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Mata Kuliah : Dinamika Struktur & Pengantar Rekayasa Kegempaan
Kode : TSP – 302
SKS : 3 SKS

Introduction to Dynamic of Structures

Pertemuan - 1

- TIU :
  - Mahasiswa dapat menjelaskan tentang teori dinamika struktur.
  - Mahasiswa dapat membuat model matematik dari masalah teknis yang ada serta mencari solusinya.
- TIK :
  - Mahasiswa dapat memformulasikan persamaan gerak sistem struktur

- Sub Pokok Bahasan :
  - Persamaan gerak
  - Newton law of Motion
  - D'alemberts Principle
  - Massa, kekakuan dan redaman

Bobot Penilaian :
Tugas : 25 %
Ujian Tengah Semester : 35%
Ujian Akhir Semester : 40%

- Text Book :
  - Paz, M. (2004). **Structural Dynamics : Theory & Computation**. 5th ed. Springer. Van Nostrand, ISBN : 978-1402076671
  - Clough and Penzien. (2003). **Dynamics of Structures**. McGraw Hill, ISBN : 0070113920
  - Chopra, A. (2006). **Dynamics of Structures**. 3rd ed. Prentice Hall. ISBN : 978-0131561748

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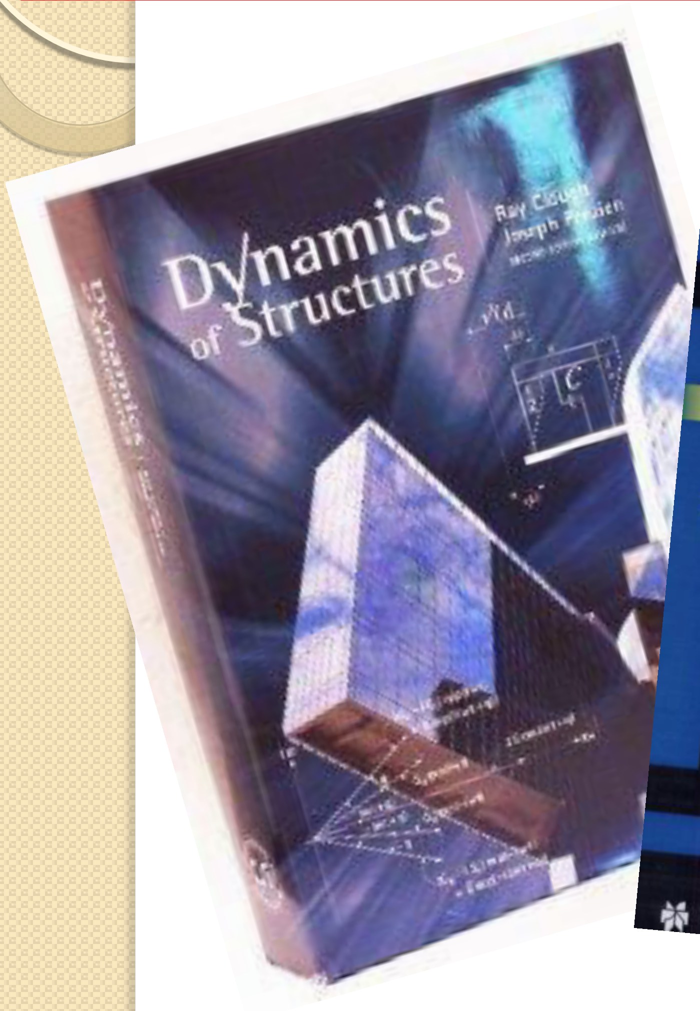
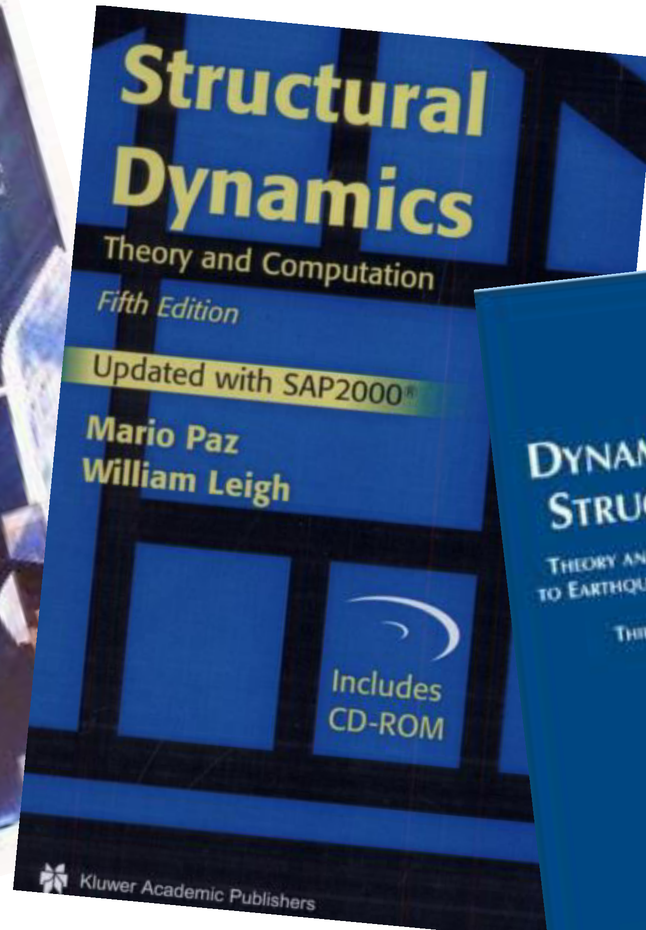
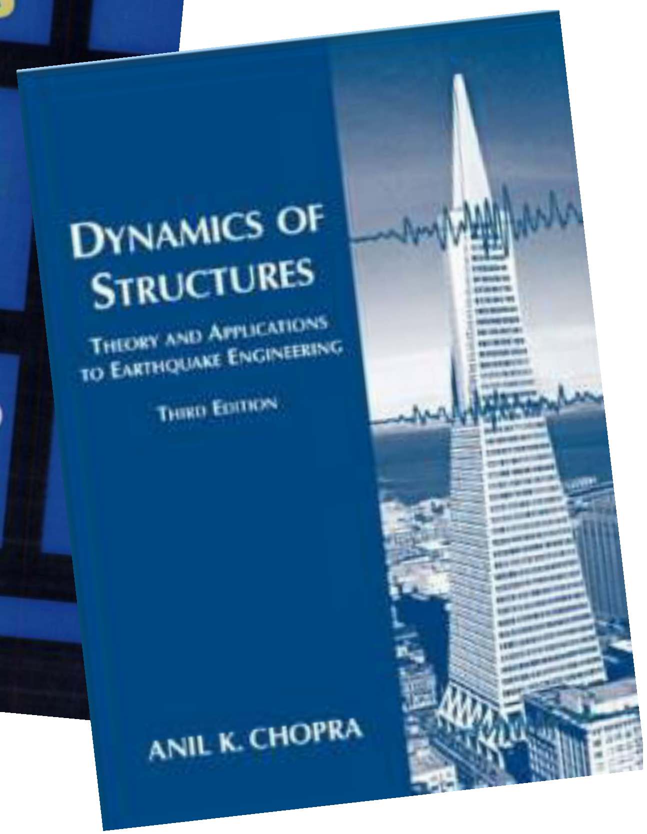




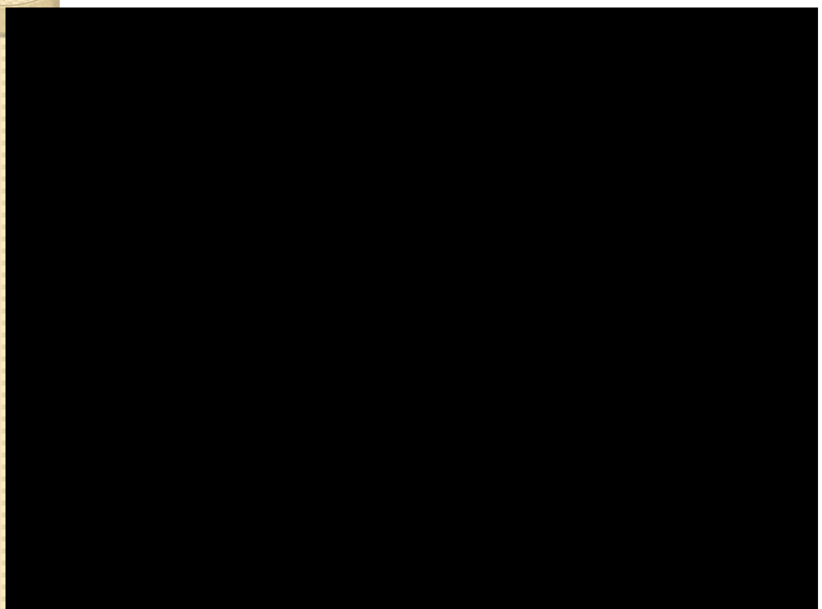


Why do we have to study about Structural Dynamic ?

http://www.youtube.com/watch?v=uzdQer1gvsU

The 1940 Tacoma Narrows Bridge

It was a steel suspension bridge in the US State of Washington. Construction began in 1938, with the opening on 1st July 1940. From the time the deck was built, it began to move vertically in windy conditions (construction workers nicknamed the bridge Galloping Gertie). The motion was observed even when the bridge opened to the public. Several measures to stop the motion were ineffective, and the bridge's main span finally collapse under 64 km/h wind conditions the morning of 7th November 1940



The Millenium Bridge

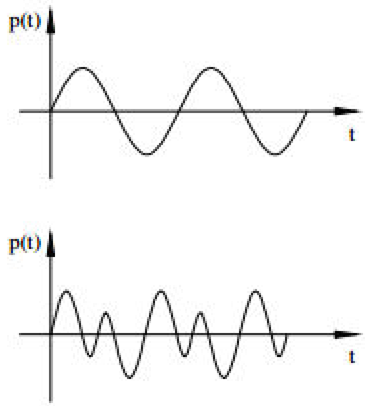
It is an iconic steel suspension bridge for pedestrians crossing the River Thames in London. Construction began in 1998, with the opening on 10th June 2000. Londoners nicknamed the bridge the Wobbly Bridge after participants in a charity walk to open the bridge felt an unexpected and uncomfortable swaying motion. The bridge was the closed for almost two years while modifications were made to eliminate the wobble entirely. It was reopened in 2002.

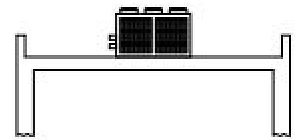
http://www.youtube.com/watch?v=eAXVa__XWZ8

- The term **dynamic** may be defined simply as time-varying
- Thus a *dynamic load* is any load of which its magnitude, direction, and/or position varies with time.
- Similarly , the structural response to a dynamic load, i.e., the resulting stresses and deflections, is also time-varying, or dynamic.
- In general, *structural response* to any dynamic loading is expressed basically in terms of the ***displacements*** of the structure.

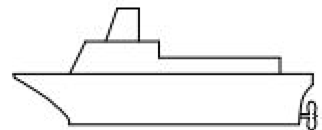
Dynamic Loading

Periodic Loading



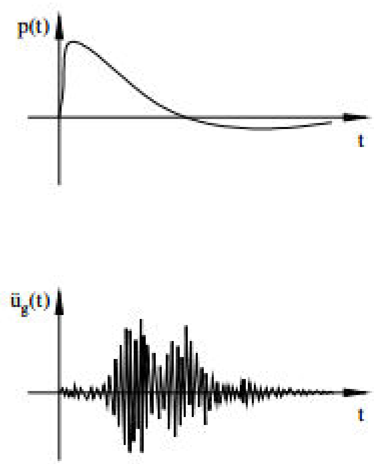


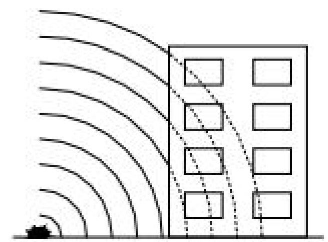
Unbalanced rotating machine in building



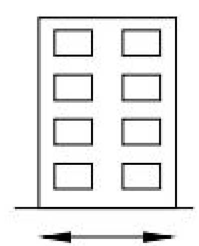
Rotating propeller at stern of ship

Non-Periodic Loading



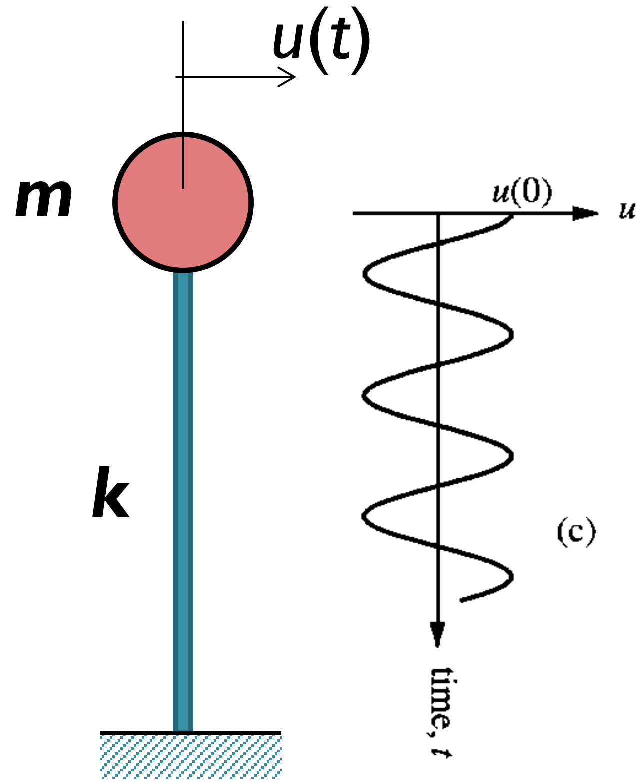


Bomb blast pressure on building



Earthquake on building

Simple Structures



Degree of Freedom

- In structural dynamics the number of independent coordinates necessary to specify the configuration or position of a system at any time is referred to as the number of **Degree of Freedom (DoF)**
- In general, a continuous structure has an ***infinite number*** of DoF.
- Nevertheless, the process of idealization or selection of an appropriate mathematical model permits the reduction to a discrete number of DoF.

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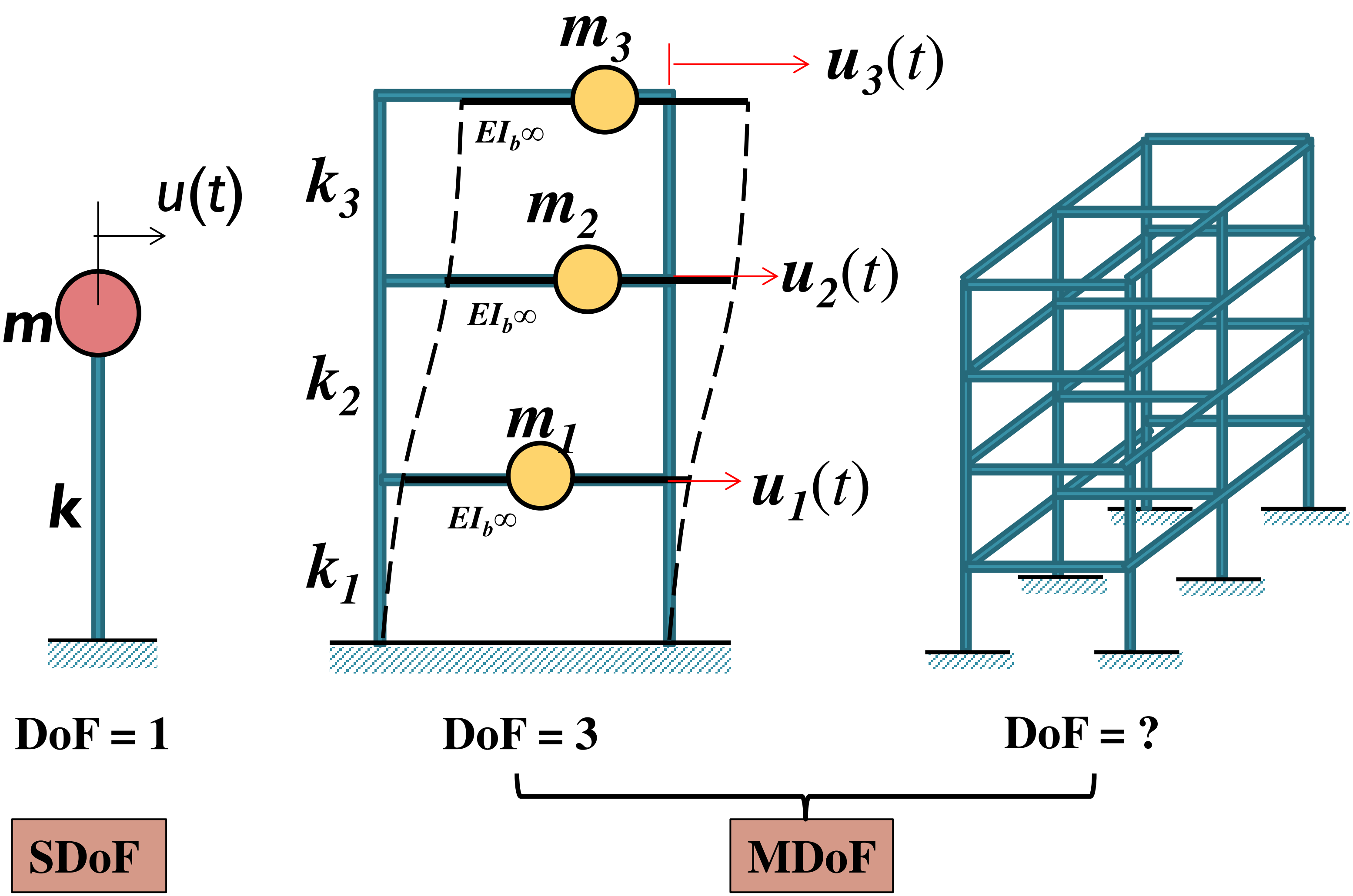


Equations of Motion (EoM)

- The mathematical expressions defining the dynamic displacements are called the ***Equations of Motion*** of the structure
- The equations of motion of any dynamic system represent expressions of Newton' s second law of motion, which states that "*the rate of change of momentum of any mass particle m is equal to the force acting on it*"

- This relationship can be expressed mathematically by the differential equation

$$\mathbf{p}(t) = \frac{d}{dt}\left(m\frac{d\mathbf{u}}{dt}\right) \qquad \textbf{(1)}$$

- where **p**(t) is the applied force vector and **u**(t) is the position vector of particle mass m.
- For most problems in structural dynamics it may be assumed that mass does not vary with time, in which case Eq. (1) may be written

$$\mathbf{p}(t) = m\frac{d^2\mathbf{u}}{dt^2} \equiv m\ddot{\mathbf{u}}(t) \qquad \textbf{(1.a)}$$

- where the dots represent differentiation with respect to time.
- Equation (1-a), indicating that force is equal to the product of mass and acceleration, may also be written in the form

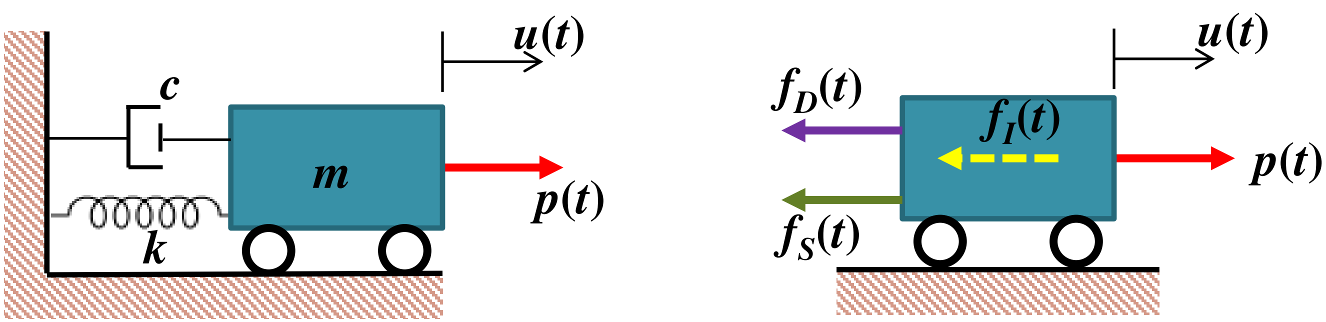
$$\boxed{\mathbf{p}(t) - m\ddot{\mathbf{u}}(t) = \mathbf{0}} \qquad \textbf{(1.b)}$$

Inertial Force

- The concept that a mass develops an inertial force proportional to its acceleration and opposing it is known as *d'Alembert's principle*.

Free Vibration Single DoF System

- The essential physical properties of any linearly elastic structural or mechanical system subjected to a dynamic loading are its **mass**, **elastic properties (stiffness)**, and **damping**.



Idealized SDOF system: (a) basic components; (b) forces in equilibrium

- The equation of motion is merely an expression of the equilibrium of these forces as given by

$$\boxed{f_I(t) + f_D(t) + f_S(t) = p(t)} \qquad \textbf{(2)}$$

- Where :

$$\boxed{f_I(t) = m\ddot{u}(t)} \Rightarrow \textit{Inertial Force} \qquad \textbf{(3.a)}$$

$$\boxed{f_D(t) = c\dot{u}(t)} \Rightarrow \textit{Damping Force} \qquad \textbf{(3.b)}$$

$$\boxed{f_S(t) = ku(t)} \Rightarrow \textit{Elastic Force} \qquad \textbf{(3.c)}$$

- When Eqs. (3.a-c) are introduced into Eq. (2), the EoM for this SDOF system is found to be

$$\boxed{m\ddot{u}(t)+c\dot{u}(t)+ku(t)=p(t)} \qquad \textbf{(4)}$$

- Where :

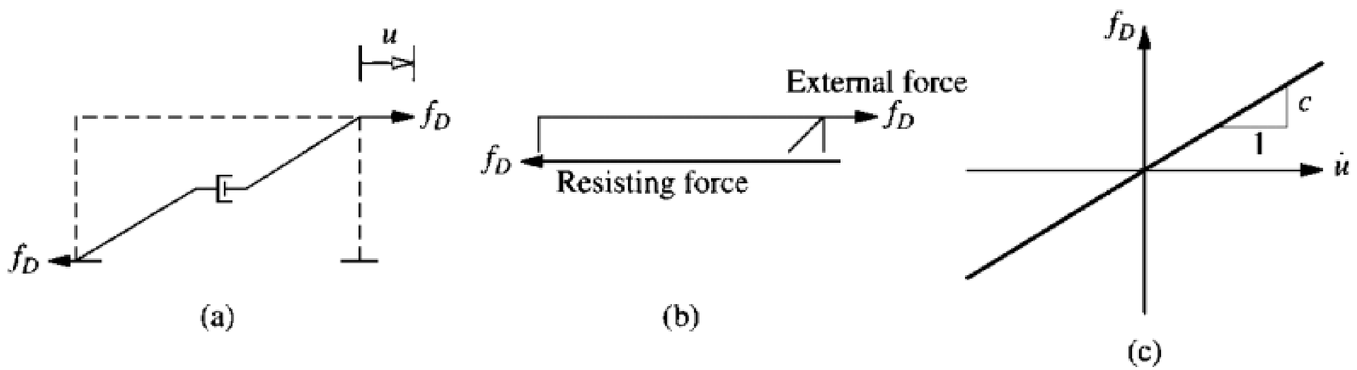
m is mass, representing the mass and inertial characteristic of the structure

c is viscous damping coeficient, representing the frictional characteristics and energy losses of the structure

k is spring constant, representing the elasting restoring force and potential energy capacity of the structure

Damping Force (f_D)

- The process by which free vibration steadily diminishes in amplitude is called damping.
- In damping, the energy of the vibrating system is dissipated by various mechanism, such as :
  - steel connections
  - opening and closing of micro cracks in concrete
  - friction between the structural and nonstructural elements
- The actual damping in a SDF structure can be idealized by a linear viscous damper or dashpot called **equivalent viscous damping**



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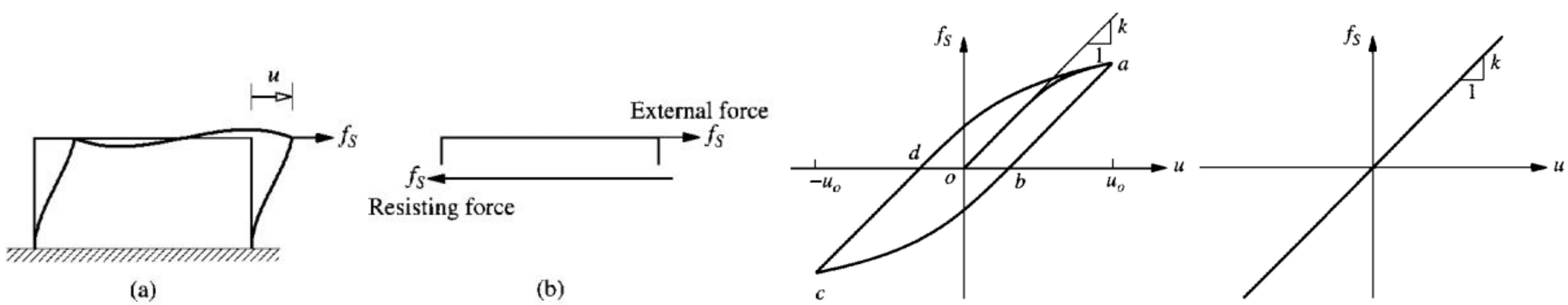
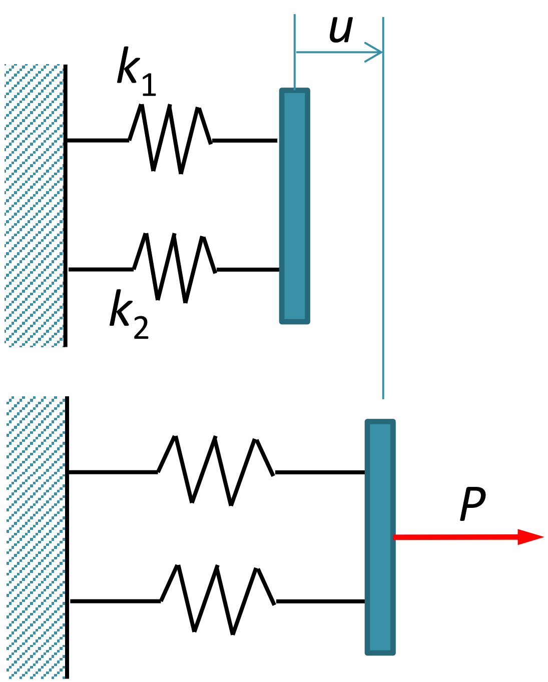
Elastic/Spring Force (f_S)

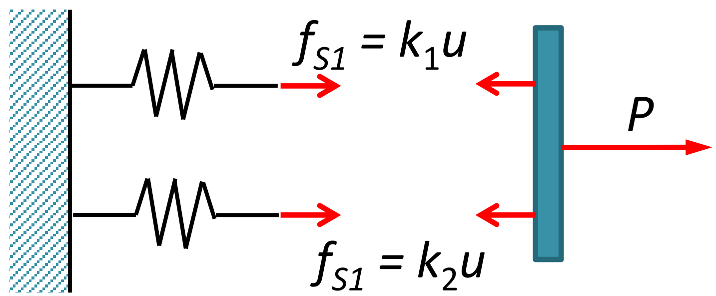
- SDoF System with no dynamic excitation subjected to an externally applied static forces f_S along the DoF u.
- The internal force resisting the displacement u is equal and opposite to the external force f_s.
- The force - displacement would be linear at small deformations but would become non linear at larger deformations



Springs in parallel or in series

- Sometimes it is necessary to determine the equivalent spring constant for a system in which two or more springs are arranged in parallel or in series





$\Sigma H = 0$

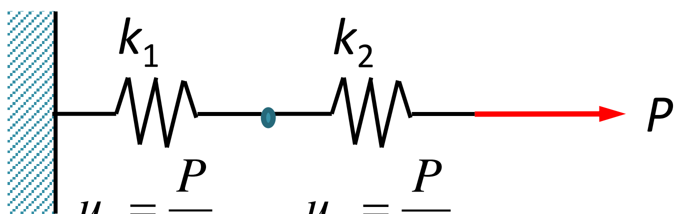
$P = f_{S1} + f_{S2}$

$k_e \cdot u = k_1 \cdot u + k_2 \cdot u \Rightarrow k_e = k_1 + k_2$

$$\boxed{k_e = \sum_{i=1}^{n} k_i}$$

For *n* springs in parallel

Springs in series



$$u_1 = \frac{P}{k_1} \qquad u_2 = \frac{P}{k_2}$$

$$u = u_1 + u_2$$

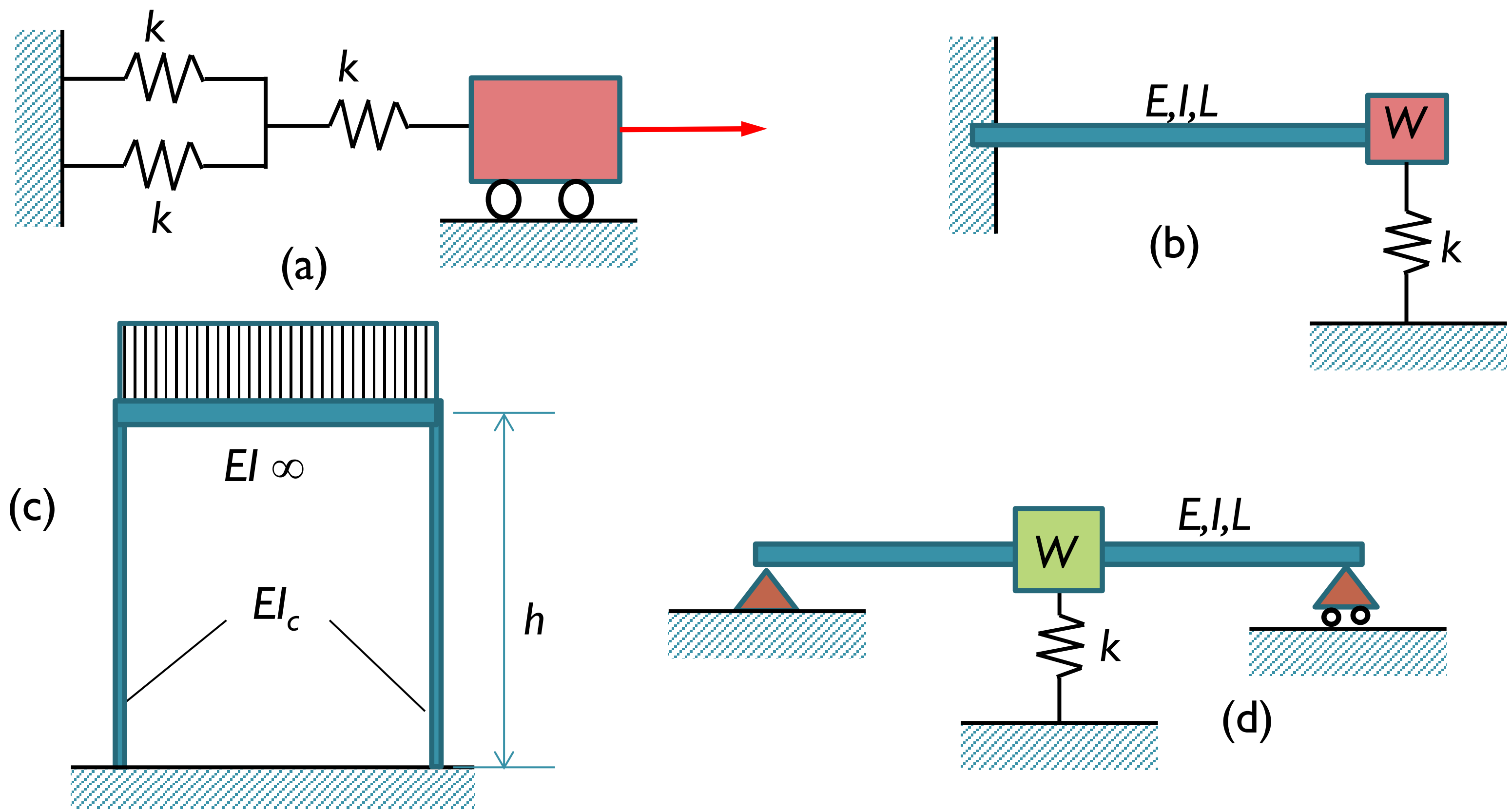
$$\frac{P}{k_e} = \frac{P}{k_1} + \frac{P}{k_2} \quad \Rightarrow \quad \frac{1}{k_e} = \frac{1}{k_1} + \frac{1}{k_2}$$

$$\boxed{\frac{1}{k_e} = \sum_{i=1}^{n} \frac{1}{k_i}}$$

For *n* springs in series

Exercise

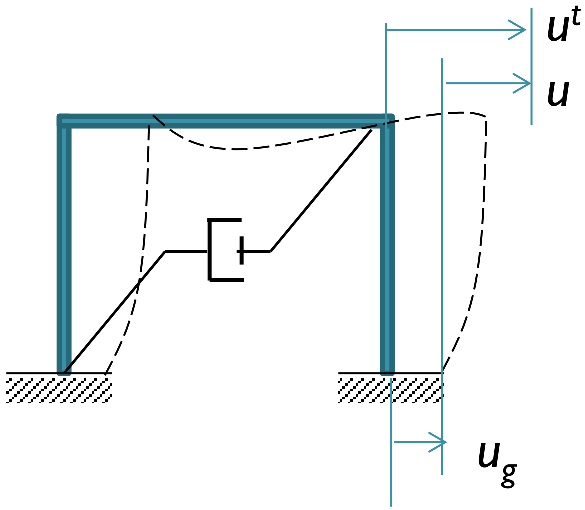
- Determine effective stiffness, k_e, from each system below

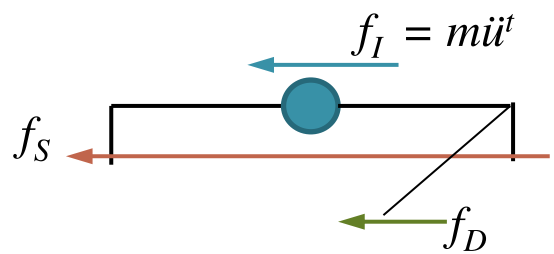


Equation of Motion : Earthquake Excitation

- In earthquake prone regions, the principal problem of structural dynamics that concern structural engineers is the behavior of structures subjected to earthquake induced motion of the base of the structure.
- The displacement of the ground is denoted by u_g, the total displacement of the mass by u^t, and relative displacement between the mass and ground by u
- At each instant of time these displacement are related by :

$$u^t(t) = u(t) + u_g(t)$$





- The resulting equation of motion is :

$$\boxed{m\ddot{u} + c\dot{u} + ku = -m\ddot{u}_g(t)} \quad \textbf{(4)}$$