STR 614 - Seismic Structural Analysis

Lecture No. 1

Seismic Design Approaches

Course Instructors

- Dr. Mostafa Abd-El-Wahab
  - E-mail: elsayemm@gmail.com

- Dr. Bahaa Hanafy
  - E-mail: bahaa1960@yahoo.com

Course Objectives

- Understanding the fundamentals of structural dynamics.
- Understanding the different analysis and design approaches.
  - Forced-based seismic analysis
  - Displacement-based seismic analysis
  - Performance-based seismic analysis
- Determining the internal straining actions in buildings using both manual and computing techniques.
- Evaluate the seismic provisions in the different seismic codes.

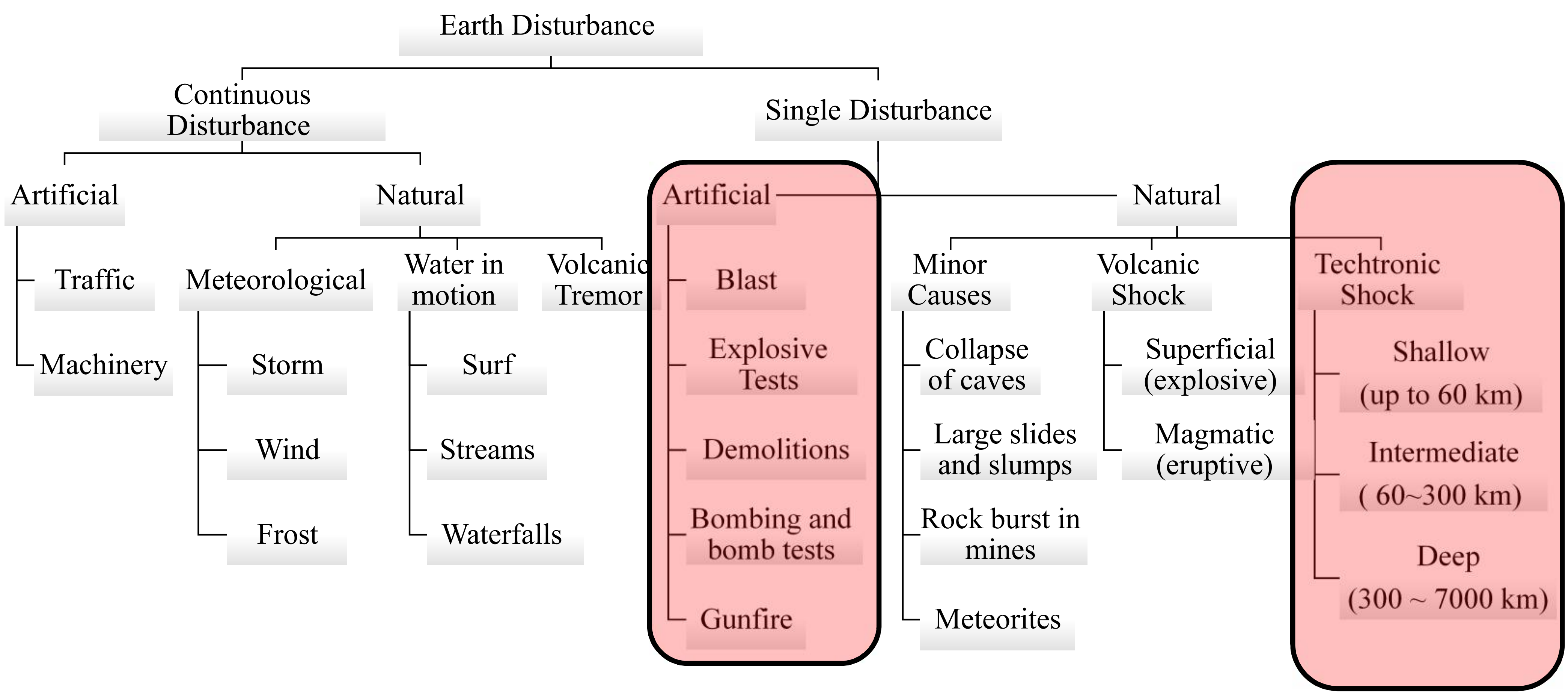
Methods and tools used for seismic analysis

- Finite element software (SAP – ETABs – SEISMOSTRUCT).
- Numerical software (EXCEL – MATLAB).
- Response spectrum Analysis.
- Modal Analysis.
- Pushover Analysis.
- Time-history Analysis.
- Fragility.
- Introduction to **BLAST LOADING**

Course evaluation & References

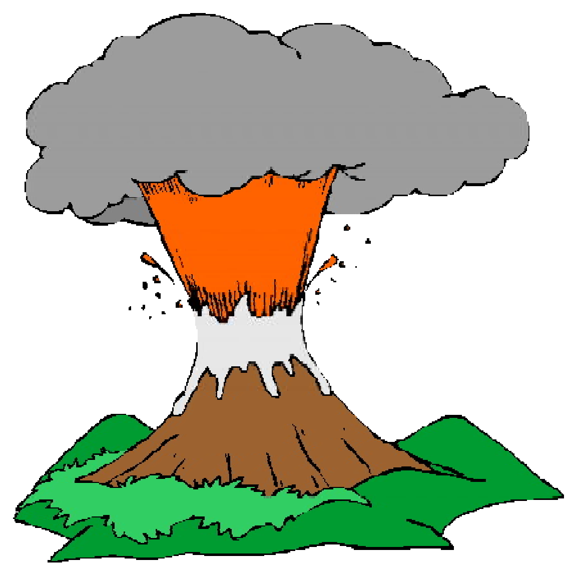
- Final exam 40%.
- Assignments 30%.
- Project 30%.
- Attendance (minimum 75% of lectures **MUST** be attended)

- Dynamics of structures: theory and applications to earthquake engineering, by Anil K. Chopra. Englewood Cliffs, N.J., Prentice Hall, 1995.
- Fundamentals of Earthquake Engineering, by Amr S. Elnashai and Luigi Di Sarno.
- Displacement-based Seismic Design of Structures by M. J. N. Priestley, G.M. Calvi and M.J. Kowalsky.


Earth Disturbance
Continuous Disturbance
Single Disturbance
Artificial
Natural
Traffic
Machinery
Meteorological
Water in motion
Volcanic Tremor
Storm
Wind
Frost
Surf
Streams
Waterfalls
Artificial
Blast
Explosive Tests
Demolitions
Bombing and bomb tests
Gunfire
Natural
Minor Causes
Volcanic Shock
Techtronic Shock
Collapse of caves
Large slides and slumps
Rock burst in mines
Meteorites
Superficial (explosive)
Magmatic (eruptive)
Shallow
(up to 60 km)
Intermediate
(60~300 km)
Deep
(300 ~ 7000 km)

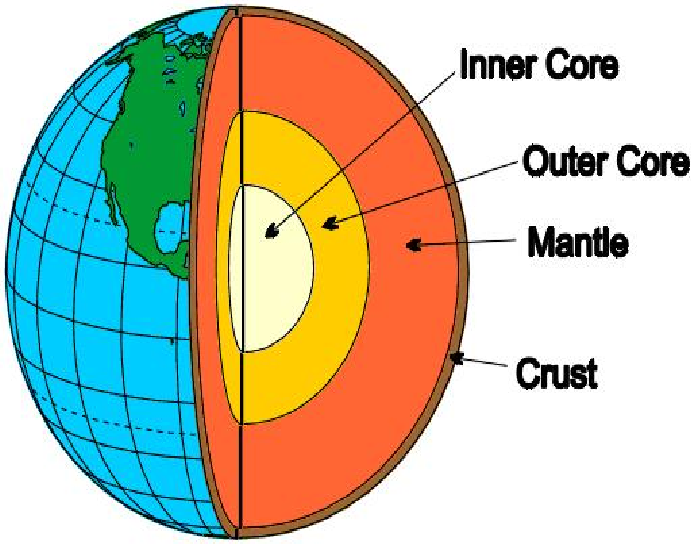
Tectonic Plates Theory

- Earthquake is a ground disturbance caused from the release of energy due to a differential movement in the crust.
- Causes:
  - Dislocation of crust.
  - Volcanic eruption.
  - Explosions.
  - Failure of underground cavities.



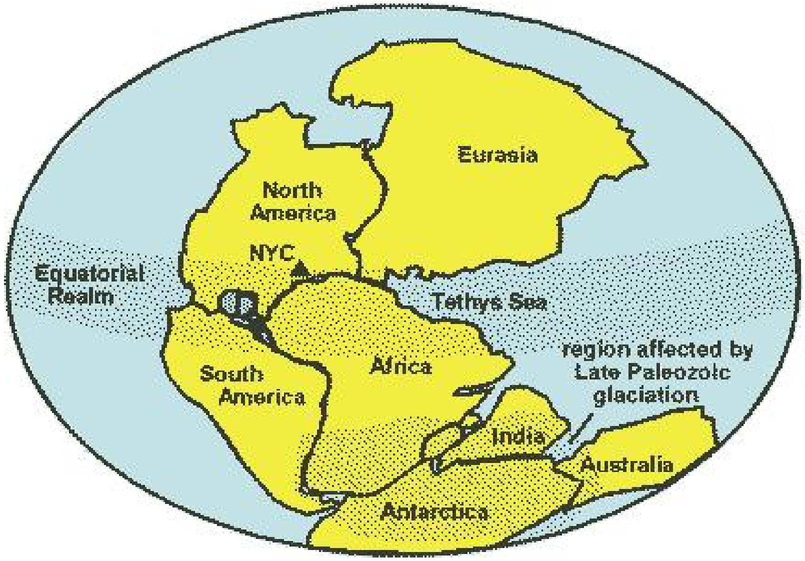
Tectonic Plates Theory

- Tectonic plates are stable and rigid (up to 100 km thickness).
- These plates consist of:
  1. The Crust: with a depth varies from 25 ~ 80 km. (oceans 4 ~ 8 km)
  2. The lithosphere: in the upper mantle, with a depth about 50 km.
- The tectonic plates move relatively to each other above the asthenosphere (around 400 km).

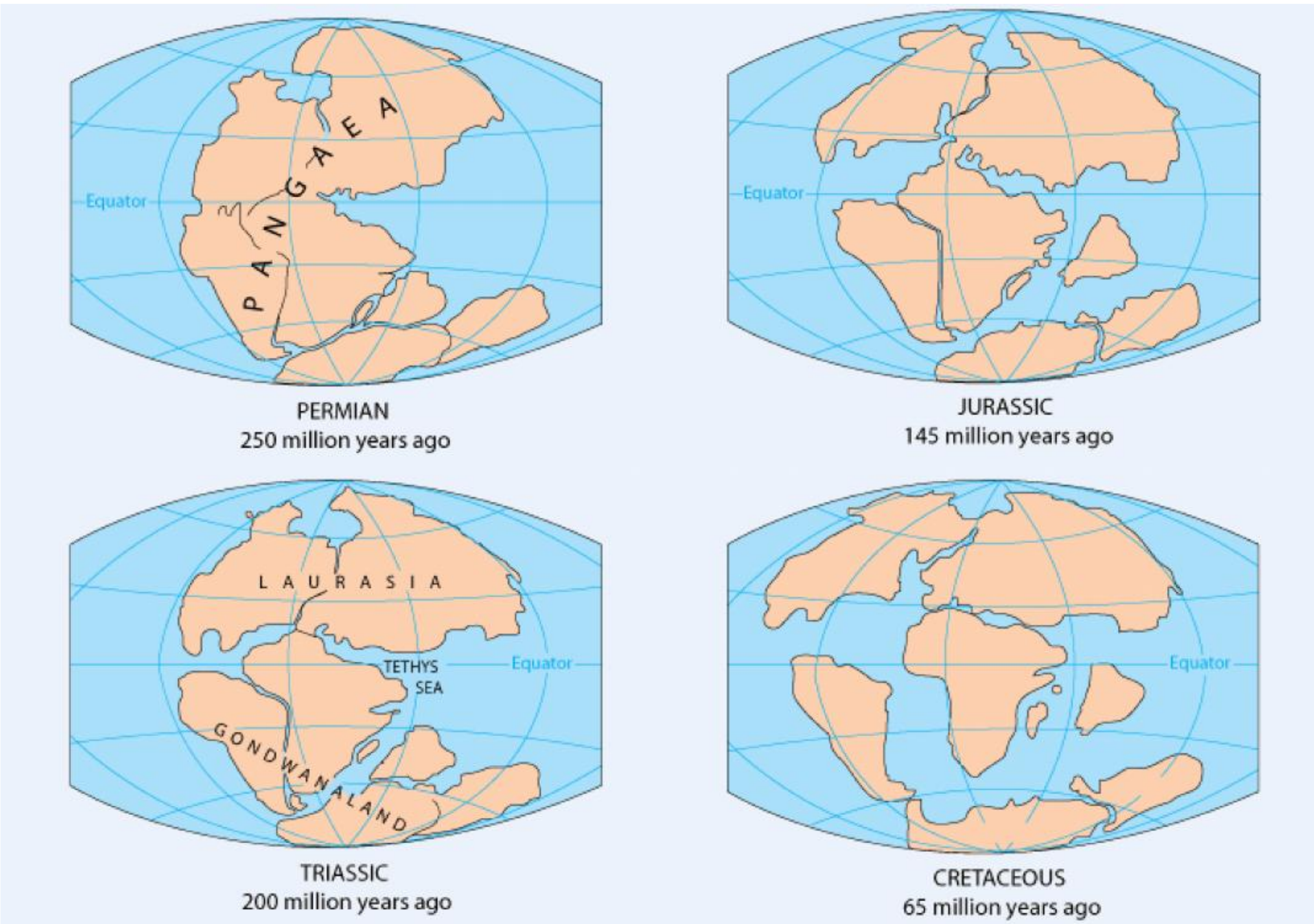


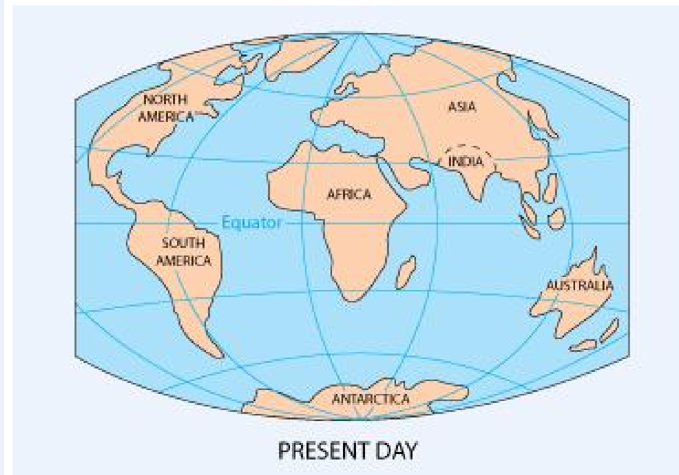
Tectonic Plates Theory

- Due to the convection between the different layers, there is a relative movement in the lithosphere. (around 1 ~ 10 cm / year).
- Such movements can be detected by satellites.
- **Pangaea**



Pangaea


Equator
P A N G A E A
PERMIAN
250 million years ago
Equator
JURASSIC
145 million years ago
L A U R A S I A
TETHYS
SEA
Equator
G O N D W A N A L A N D
TRIASSIC
200 million years ago
Equator
CRETACEOUS
65 million years ago

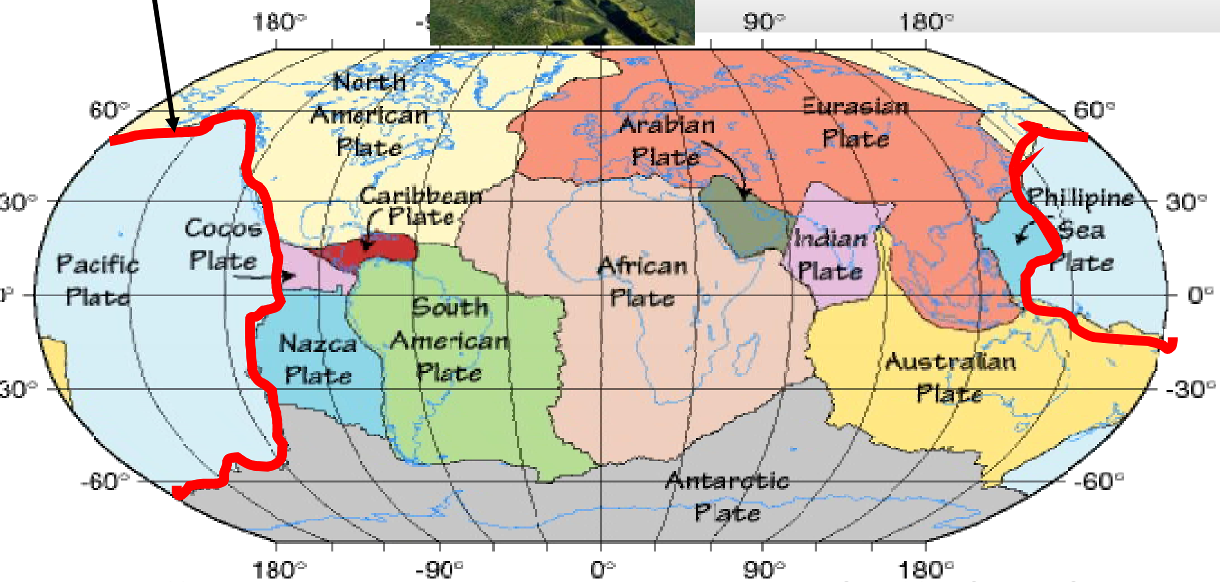

NORTH
AMERICA
ASIA
INDIA
AFRICA
Equator
SOUTH
AMERICA
AUSTRALIA
ANTARCTICA
PRESENT DAY

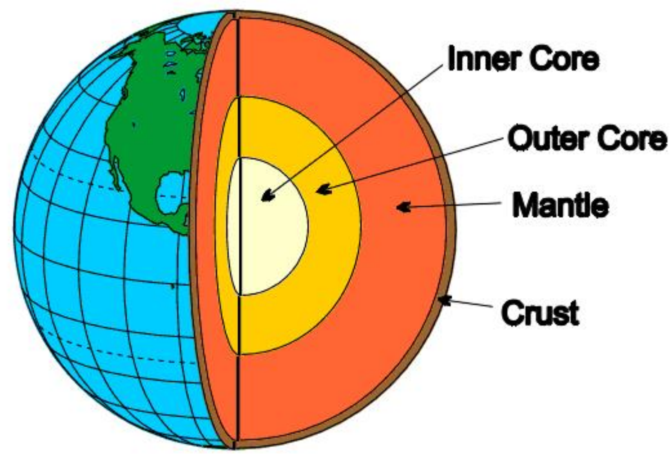
Tectonic Plates Theory & Seismic Belt

15 Rigid Plates

- Continentals
- Oceans

Circum-Pacific and Euro-Asian Seismic Belt (causing a fault)

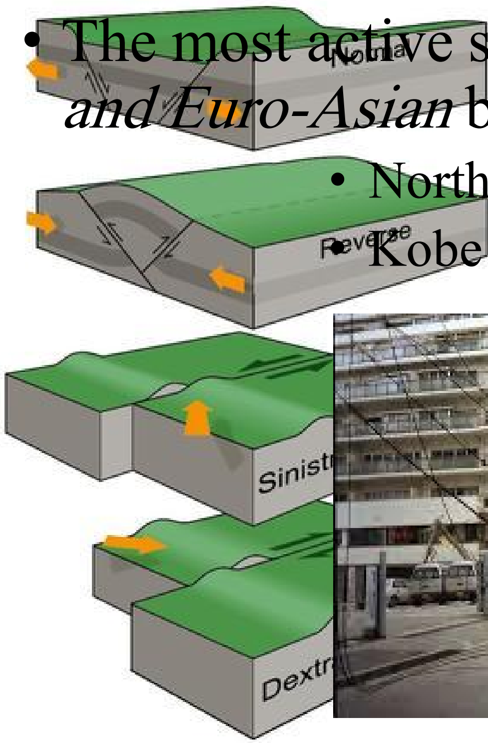




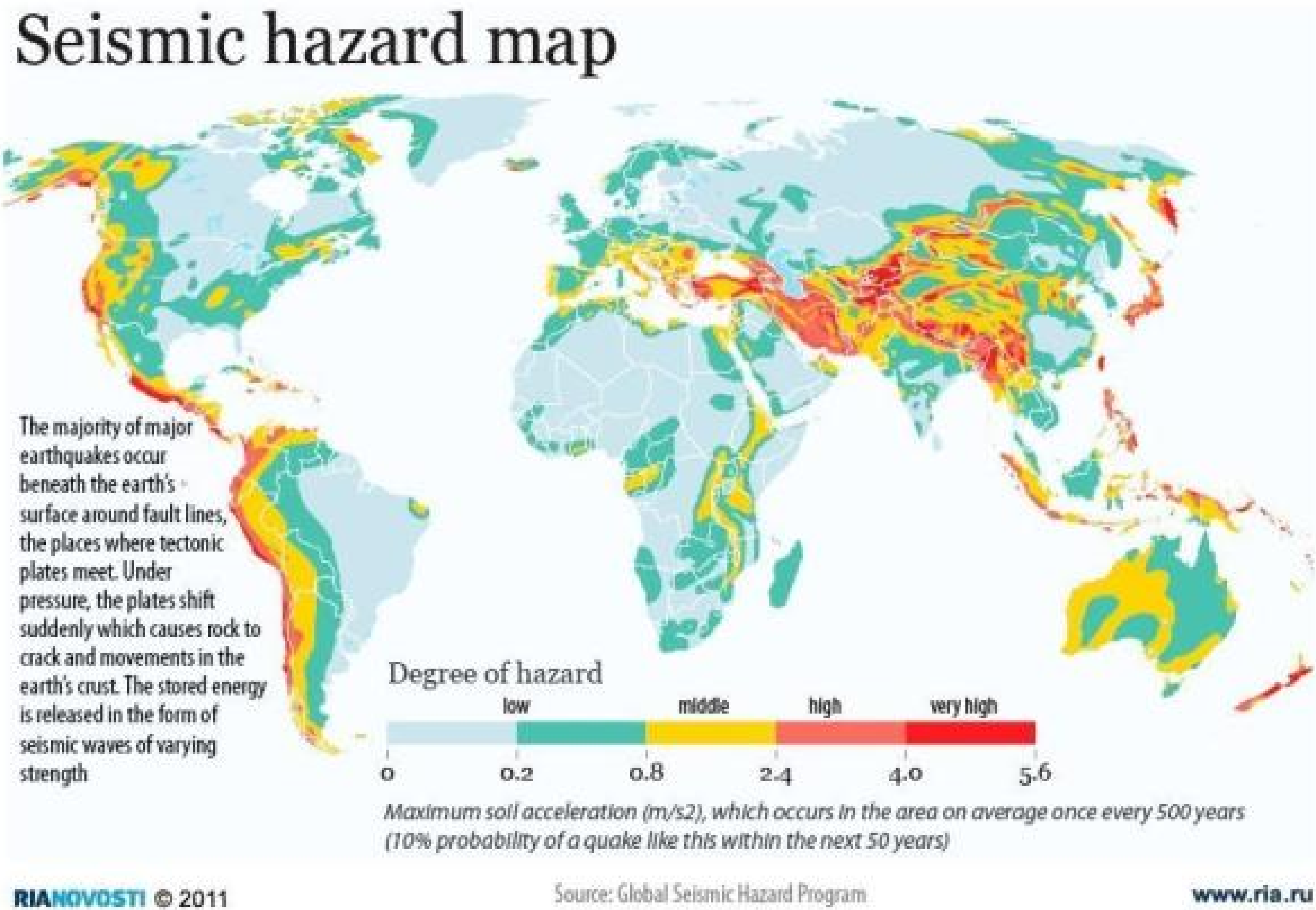
Faults

San Andrea Fault (California)

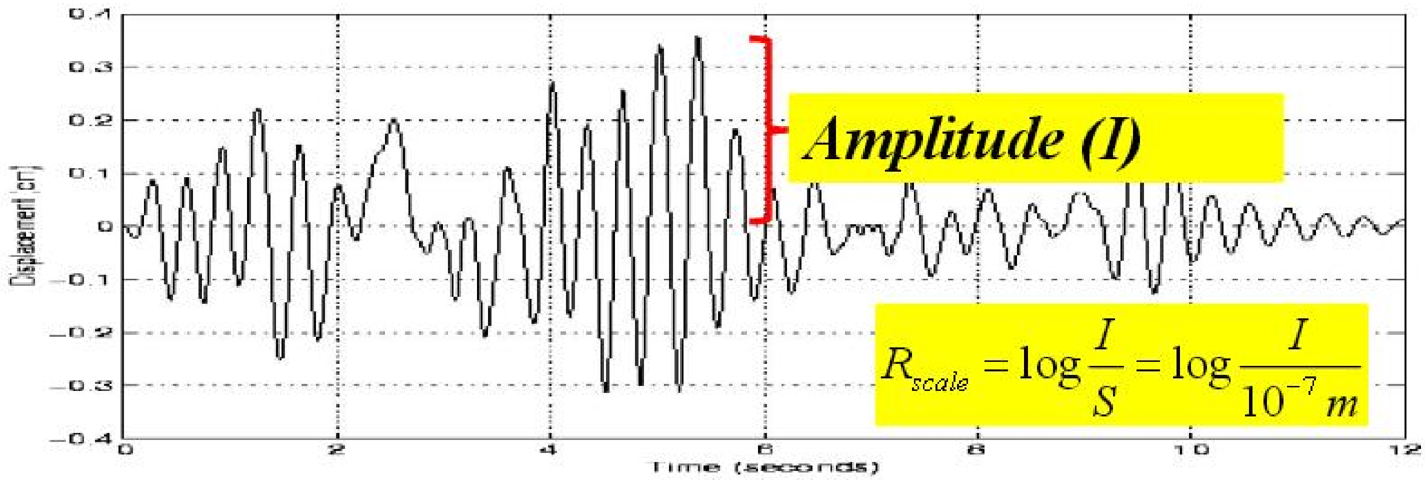
- Due to the relative movements among the tectonic plates, faults performs.
- The most active seismic belt is *Circum – pacific and Euro-Asian* belt.
  - Northridge 1994 (California)
  - Kobe 1995 (Japan)



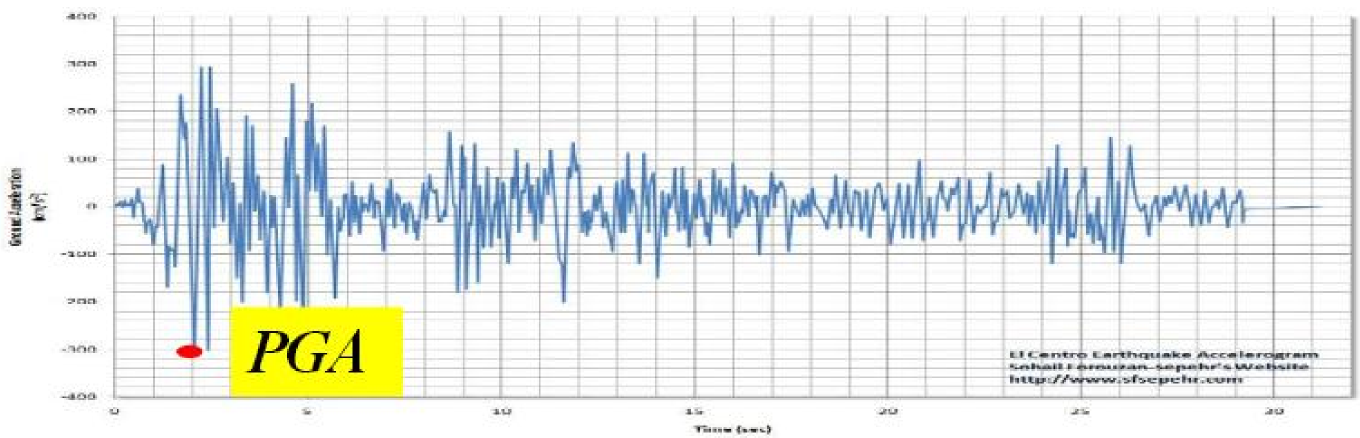
- The majority of major EQs occur beneath the earth's surfaces around fault lines, the plates where tectonic plates meet.
- Under pressure, the plates shift suddenly, which causes rock to crack and movements in he earth's crust.
- The stored energy is released in the form of seismic waves of varying length.



Richter Scale and EQ Magnitude



$$R_{scale} = \log \frac{I}{S} = \log \frac{I}{10^{-7}\,m}$$



Richter Scale and EQ Magnitude (Example)

- Early in the century the earthquake in San Francisco registered 8.3 on the Richter scale. In the same year, another earthquake was recorded in South America that was four time stronger. What was the magnitude, on Richter scale, of the earthquake in South American?

$$M_{SF} = \log \frac{I_{SF}}{S} = 8.3$$

$$M_{SA} = \log \frac{I_{SA}}{S} = \log \frac{4I_{SF}}{S} = \log 4 + \log \frac{I_{SF}}{S}$$

$$M_{SA} = 0.6 + 8.3 = 8.9$$

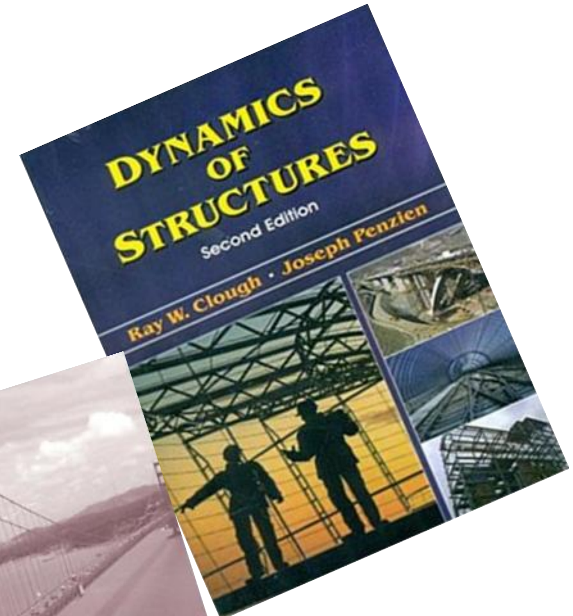
Richter Scale and EQ Magnitude

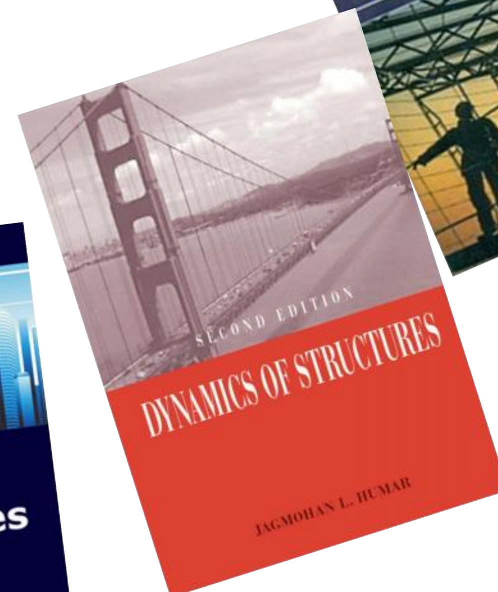
Richter Magnitude	Earthquake Effects
0-2	Not felt by People
2-3	Felt little by people
3-4	Celling Lights swing
4-5	Walls crack
5-6	Furniture moves
6-7	Some building collapse
7-8	Many building destroyed
8 and up	Total destruction of buildings, bridges and roads

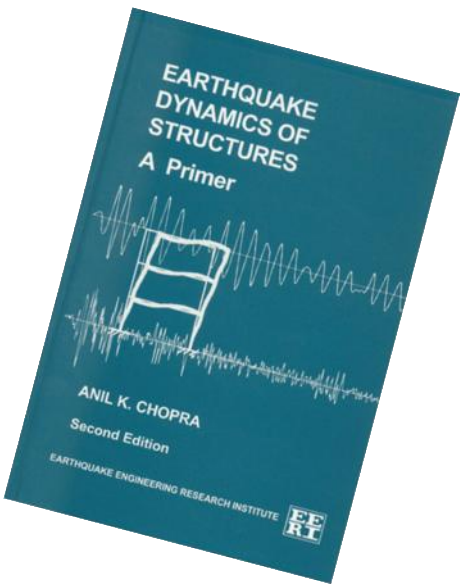
Intensity	PGA	Earthquake Effects	Damage Level
I	*<0.0017*	Not felt	None
II~III	*0.014*	Weak	None
IV	*0.039*	Light	None
V	*0.092*	Moderate	Very light
VI	*0.18*	Strong	Light
VII	*0.34*	Very strong	Moderate
VIII	*0.65*	Severe	Moderate-heavy
IX	*1.24*	Violent	Heavy
X+	*>1.24*	Extreme	Very heavy

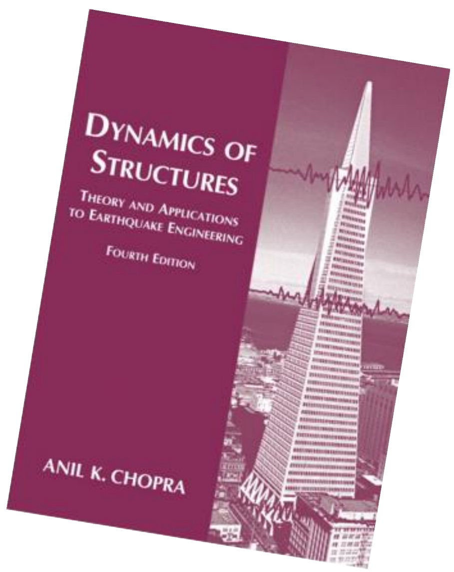
Introduction to the Dynamics of Structures

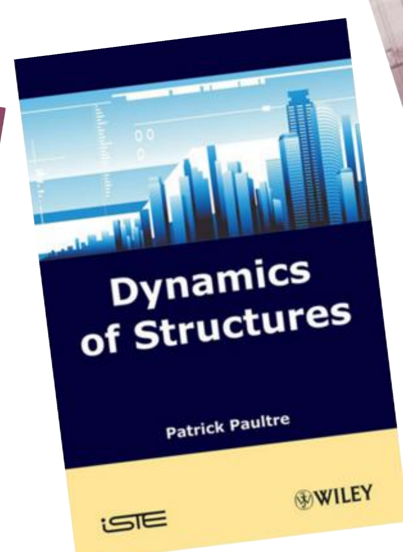
Revision





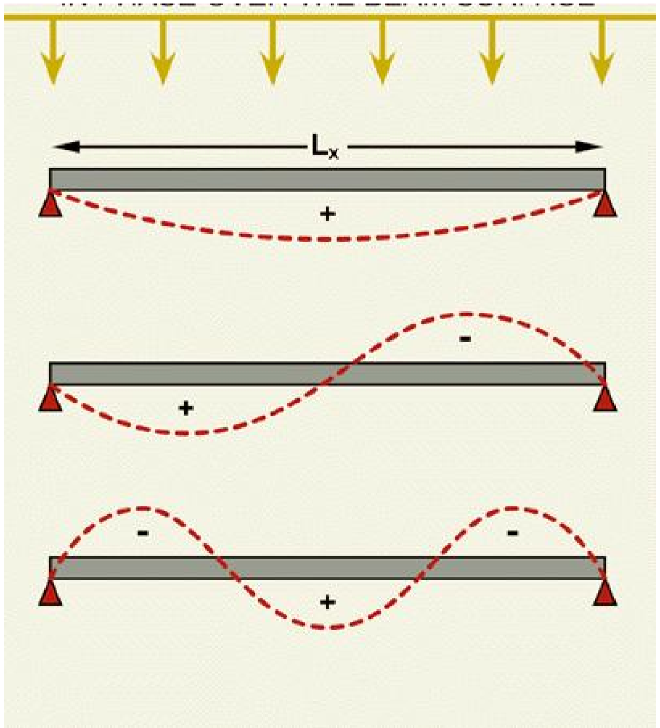






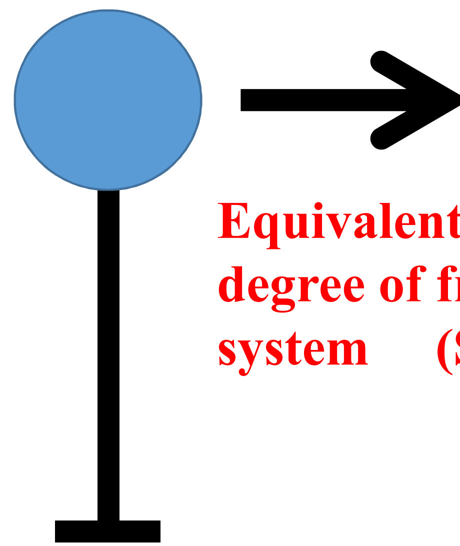
Introduction to dynamics

- The term dynamics may be defined simply as time varying.
- For example: a load whose magnitude, duration, and / or position vary with time is defined as a dynamic load.



Modeling of Single Story Structures

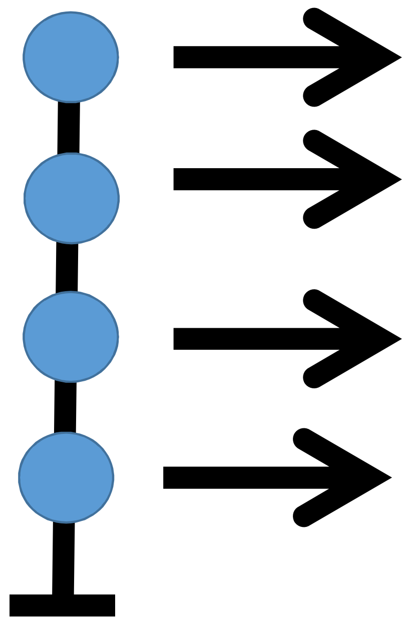
- In this procedure, the mass of the system is assumed to be concentrated at discrete locations.
- This is suitable for systems in which a large portion of the total mass actually is concentrated at a few discrete locations.



Equivalent Single degree of freedom system (SDOF)

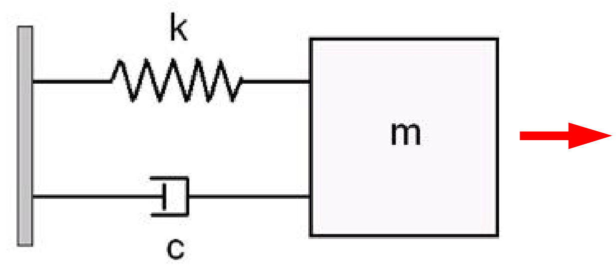
Modeling of Single Story Structures

- The masses are (almost) lumped @ the floor levels
- The lateral stiffness is from the framing actions.



Equivalent Multi-degree of freedom system (MDOF)

Governing equation of motion



- For the single degree of freedom system

$$m\ddot{x} + c\dot{x} + kx = p(t)$$

- For the Multi-degree of freedom system

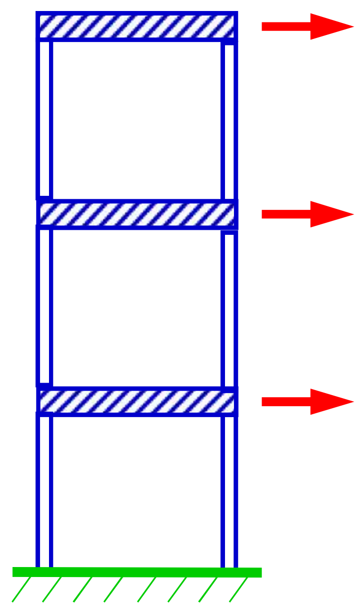
$$[M]\{\ddot{X}\} + [C]\{\dot{X}\} + [K]\{X\} = \{P(t)\}$$

Inertia Force

Damping Force

Stiffness Force

External Force



Analysis of Dynamic Systems

- Analysis of SDOF system
  - Free Vibration
    - Un-damped
    - Damped
  - Forced Vibration
    - Un-damped
    - Damped

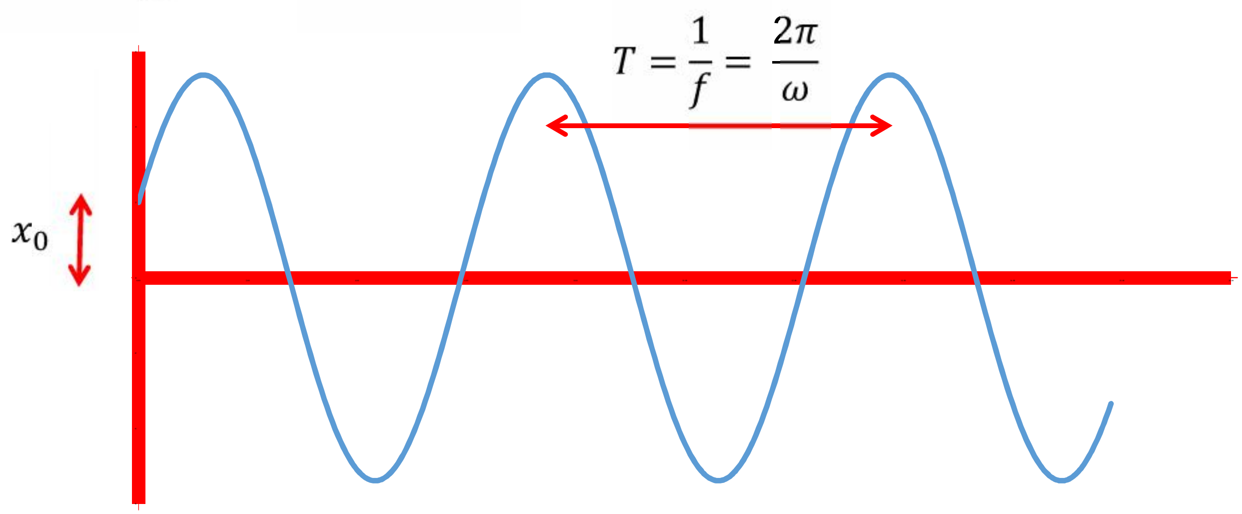
Free Undamped free vibration (SDOF)

- For the single degree of freedom system

$$m\ddot{x} + kx = 0$$

$$\square\ x = x_0 \cos(\omega t) + \frac{\dot{x}_0}{\omega} \sin(\omega t)$$

Where $\omega = \sqrt{k/m}$



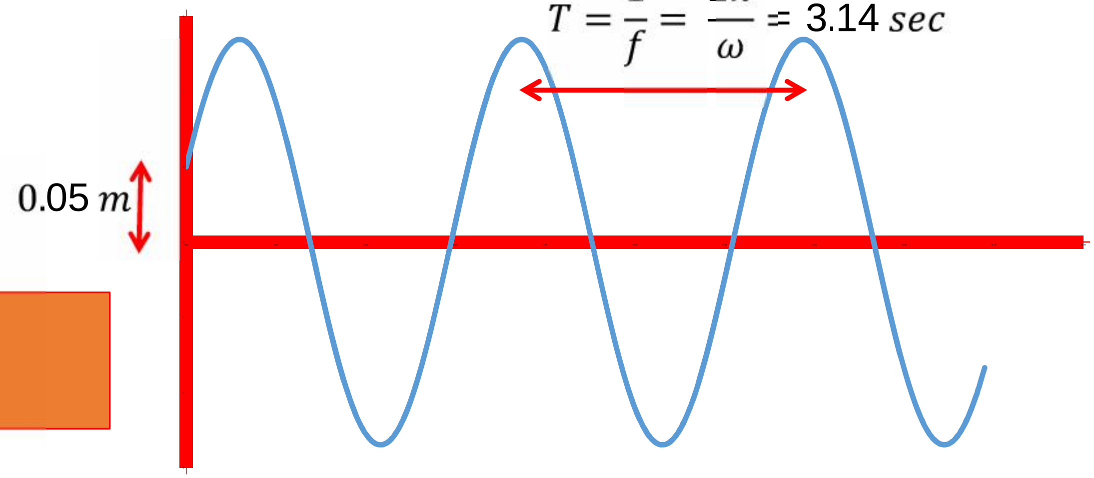
Free Undamped free vibration (SDOF)

- Assume we have a SDOF structure, with an equivalent mass 50 kg and a linear stiffness 200 N/m'… This structure is subjected to an initial displacement 0.05 m and initial velocity 1 m/sec.

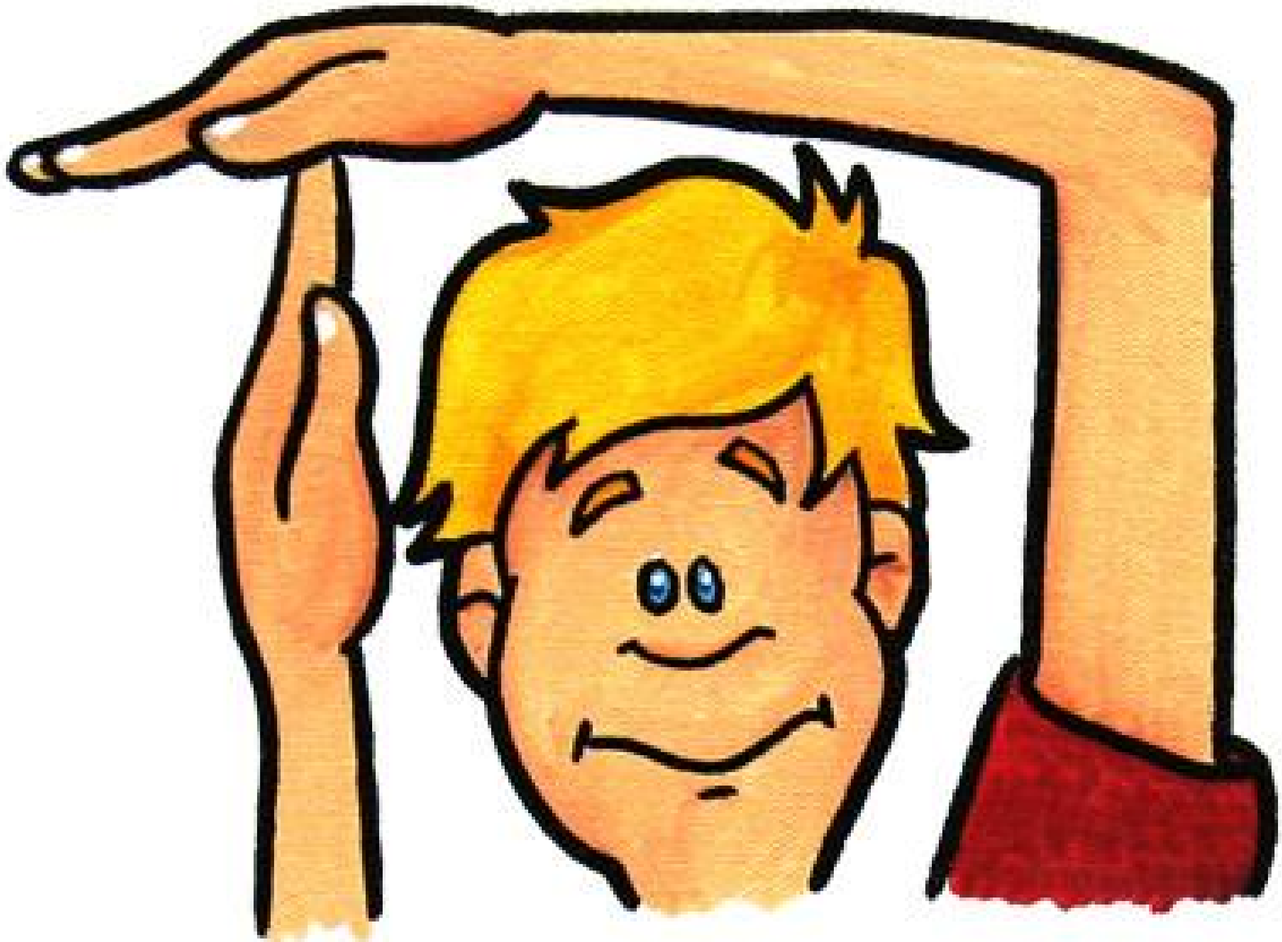
- m=50 kg, k=200 $\quad \omega = \sqrt{k/m} = \sqrt{200/5}$=2 rad / sec

- $T = \frac{2\pi}{\omega} = 3.14\ sec$

$$T = \frac{1}{f} = \frac{2\pi}{\omega} = 3.14\ sec$$



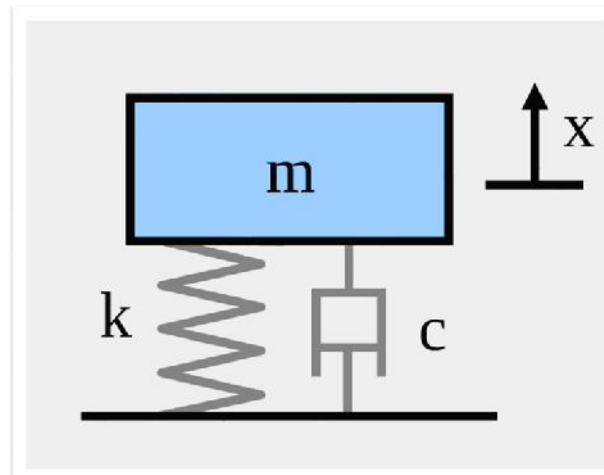
$$x = 0.05\cos(2\,t) + \frac{1}{2}\sin(2\,t)$$



Free Damped Vibration

The equation of motion can be written as:

$$m\ddot{x} + c\dot{x} + kx = 0$$



Diving by m gives

$$\ddot{x} + 2\xi\omega\dot{x} + \omega^2 x = 0$$

Where

(damping ratio) $$x = \frac{c}{2mw} = \frac{c}{c_{cr}}$$

critical damping coeff.

Free Damped Vibration

$$\boxed{\ddot{x} + 2\xi\omega\,\dot{x} + \omega^2 x = 0}$$

Therefore, the solution of the equation of motion has the form $x(t) = e^{st}$

Substituting into the equation of motion

$$\left(s^2 + 2xw\,s + w^2\right)e^{st} = 0$$

$$\backslash\ s^2 + 2xw\,s + w^2 = 0$$

The solution of this expression can represent three types of motion , depending on the quantity under the square root

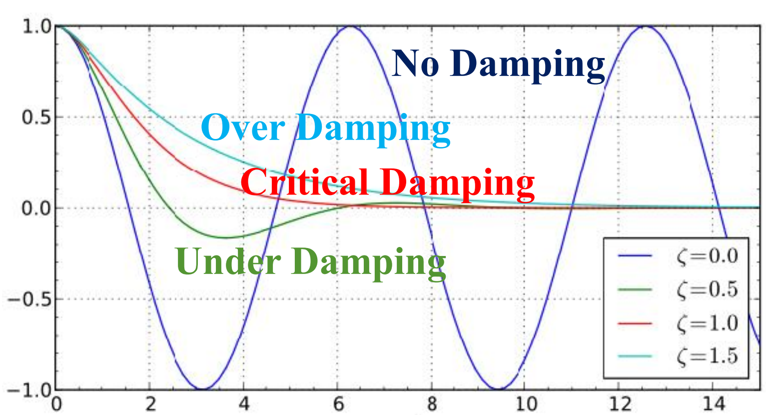
Free Damped Vibration

Motion Types

Over Damping $\xi > 1$

Critical Damping $\xi = 1$

under Damping $\xi < 1$



Critical Damping Systems ($\xi = 1.0$)

$$\boxed{\ddot{x} + 2\xi\omega\dot{x} + \omega^2 x = 0}$$

In case of critical damping, roots are equal. So, the general solution of the equation of motion has the form:

$$x(t) = e^{-wt}\left[G_1 + G_2 t\right]$$

using initial velocity $\dot{x}_0$ and initial displacement

$$\boxed{x(t) = e^{-\omega t}\left[x_0\left(1 + \omega t\right) + \dot{x}_0 t\right]}$$

Over Damping Systems ($\xi > 1.0$)

$$\ddot{x} + 2\xi\omega\,\dot{x} + \omega^2 x = 0$$
$$x(t) = e^{st}$$
$$\therefore\ s^2 + 2\xi\omega\, s + \omega^2 = 0$$

In case of over damping systems, the root values are found to be:

$$s_{1,2} = -\xi\omega \pm \omega\sqrt{\xi^2 - 1} = -\xi\omega \pm \hat{\omega}$$

Recalling the identities

$$e^{x} = \sinh(x) + \cosh(x)$$
$$e^{-x} = -\sinh(x) + \cosh(x)$$

Over Damping Systems ($\xi > 1.0$)

$$\ddot{x} + 2\xi\omega\,\dot{x} + \omega^2 x = 0$$
$$x(t) = e^{st}$$
$$\therefore\ s^2 + 2\xi\omega\, s + \omega^2 = 0$$

As such, the solution of the governing equation of motion can be expressed as

$$x(t) = e^{-\xi\omega t}\left[A\sinh(\hat{\omega}t) + B\cosh(\hat{\omega}t)\right]$$

using initial velocity $\dot{x}_0$ and initial displacement x_0

$$\boxed{x(t) = e^{-\xi\omega t}\left[x_0\cosh(\hat{\omega}t) + \frac{\dot{x}_0 + x_0\xi\omega}{\hat{\omega}}\sinh(\hat{\omega}t)\right]}$$

Under Damping Systems ($\xi < 1.0$)

Structures of interest: buildings, bridges, dams…etc.

In this case, the two roots are imaginary

$$\ddot{x} + 2\xi\omega\,\dot{x} + \omega^2 x = 0$$

$$x(t) = e^{st}$$

$$\backslash\ s^2 + 2xw\,s + w^2 = 0$$

$$s_{1,2} = -xw \pm i w_D$$

where

$$w_D = w\sqrt{1 - x^2}$$

Under Damping Systems ($\xi < 1.0$)

The general solution for such problem is:

$$\ddot{x}+2\xi\omega\dot{x}+\omega^2x=0$$
$$x(t)=e^{st}$$
$$\therefore s^2+2\xi\omega s+\omega^2=0$$

$$x(t)=e^{-\xi\omega t}\left[G_1e^{i\omega_Dt}+G_2e^{-i\omega_Dt}\right]$$

or

$$x(t)=e^{-\xi\omega t}\left[A\cos(\omega_Dt)+B\sin(\omega_Dt)\right]$$

using initial velocity $\dot{x}_0$ and initial displacement x_0

$$\boxed{x(t)=e^{-\xi\omega t}\left[x_0\cos(\omega_Dt)+\frac{\dot{x}_0+x_0\xi\omega}{\omega_D}\sin(\omega_Dt)\right]}$$

Sample of Damping Ratio

System	ξ (%)
Metal (in elastic range)	< 1
Continuous metal structures	2 ~ 4
Metal structures with joints	3 ~ 7
Aluminum / Steel Transmission Lines	0.4
Large Buildings during Earthquakes	1 ~ 5
Prestressed Concrete Structures	2 ~ 5
Reinforced Concrete Structures	4 ~ 7
Composite Components	2 ~ 3

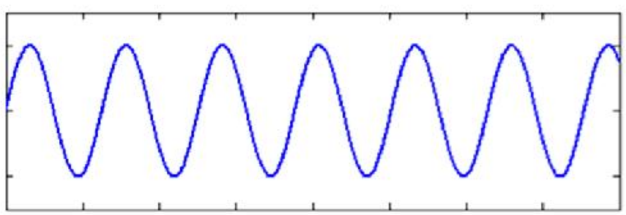
Remember

Forced motion

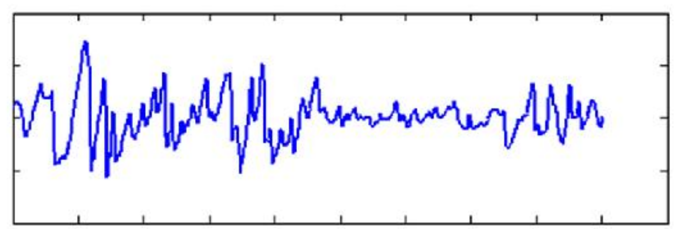
Forces

Ideal Force

Sinusoidal - Harmonic



General Force



Harmonic vibration un-damped system

The harmonic force is $p(t) = p_0 \sin(Wt)$ or $p_0 \cos(Wt)$

The equation of motion has the form $m\ddot{x} + kx = p(t)$

The particular solution of this differential equation can be assumed $x_p(t) = C\sin(Wt)$

$$\therefore \ddot{x}_p(t) = -C\,\Omega^2 \sin(\Omega t)$$

And the displacement equation will be

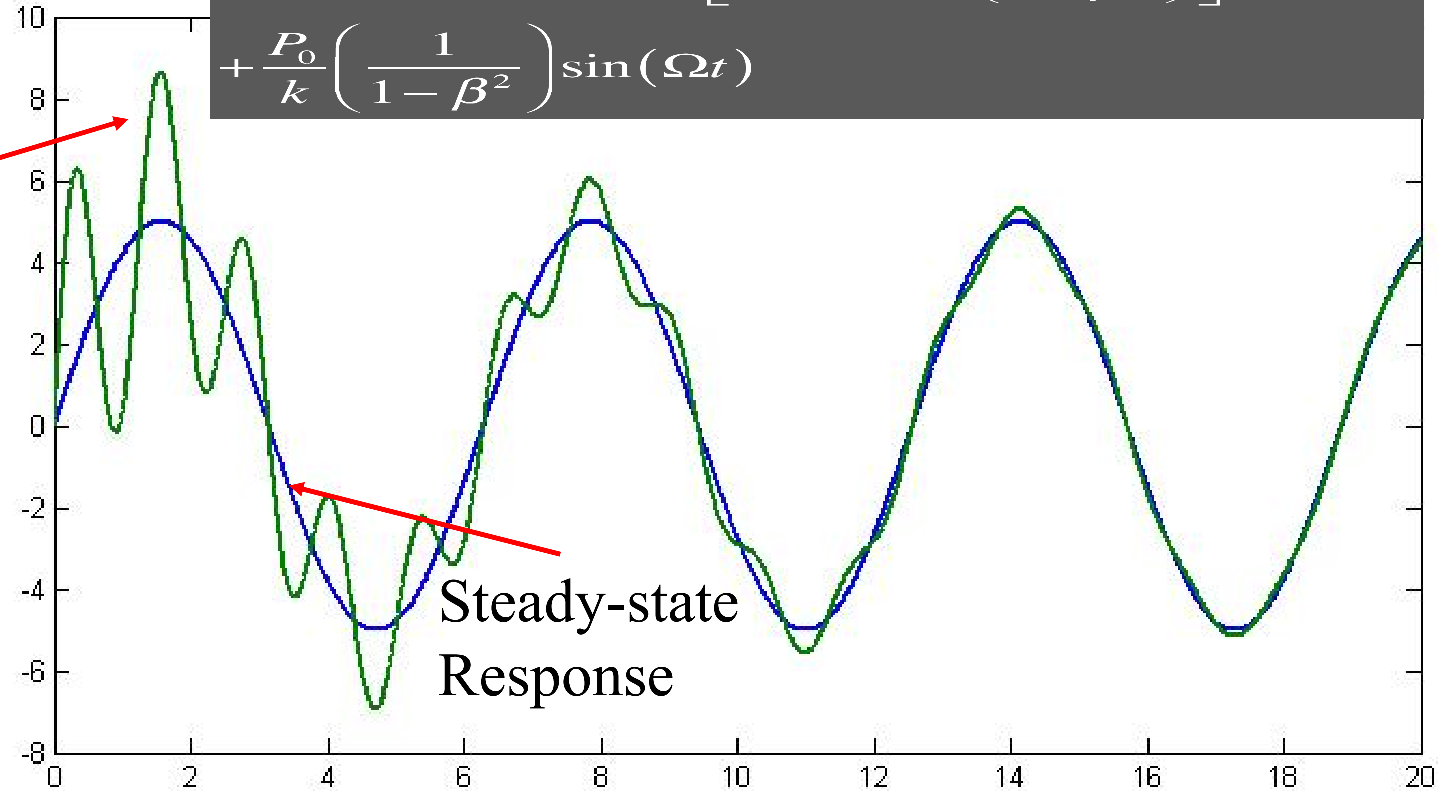
$$x(t) = x_0 \cos(\omega t) + \left[\frac{\dot{x}_0}{\omega} - \frac{p_0 \beta}{k}\left(\frac{1}{1-\beta^2}\right)\right]\sin(\omega t)$$
$$+\frac{P_0}{k}\left(\frac{1}{1-\beta^2}\right)\sin(\Omega t)$$

Where $\beta = \dfrac{\Omega}{\omega}$

Harmonic vibration

$$x(t) = x_0 \cos(\omega t) + \left[\frac{\dot{x}_0}{\omega} - \frac{p_0 \beta}{k} \left(\frac{1}{1-\beta^2} \right) \right] \sin(\omega t) + \frac{P_0}{k} \left(\frac{1}{1-\beta^2} \right) \sin(\Omega t)$$

Total Response

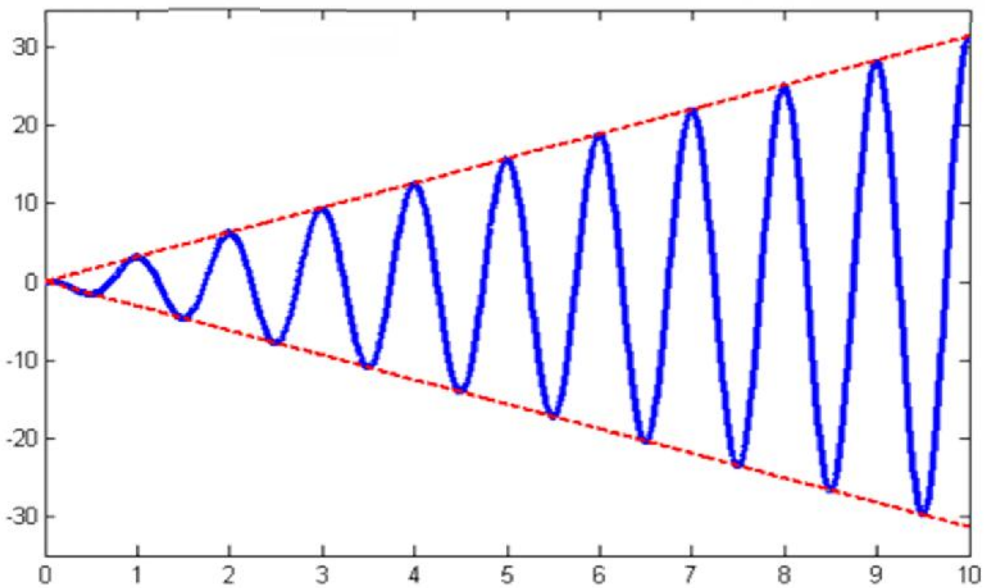


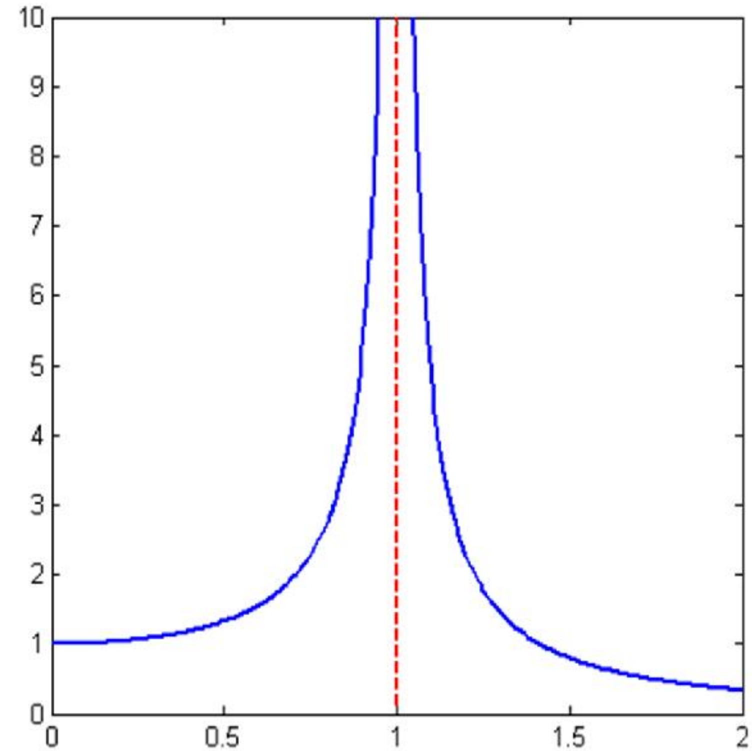
Steady-state Response

Resonance

- This happen when $\beta = 1$

$$x = -\frac{1}{2}\frac{p_0}{k}\left(\omega t\cos(\omega t) - \sin(\omega t)\right)$$





Upcoming Lectures

- MDOF systems and modal properties
- Seismic design approaches (According to seismic codes)
- >>>>>>>>First Assignment
- Time-history analysis and Pounding effects
- Pushover analysis and coupled shear walls
- >>>>>>>>>   Report problem
- Risk assessment and Fragility
- Blast Loading
- >>>>>>>>>>   Second Assignment
- Response spectrum analysis   (DR. Bahaa)