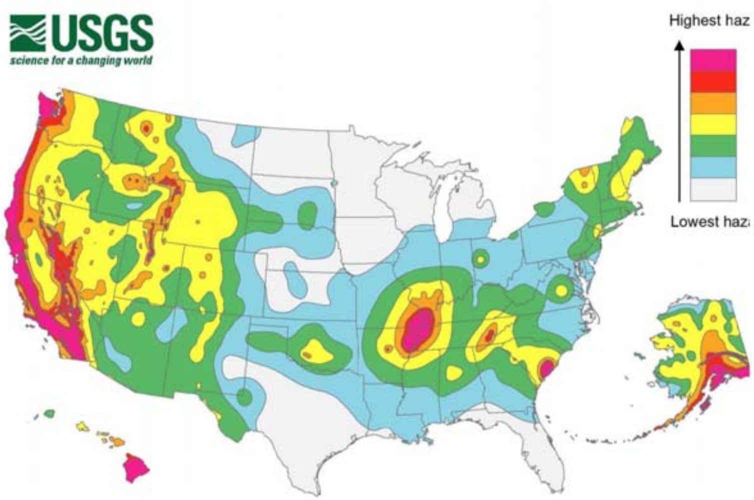
Dec. 16, 1811 New Madrid EQ:
Estimated Intensities



Source: USGS 23

Charleston, South Carolina
EQ Sept 1, 1886
Mag. ~7.3
Approx. 60 fatalities

Source: USGS 24



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Earthquake Fatalities....Some of the World's Deadliest Earthquakes

Fatalities	Year	Location
316,000	2010	Haiti
243,000	1976	Tangshan, China
228,000	2004	Sumatra
200,000	1920	Haiyuan, China
143,000	1923	Kanto, Japan
110,000	1948	Turkmeniya, USSR
88,000	2008	Eastern Sichuan, China
86,000	2005	Pakistan
72,000	1908	Messina, Italy
70,000	1970	Chimbote, Peru
40,000	1990	Iran
40,000	1927	Gulang, China
33,000	1939	Erzincan, Turkey
33,000	1915	Avezzano, Italy

Source: USGS

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Earthquake Fatalities....Some of the World's Deadliest Earthquakes

Fatalities	Year	Location
21,000	2011	Japan
316,000	2010	Haiti
88,000	2008	Eastern Sichuan, China
86,000	2005	Pakistan
228,000	2004	Sumatra
31,000	2003	Southeastern Iran
40,000	1990	Iran
25,000	1988	Spitak, Armenia
243,000	1976	Tangshan, China
23,000	1976	Guatemala
70,000	1970	Chimbote, Peru
110,000	1948	Turkmeniya, USSR
33,000	1939	Erzincan, Turkey
28,000	1939	Chillan, Chile

Source: USGS

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Earthquake Fatalities....U.S. Earthquakes

Fatalities	Year	Location
3000	1906	San Francisco
165	1946	Aleutian Islands, Alaska
128	1964	Prince William Sound, Alaska
115	1933	Long Beach, California
77	1868	Hawaii
65	1971	San Fernando, California
63	1989	Loma Prieta, California
60	1994	Northridge, California
60	1886	Charleston, South Carolina

Source: USGS

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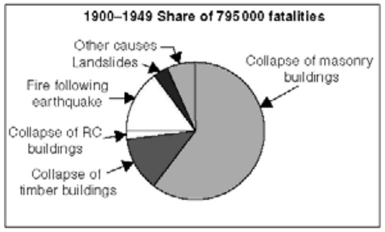
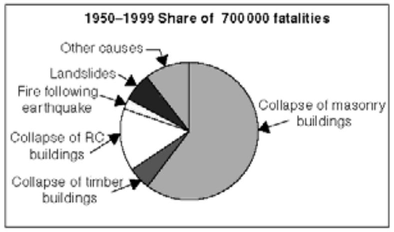
Earthquake Fatalities....Causes





75% of fatalities due to building collapse.

Source: "Earthquake Protection," 2nd Ed.
Andrew Coburn and Robin Spence, Wiley, 2002

29

Major US Earthquakes over Last 50 Years

Year	Location	Fatalities	Property Losses
1964	Prince William Sound, Alaska	125	$300 Million
1971	San Fernando, California	65	$500 Million
1989	Loma Prieta, California	63	$6 Billion
1994	Northridge, California	60	$20 Billion

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Northridge Earthquake

- January 17, 1994
- Magnitude = 6.8
- Epicenter at Northridge - San Fernando Valley
- Fatalities: 60
- Estimated Damage: $20 Billion

31

Source: FEMA

32

Source: USGS

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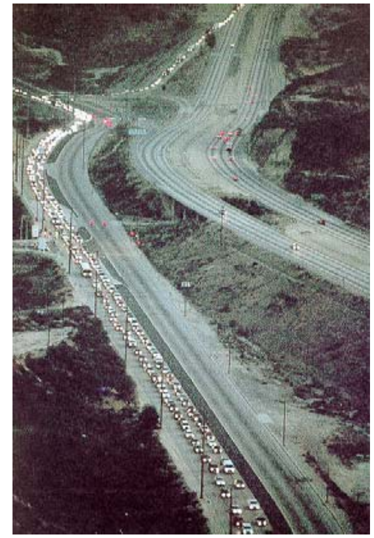

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Source: USGS

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Source: USGS

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Source: USGS 39

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Seismic Design for Non-West Coast Engineers

Part 1

- **Causes, Location, and Impact of Earthquakes**
- **EQ Forces on Buildings**
- **Overall Philosophy and Approach for EQ-Resistant Design**
- **Role of Ductility in EQ-Resistant Design**

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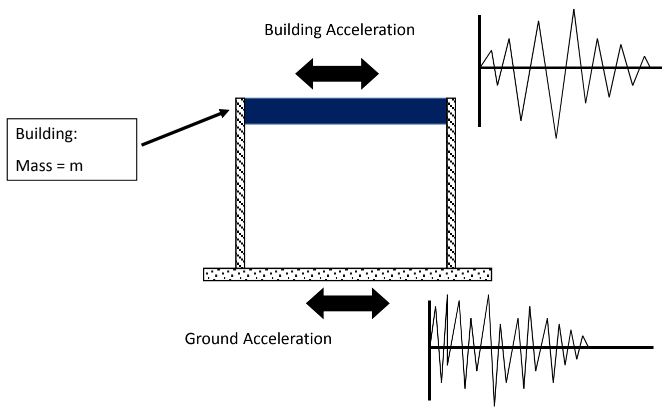
Effect of EQ Ground Motions on Buildings



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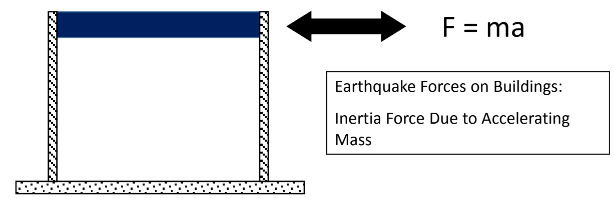

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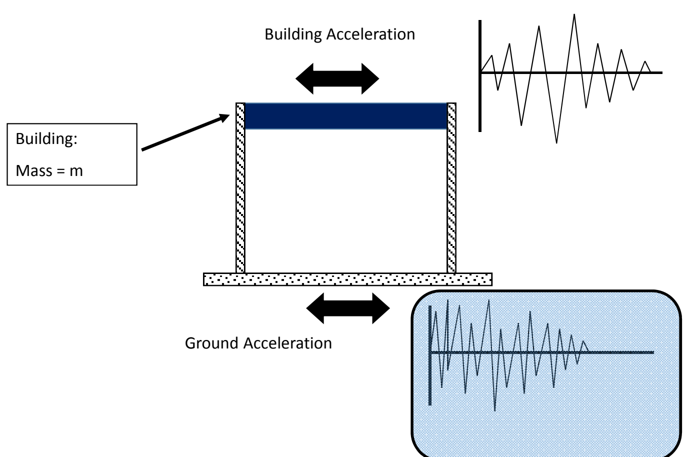
Ground Accelerations



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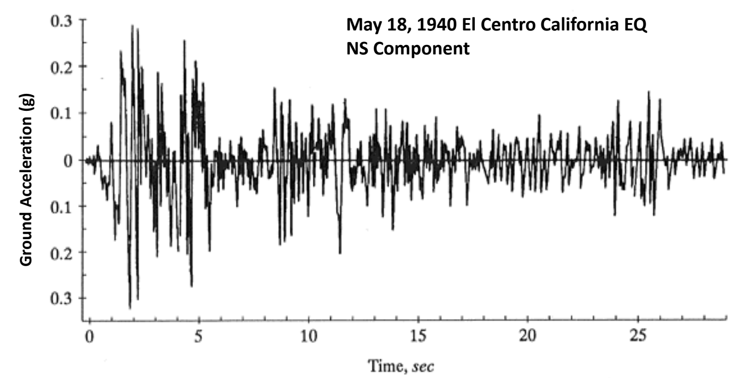
Examples of Recorded EQ Ground Motions



Source: "Dynamics of Structures." Ray Clough and Joseph Penzien

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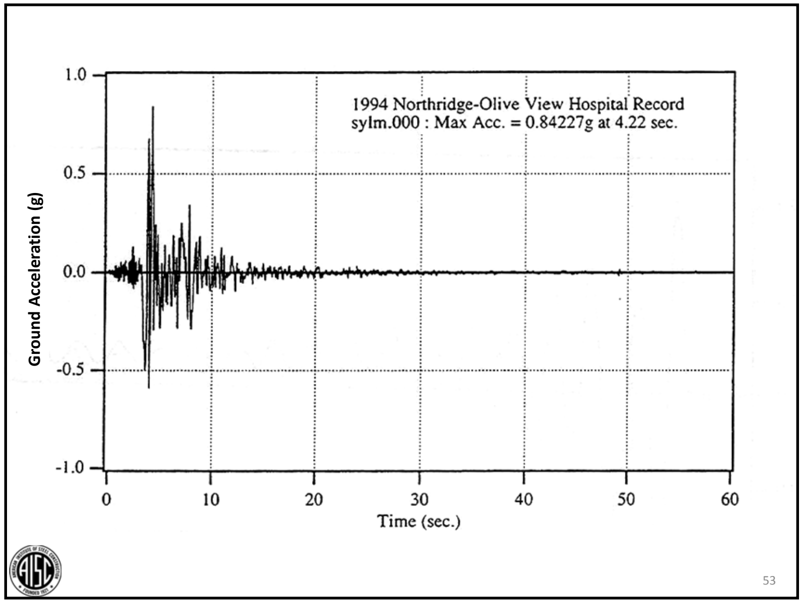
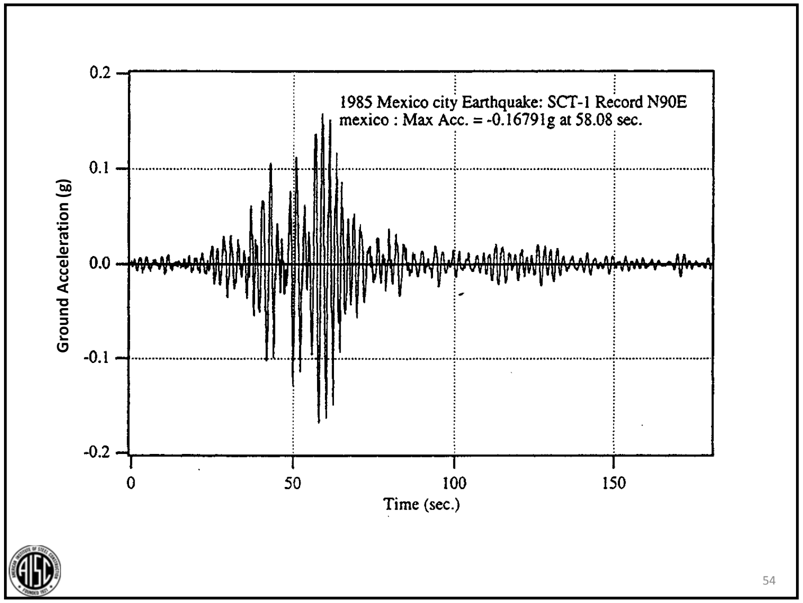
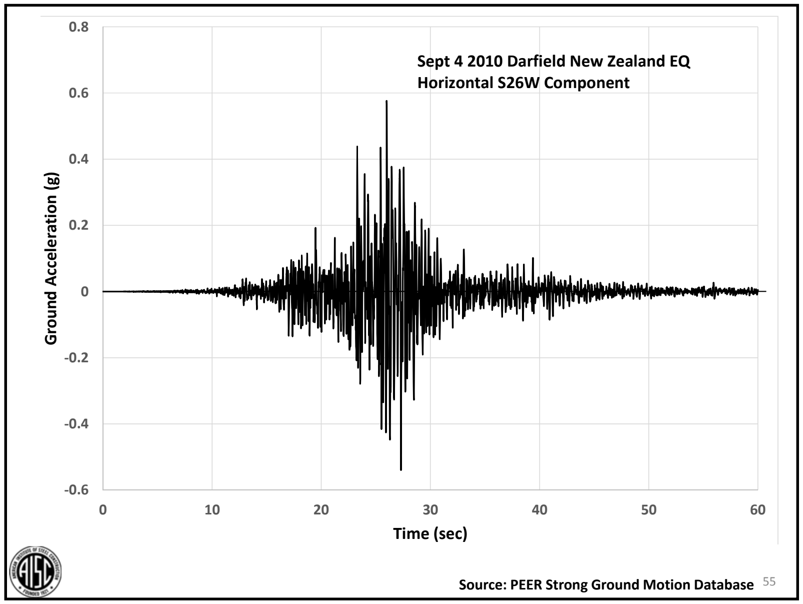
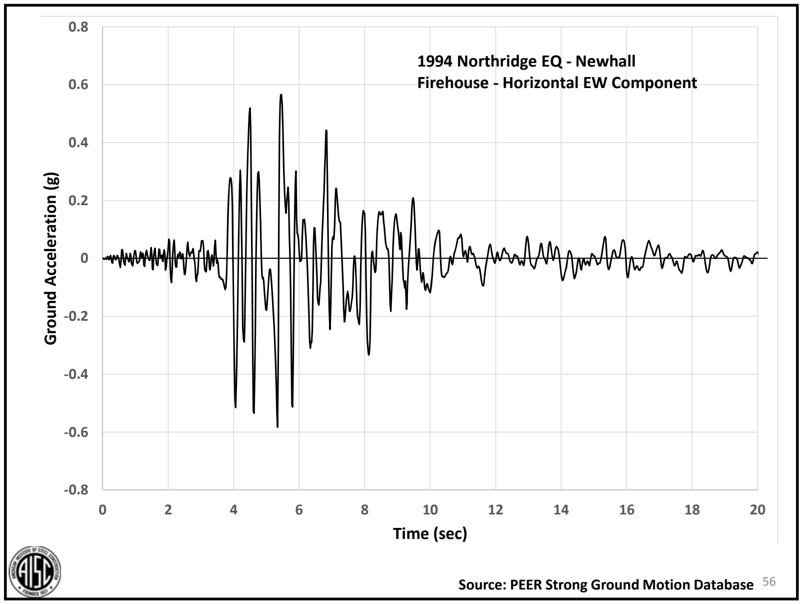
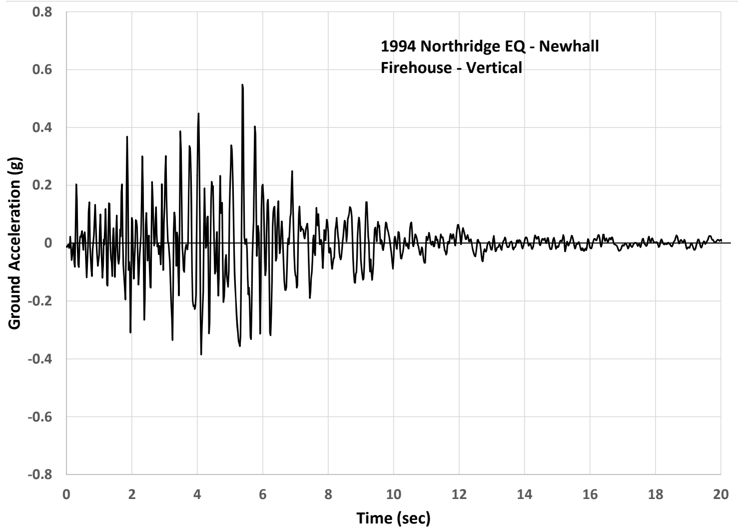

1994 Northridge-Olive View Hospital Record
sylm.000 : Max Acc. = 0.84227g at 4.22 sec.
Ground Acceleration (g)
Time (sec.)
53


1985 Mexico city Earthquake: SCT-1 Record N90E
mexico : Max Acc. = -0.16791g at 58.08 sec.
Ground Acceleration (g)
Time (sec.)
54

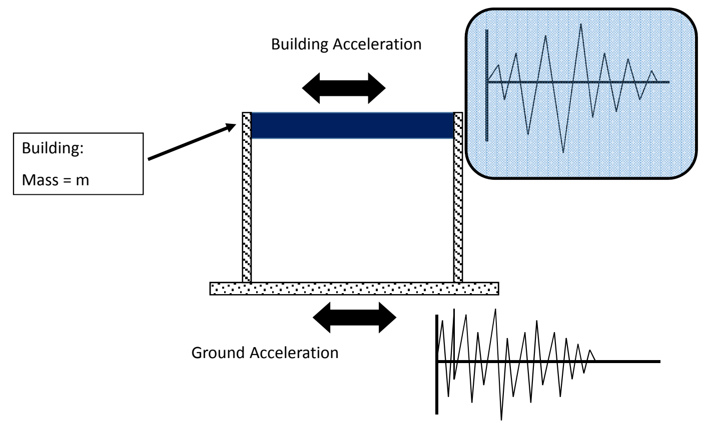

Sept 4 2010 Darfield New Zealand EQ
Horizontal S26W Component
Ground Acceleration (g)
Time (sec)
Source: PEER Strong Ground Motion Database
55


1994 Northridge EQ - Newhall
Firehouse - Horizontal EW Component
Ground Acceleration (g)
Time (sec)
Source: PEER Strong Ground Motion Database
56



Source: PEER Strong Ground Motion Database 57

Building Accelerations (Spectral Accelerations)



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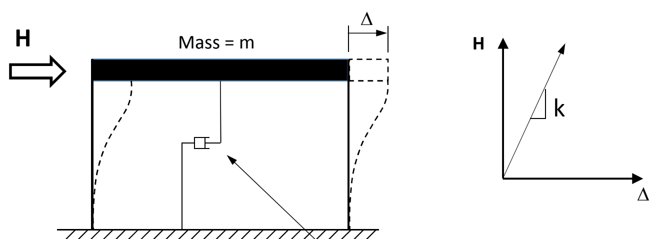
Structural Response to EQ Ground Motions: Elastic Response Spectrum for SDOF Systems

Elastic Single Degree of Freedom (SDOF) System



Characteristics of SDOF System:

Mass = m
Elastic stiffness = k
Damping ratio (0.02, 0.05 etc)

Damping (expressed as a damping ratio)

Natural Period of Vibration:

$$T = 2\pi\sqrt{\frac{m}{k}}$$

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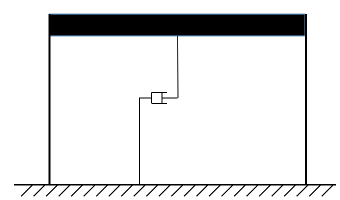
Structural Response to EQ Ground Motions: Elastic Response Spectrum for SDOF Systems

- Choose (SDOF) System with specified period T and specified damping ratio
- Choose ground acceleration record.
- Determine response of SDOF system to ground motion record.
- Peak acceleration of SDOF = **spectral acceleration** for selected period and damping ratio.
- Repeat analysis for different values of SDOF period T.
- Plot results as an **acceleration response spectrum**.



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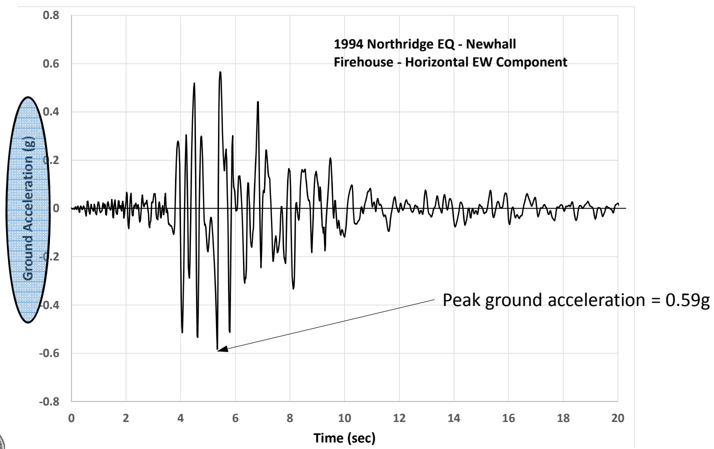
Example SDOF Response
Record: 1994 Northridge EQ Newhall Firehouse EW Record



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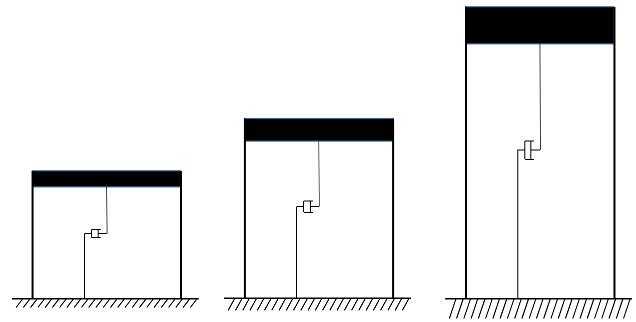
Example SDOF Response
Record: 1994 Northridge EQ Newhall Firehouse EW Record

Analysis of Three SDOF Systems:



T = 0.25 Sec.
0.05 damping ratio

T = 0.50 Sec.
0.05 damping ratio

T = 1.0 Sec.
0.05 damping ratio

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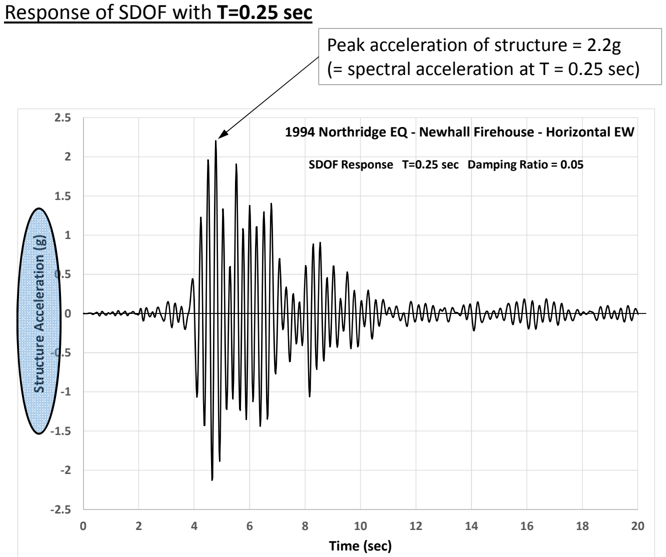
Response of SDOF with **T=0.25 sec**



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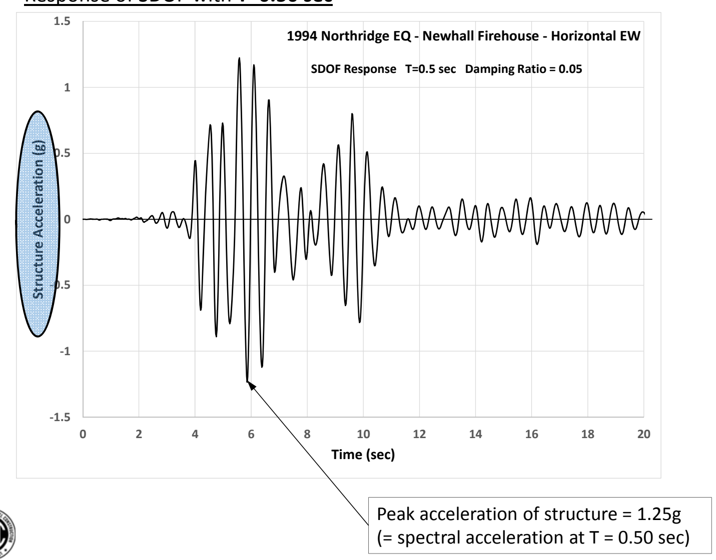
Response of SDOF with **T=0.50 sec**



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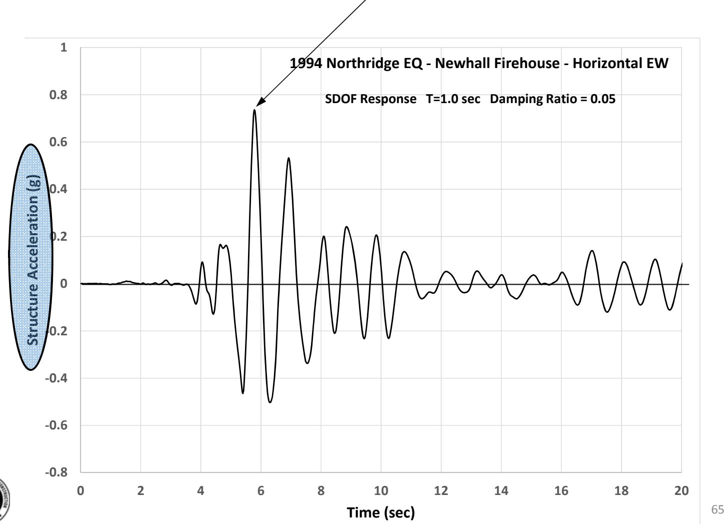
Response of SDOF with **T=1.0 sec**

Peak acceleration of structure = 0.7g
(= spectral acceleration at T = 1.0 sec)



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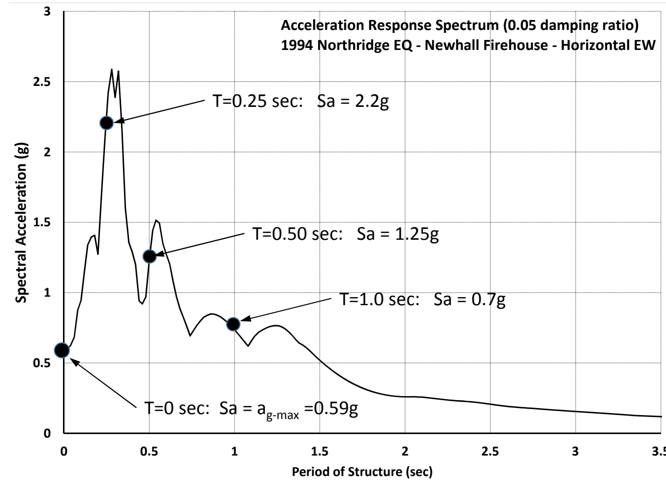
Plot Spectral Accelerations for SDOF Systems with Varying T



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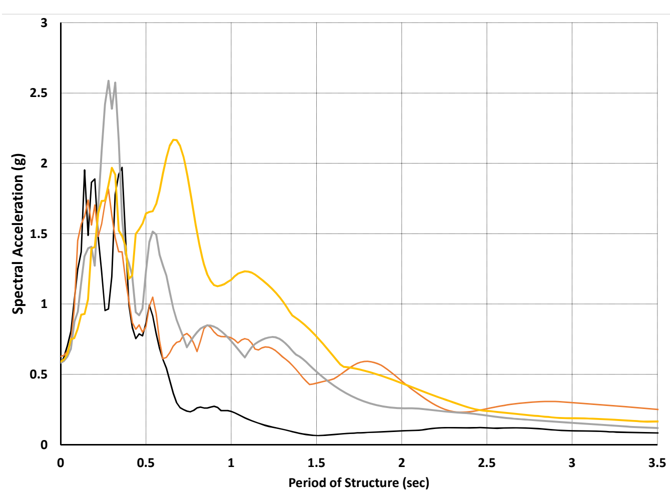
Acceleration Response Spectra for Several EQ Records



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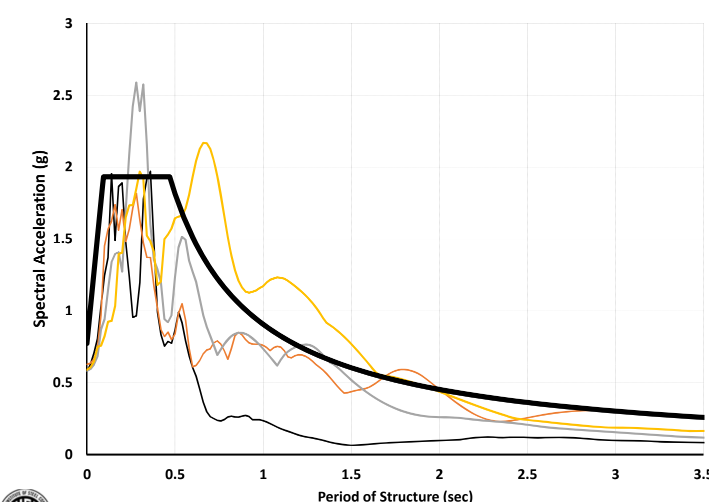
For Design: Use smoothed design acceleration response spectrum



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Approximate Fundamental Period of a Building Structure

See ASCE 7-10: Section 12.8.2 *Period Determination*

Approximate Fundamental Period = T_a (seconds)

For buildings with moment frames and no more than 12 stories:

$$T_a = \frac{N}{10}$$

N = number of stories

Examples:

N = 2 stories: T = 0.2 sec

N = 5 stories T = 0.5 sec

N = 10 stories T = 1.0 sec

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Approximate Fundamental Period of a Building Structure

See ASCE 7-10: Section 12.8.2 *Period Determination*

For any system:

$$T_a = C_t h_n^x$$

h_n = structural height (ft.)

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.

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Examples:

- 5 Story Steel Moment Frame. $h_n = 65$ *ft.*

  $C_t = 0.028$ $x = 0.8$ $T_a = 0.028\,(65)^{0.8} = 0.8$ sec

- 5 Story Steel Concentrically Braced Frame. $h_n = 65$ *ft.*

  $C_t = 0.02$ $x = 0.75$ $T_a = 0.02\,(65)^{0.75} = 0.46$ sec

- 20 Story Steel Moment Frame. $h_n = 250$ *ft.*

  $C_t = 0.028$ $x = 0.8$ $T_a = 0.028\,(250)^{0.8} = 2.32$ sec

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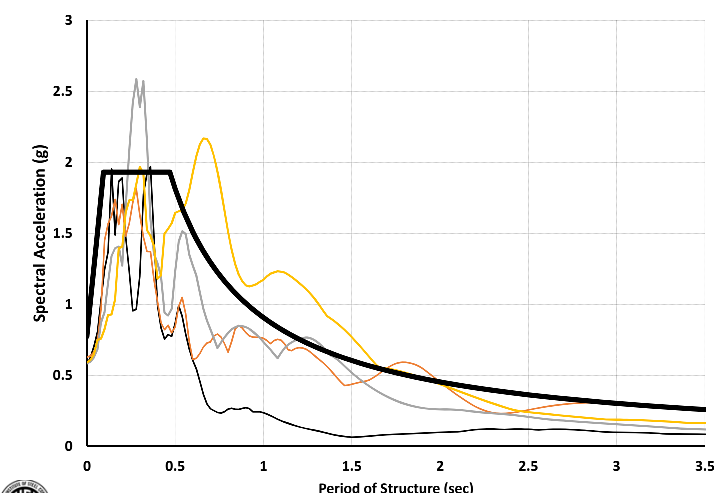

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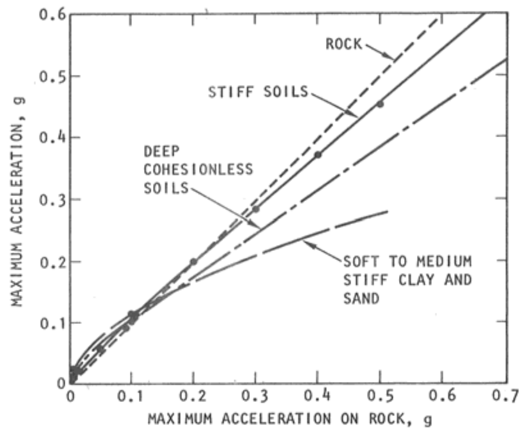
Effect of Soil Conditions on Ground Motions



Source: "Ground Motions and Soil Liquefaction During Earthquakes." H. Bolton Seed and I.M. Idriss. EERI Monograph 1982

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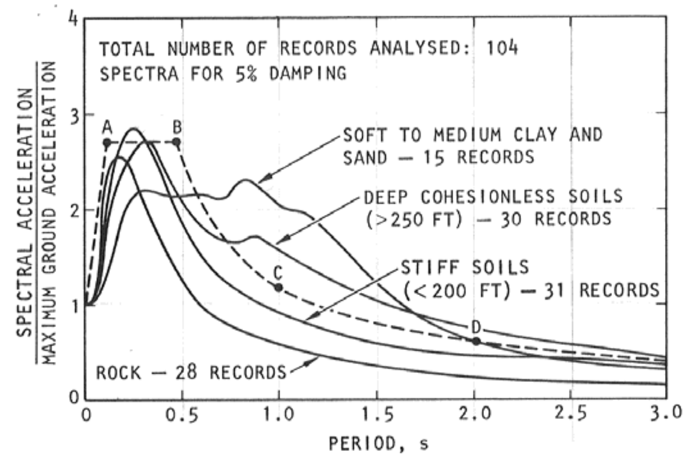

Source: "Ground Motions and Soil Liquefaction During Earthquakes." H. Bolton Seed and I.M. Idriss. EERI Monograph 1982

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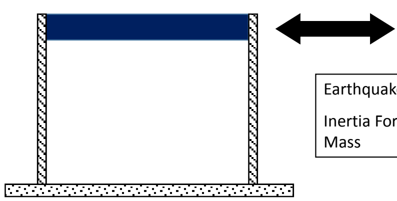
Earthquake Forces on Elastic Structure



F = ma

Earthquake Forces on Buildings:

Inertia Force Due to Accelerating Mass

For a strong earthquake:

Max ground acceleration = $a_{g\text{-}max} \approx 0.2\,g$ to $0.8\,g$

Max. acceleration of structure (= S_a) $\approx$ 1 g to 2.5 g

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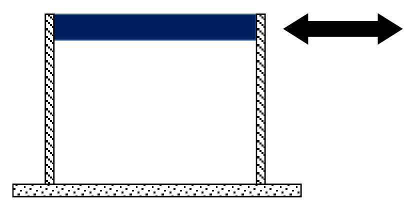
Earthquake Forces on Elastic Structure



F = ma

Say $S_a = 1.5\,g$

$$F_{max} = m\,(1.5g) \qquad m = \frac{W}{g}$$

$$F_{max} = \left(\frac{W}{g}\right)1.5g$$

$$\boxed{F_{max} = 1.5\,W}$$

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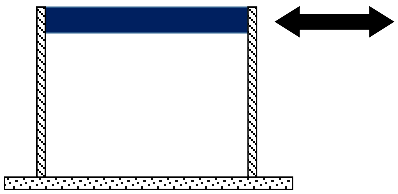
Earthquake Forces on Elastic Structure



F = ma

Maximum force experienced by an elastic structure ≈ (1 to 2.5) ∗ W

Typical design lateral force per building code: F_{max} ≈ (0.1 to 0.2) ∗ W

How is this possible ?

We do not design buildings to remain elastic in strong earthquakes

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Seismic Design for Non-West Coast Engineers

Part 1

- **Causes, Location, and Impact of Earthquakes**
- **EQ Forces on Buildings**
- **Overall Philosophy and Approach for EQ-Resistant Design**
- **Role of Ductility in EQ-Resistant Design**

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Conventional Building Code Philosophy for Earthquake-Resistant Design

Objective: **Prevent collapse in the extreme earthquake likely to occur at a building site.**

Objectives are not to:

- **limit damage**
- **maintain function**
- **provide for easy repair**

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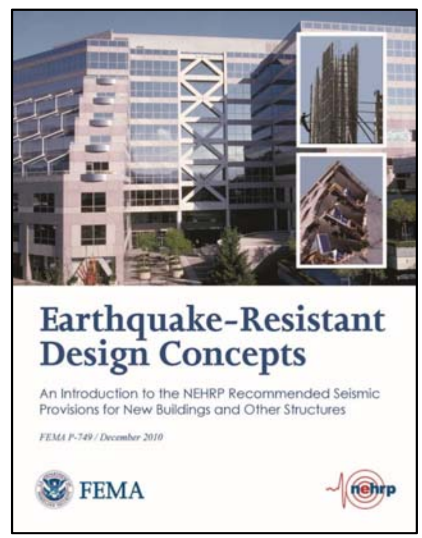

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FEMA P-749

2.2 Acceptable Risk

Defining acceptable risk is difficult because the risk that is acceptable to one person may be unacceptable to many others. Often a person's perception of an acceptable level of risk depends on whether or not the person believes he or she will be personally affected and how much the person is being asked to personally spend to avoid the risk. The *NEHRP Recommended Seismic Provisions* has adopted the following target risks as the minimum acceptable for buildings and structures constructed in the United States:

A small chance (on the order of 10 percent) that any structure will experience partial or total collapse as a result of the most intense earthquake ground motion considered by the building codes. These very rare and intense earthquake effects are called risk-targeted maximum considered earthquake (MCE_R) ground motions and the probability of their occurrence varies across the nation. This collapse-prevention goal is intended as the primary means of ensuring life safety in that most casualties in past earthquakes occurred as a result of structural collapse. Although protection at this level does not guarantee no lives will be lost, it should prevent the loss of tens of thousands of lives in individual earthquake events such as those that occurred in Armenia, China, Haiti, Turkey, and other nations in recent years.

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Conventional Building Code Philosophy for Earthquake-Resistant Design

Objective: **Prevent collapse in the extreme earthquake likely to occur at a building site.**

Objectives are not to:

- **limit damage**
- **maintain function**
- **provide for easy repair**

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Seismic Design for Non-West Coast Engineers

Part 1

- **Causes, Location, and Impact of Earthquakes**
- **EQ Forces on Buildings**
- **Overall Philosophy and Approach for EQ-Resistant Design**
- **Role of Ductility in EQ-Resistant Design**

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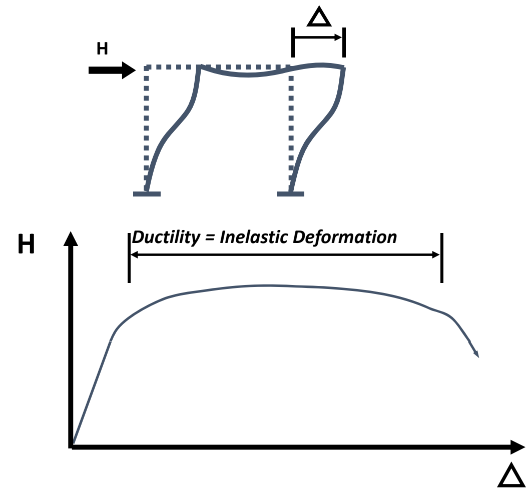
To Survive Strong Earthquake without Collapse:
Design for Ductile Behavior



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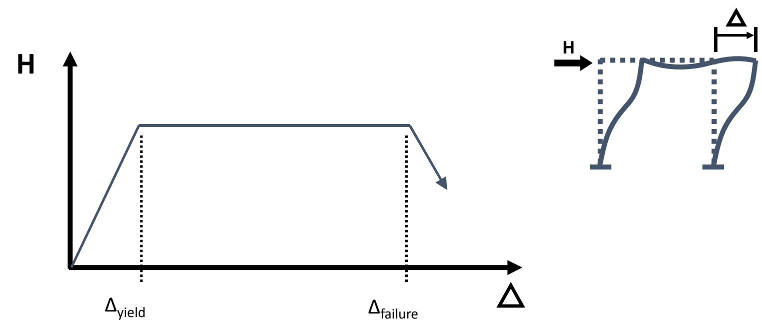

Ductility Factor $\mu = \dfrac{\Delta_{failure}}{\Delta_{yield}}$

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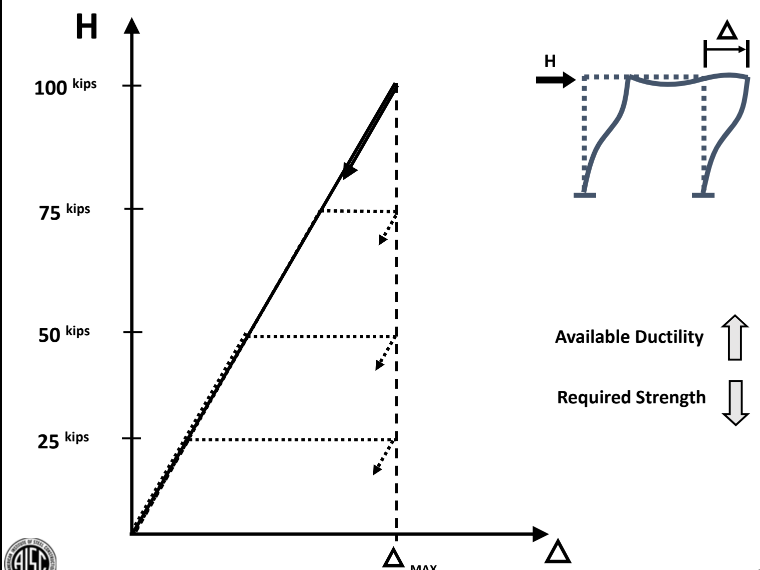
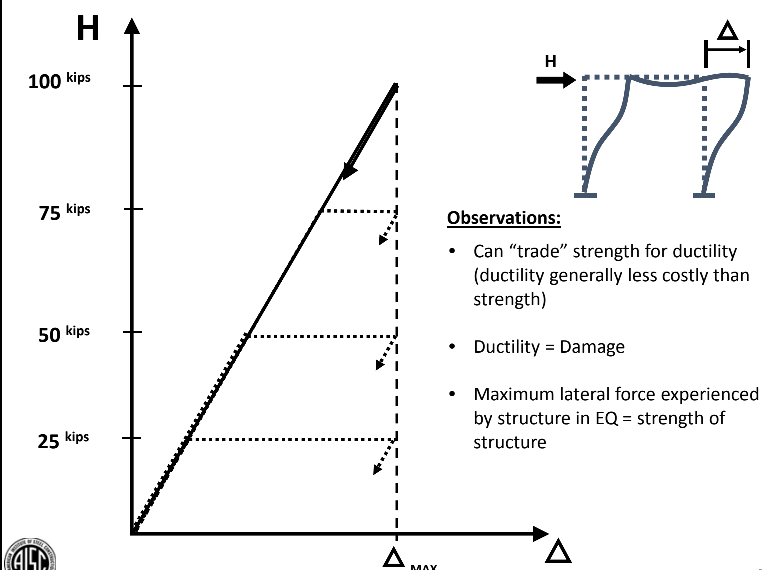


87



Observations:

- Can "trade" strength for ductility (ductility generally less costly than strength)
- Ductility = Damage
- Maximum lateral force experienced by structure in EQ = strength of structure

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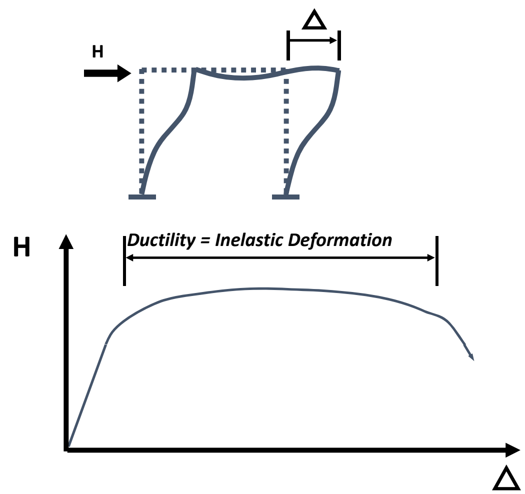
To Survive Strong Earthquake without Collapse: Design for Ductile Behavior



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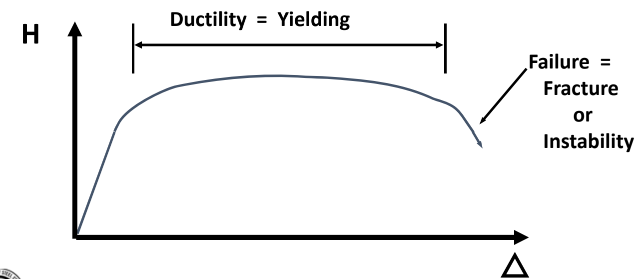
Ductility in Steel Structures: ***Yielding***

Nonductile Failure Modes: ***Fracture or Instability***



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Seismic Design for Non-West Coast Engineers

Part 1 (August 10, 2017)

- **Causes, Location, and Impact of Earthquakes**
- **EQ Forces on Buildings**
- **Overall Philosophy and Approach for EQ-Resistant Design**
- **Role of Ductility in EQ-Resistant Design**

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Seismic Design for Non-West Coast Engineers

Part 2 (August 17, 2017)

- **Steel Structures: Performance in Past EQs**
- **EQ Resistant Design per ASCE 7-10**
- **Structural Steel Seismic Force-Resisting Systems in the AISC *Seismic Provisions***
- **References for Further Learning**

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Question 1

True or False: The term “spectral acceleration” refers to the peak ground acceleration in an earthquake.

a) True
b) False

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Question 2

True or False: Most buildings designed in accordance with the building code would be expected to experience significant structural damage during a major earthquake.

a) True
b) False

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PDH Certificates

Within 2 business days…

- You will receive an email on how to report attendance from: registration@aisc.org.
- Be on the lookout: Check your spam filter! Check your junk folder!
- Completely fill out online form. Don't forget to check the boxes next to each attendee's name!

PDH Certificates

Within 2 business days…

- Reporting site (URL will be provided in the forthcoming email).
- Username: Same as AISC website username.
- Password: Same as AISC website password.

There's always a solution in steel.

Thank You

Please give us your feedback!
Survey at conclusion of webinar.

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