CE 809 - Structural Dynamics

Lecture 0: Course Introduction

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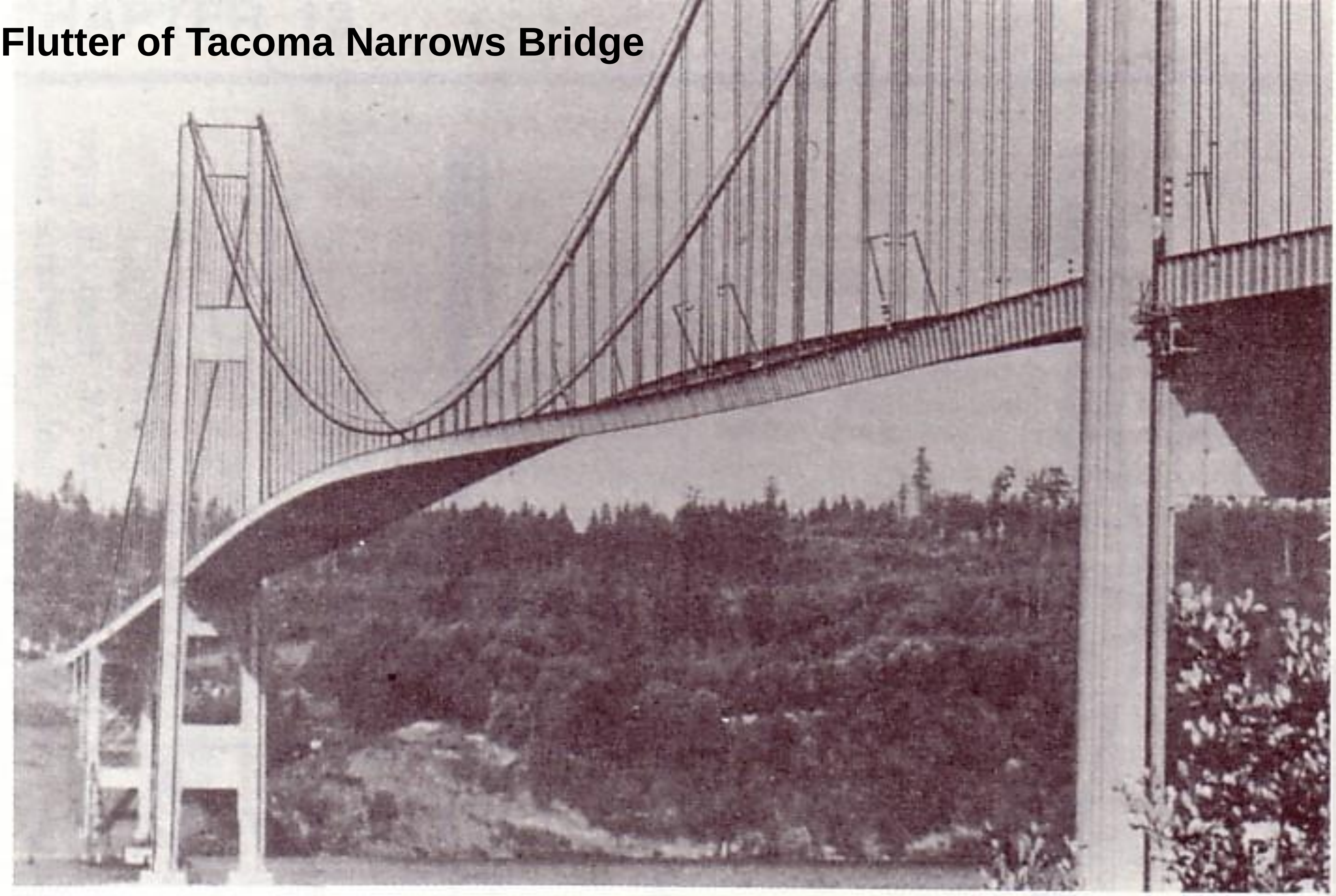
Examples of Problems related to Structural Dynamics

Tacoma Narrows bridge

- A classic example
- A suspension bridge built in 1940s
- The bridge was designed by one of the leading experts in suspension bridges at that time.
- Dead load, traffic load, and wind induced drag load (lateral force) were considered in the structural design.
- However, the bridge collapsed during a wind storm in which the wind velocity was much lower than the maximum wind speed used in the design.

Flutter of Tacoma Narrows Bridge



Tacoma Narrows bridge

- The design, based on static concept, was perfectly correct, but the dynamic effects were not considered.
- From the recorded motion picture, we found that the bridge collapsed by a certain unstable dynamic excitation mechanism (torsional flutter).
- Starting from small amplitude torsional oscillation, the motion grew up until suspended ropes broke by fatigue, and then the bridge collapsed.
- After this failure, many studies on bridge dynamics were conducted, and every bridge engineer who involves in the design of long-span bridges has to learn the theory of structural dynamics.

Flutter of Tacoma Narrows Bridge

Wind Effects on Structures

<table>
<tr><td rowspan="4">Static effects</td><td colspan="4">Deformation due to time-averaged aerodynamic force</td></tr>
<tr><td colspan="4">Stress due to wind-induced pressure or force</td></tr>
<tr><td rowspan="2">Static instability</td><td colspan="3">Torsional divergence (negative stiffness)</td></tr>
<tr><td colspan="3">Lateral buckling</td></tr>
<tr><td rowspan="8">Dynamic effects</td><td rowspan="3">Forced vibration</td><td rowspan="2">Buffeting (random vibration)</td><td>due to atmospheric turbulence</td><td rowspan="3">Limited-amplitude response</td></tr>
<tr><td>due to body-induced turbulence (wake)</td></tr>
<tr><td colspan="2">Vortex excitation</td></tr>
<tr><td rowspan="5">Dynamic instability (negative damping)</td><td colspan="2">Galloping</td><td rowspan="5">Divergent-amplitude response</td></tr>
<tr><td colspan="2">Wake galloping</td></tr>
<tr><td colspan="2">Torsional flutter</td></tr>
<tr><td colspan="2">Coupled flutter</td></tr>
<tr><td colspan="2">Rain-induced vibration</td></tr>
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A Hospital Building subjected to an earthquake

- Structural safety is the main concern.

- A hospital building was subjected to the San Fernando earthquake in 1971, and it was severely damaged.

- The building vibrated like a large rigid mass shaking on flexible columns. These columns had to resist large cyclic shear force, and after few cycles they failed.

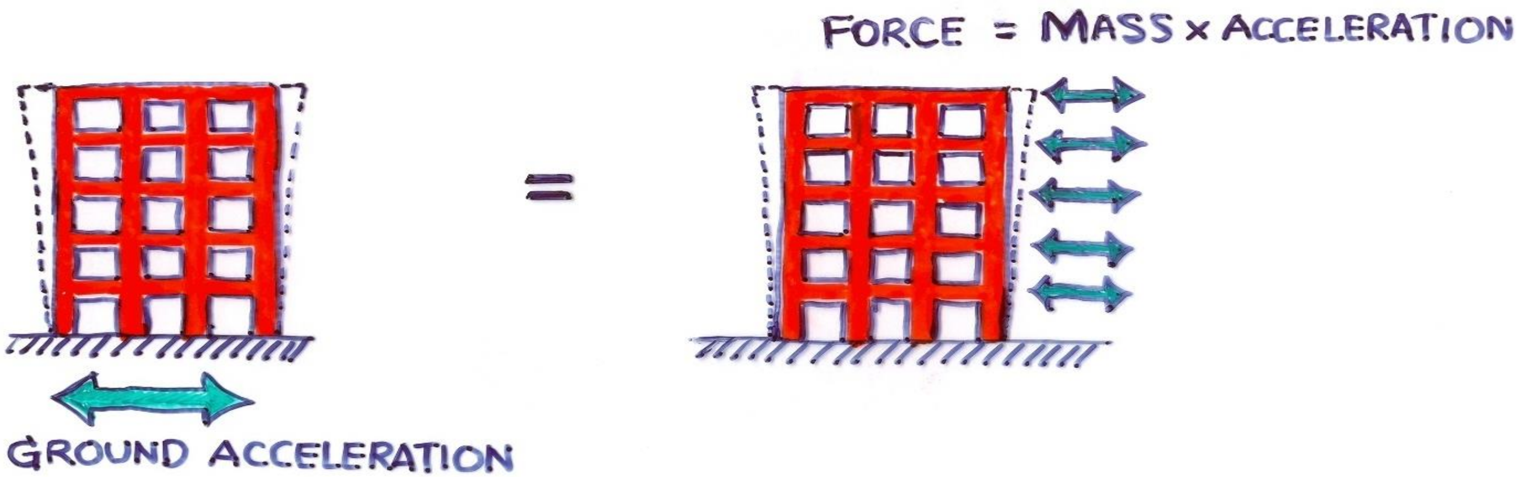
- The dynamic shear force is proportional to the product of mass and acceleration of the building

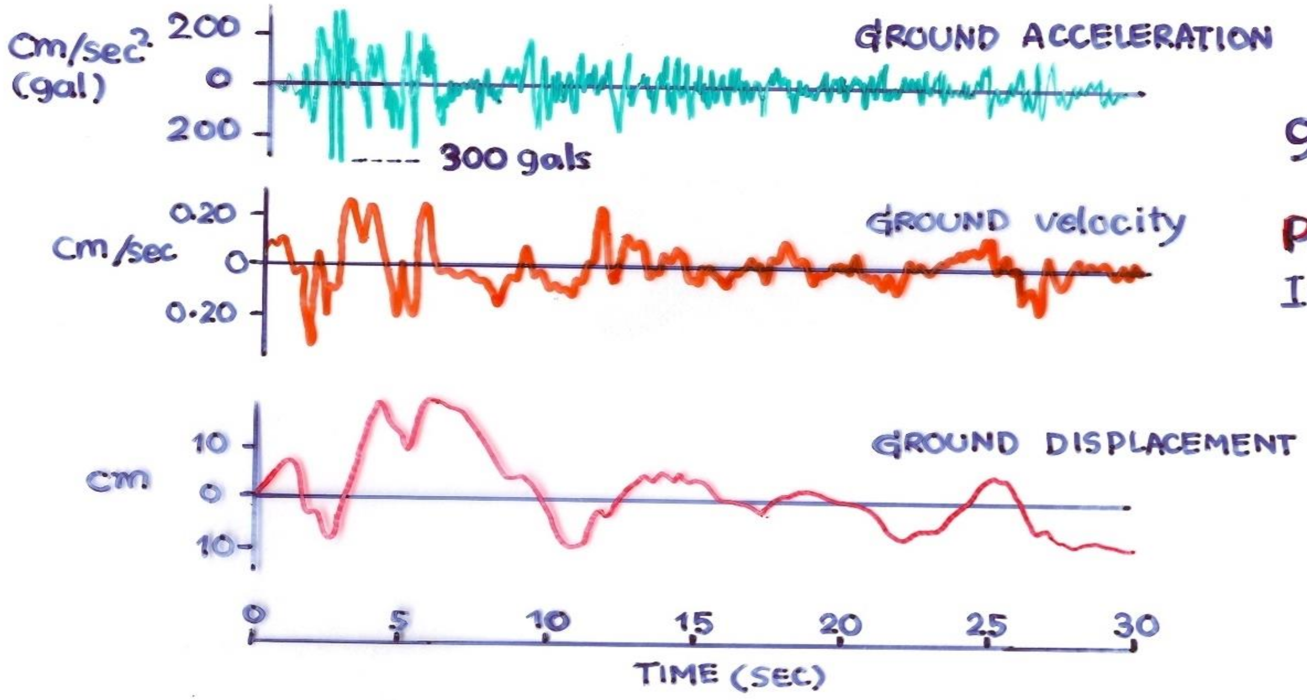
$$F = m\,a$$

Olive View Hospital
(First story has a permanent displacement of 2 feet (61 cm)

Courtesy: P. C. Jennings and G. W. Housner

Earthquake Loading on Structures



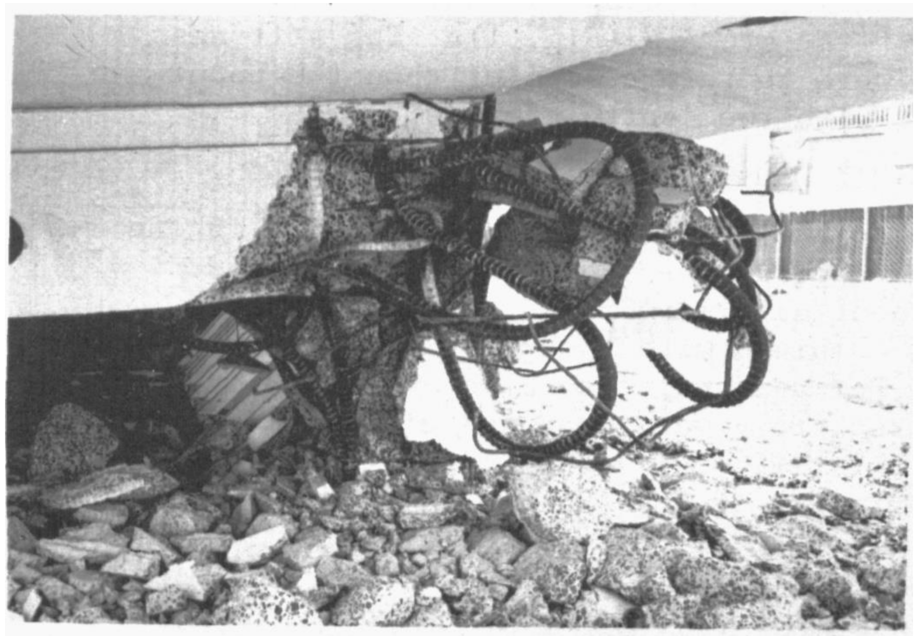


980 gals= 1 G

Peak Ground Acceleration:
Index of Seismic Loading

A Hospital Building subjected to an earthquake (continued)

Olive View Hospital after February 1971 San Fernando earthquake



Collapsed first story of Psychiatric building at Olive View Hospital

Second story column fracture in Olive View Hospital

During the 9 February 1971 San Fernando earthquake the new Olive View Hospital building was severely damaged. In response to very strong ground shaking. the building vibrated essentially as a large mass on relatively flexible columns. The spirally reinforced concrete columns were deformed far beyond the requirements of the building code.

Courtesy: P. C. Jennings and G. W. Housner

A Hospital Building subjected to an earthquake (continued)

- In many current seismic resistant design codes, a regular building may be designed by a static method, that is, the building may be designed to resist an **equivalent static lateral force** (of earthquake).

- Although the analysis involved is static analysis, the equivalent static force is entirely formulated from the consideration of the dynamic behavior of the building.

- For the seismic design of complex structures and/or important structures, an **explicit dynamic analysis** may be required.

Wenchuan Earthquake (2008), China

Magnitude = 7.9

Death Toll > 70,000


Balakot, Kashmir Earthquake (2005)
Magnitude = 7.6
Death Toll = 79,000

Yogyakarta Earthquake (2006)

Magnitude = 6.2
Death Toll = 5,000

Kobe Earthquake (1995)

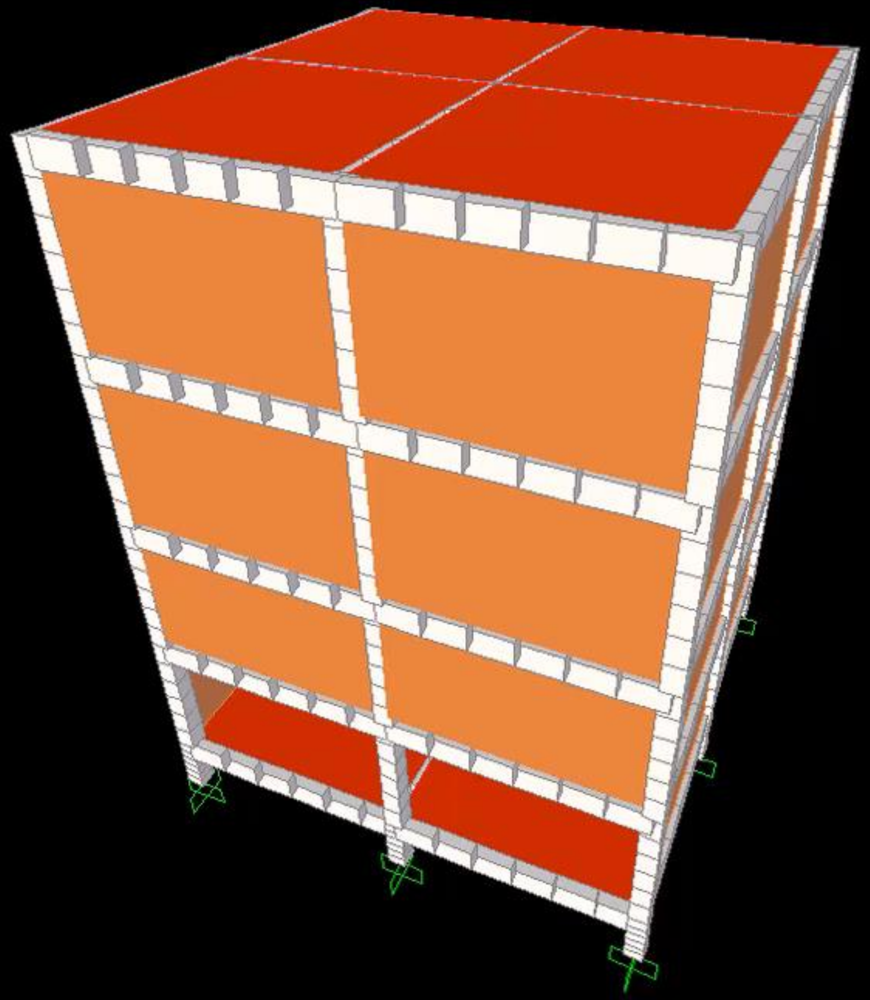
Magnitude = 6.9

Death Toll > 6000


2006/01/13
JMA Kobe 100%
TCR 00:00:10:02
E-Defense
独立行政法人防災科学技術研究所

Typical Commercial Concrete Buildings

Building Response to EQ Ground Shaking



Lateral-Torsional Movement (period = 0.50 sec)

First-story Collapse of Commercial Buildings

The 1999 Chi-Chi Earthquake (Taiwan)

Tower structures

- Marine observation towers, airport control towers, tall and slender buildings (see the following slides).
- These structures are safe against wind and earthquake.
- But the wind-induced vibration may causes human discomfort – motion sickness, difficult to perform desk work, furniture and fixtures make sounds
- Serviceability problems

The Yokohama Marine Tower (Japan, 1961)

The Sydney Tower
(Australia, 1981)

The CN Tower
(Canada, 1976)

Tall Buildings - *Dynamic Wind Effects need to be considered !*

Tall Buildings - *Dynamic Wind Effects need to be considered !*

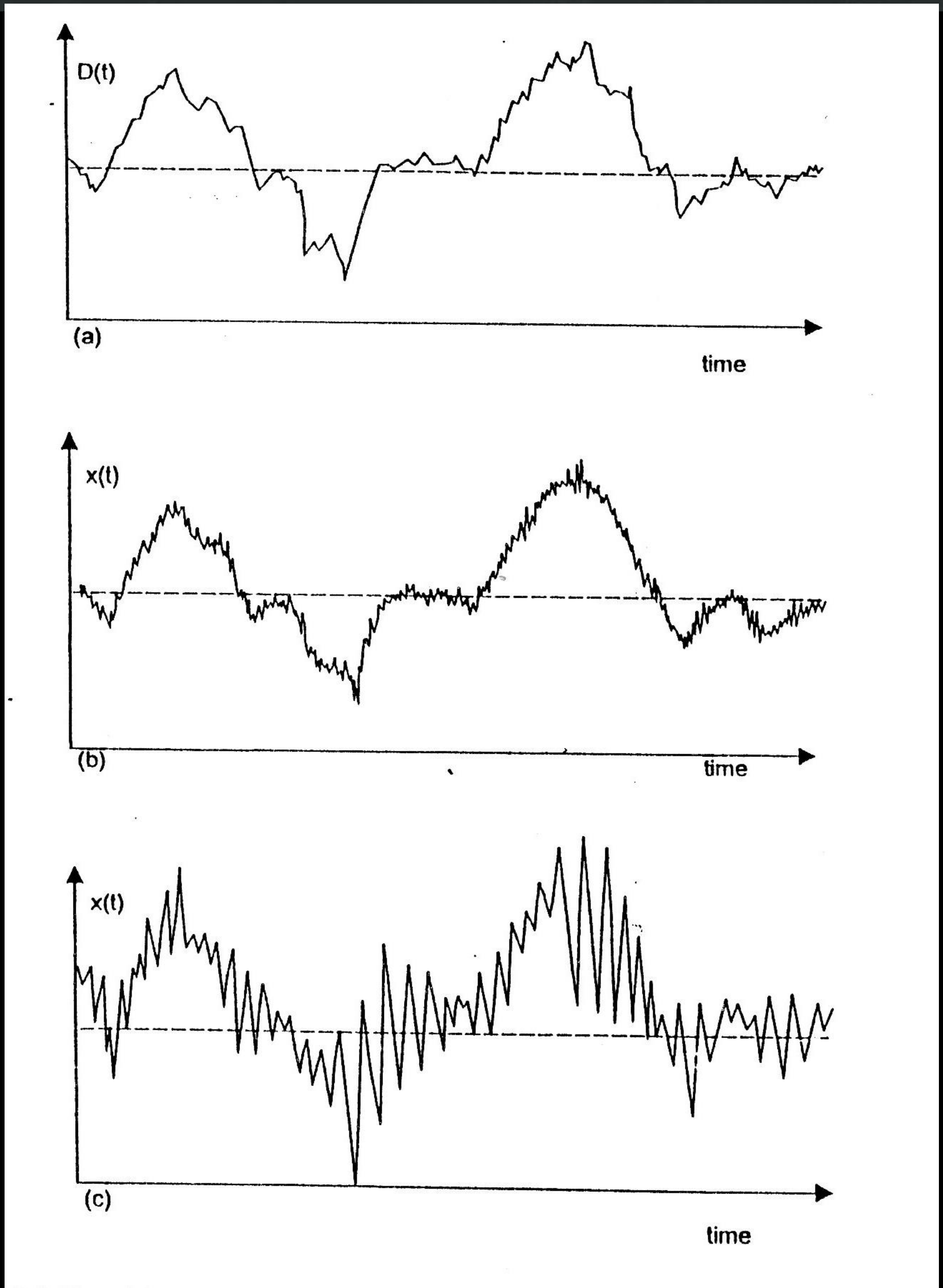
Photo Courtesy: https://www.bangkokpost.com/learning/advanced/1073529/

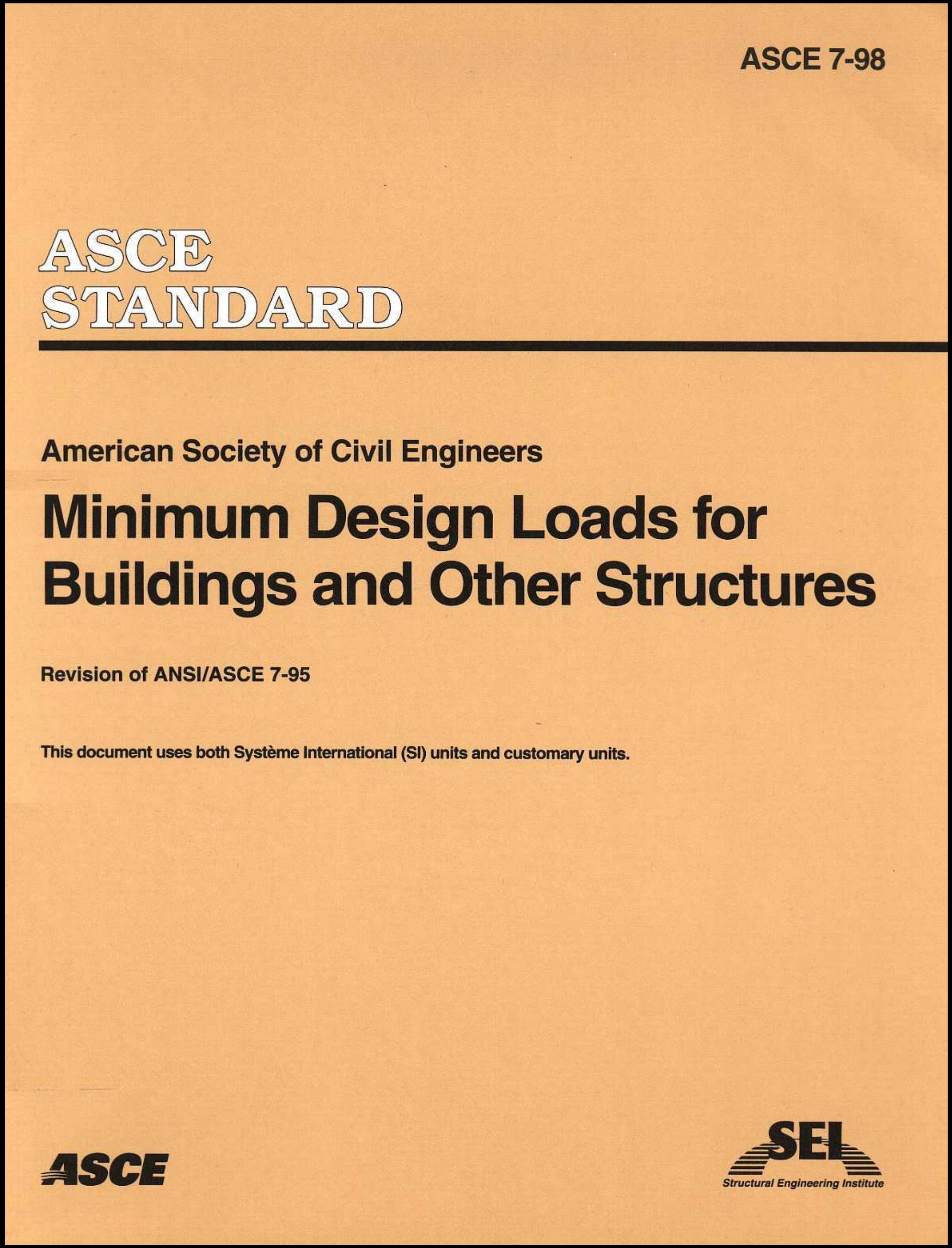
Photo Courtesy: http://www.bangkok.com/magazine/baiyoke-tower-II.htm

Wind force (Drag)

Response of a mid-rise building with a high natural frequency

Response of a high-rise building with a low natural frequency





ASCE 7-98

ASCE STANDARD

American Society of Civil Engineers

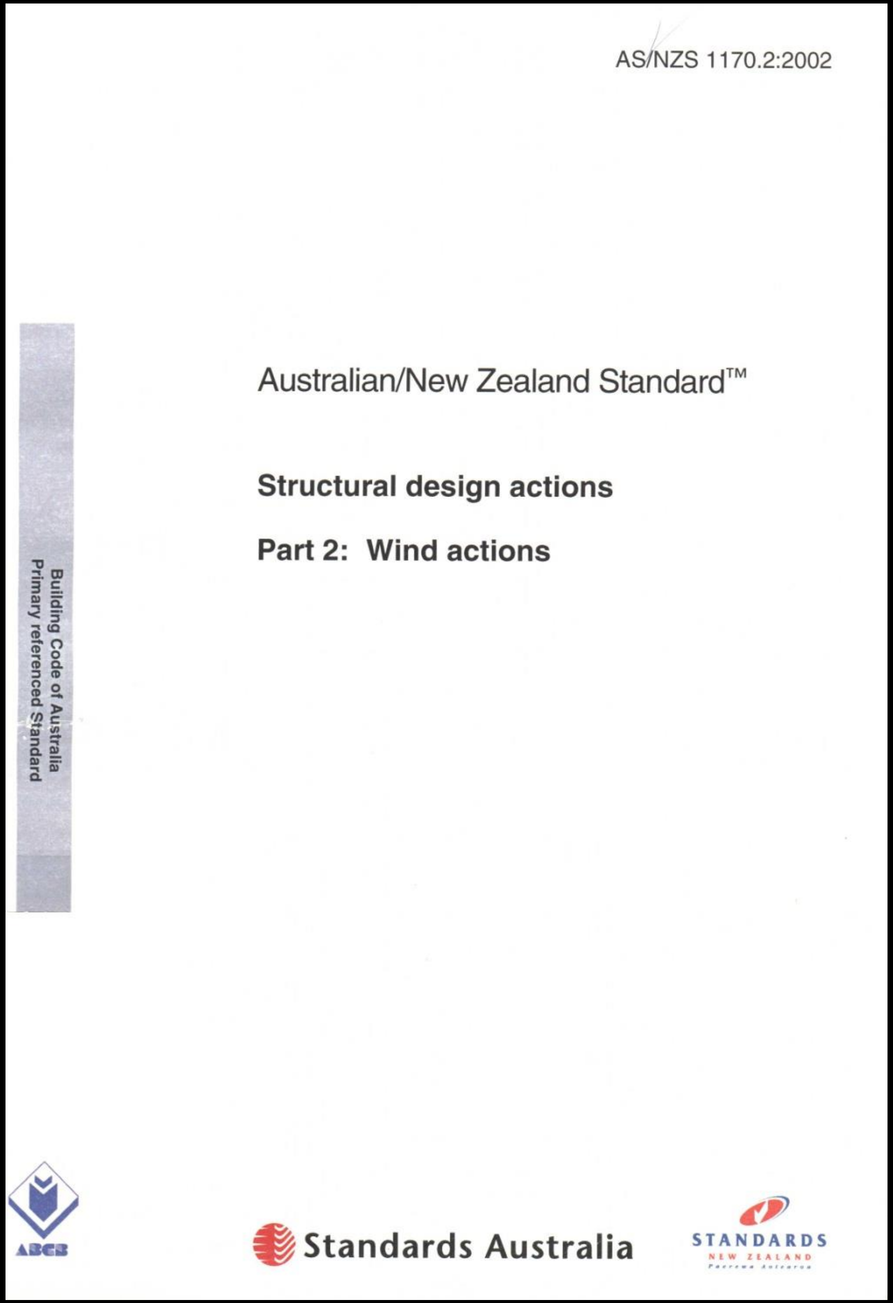
Minimum Design Loads for Buildings and Other Structures

Revision of ANSI/ASCE 7-95

This document uses both Système International (SI) units and customary units.

ASCE

SEI Structural Engineering Institute



AS/NZS 1170.2:2002

Building Code of Australia
Primary referenced Standard

Australian/New Zealand Standard™

Structural design actions

Part 2: Wind actions

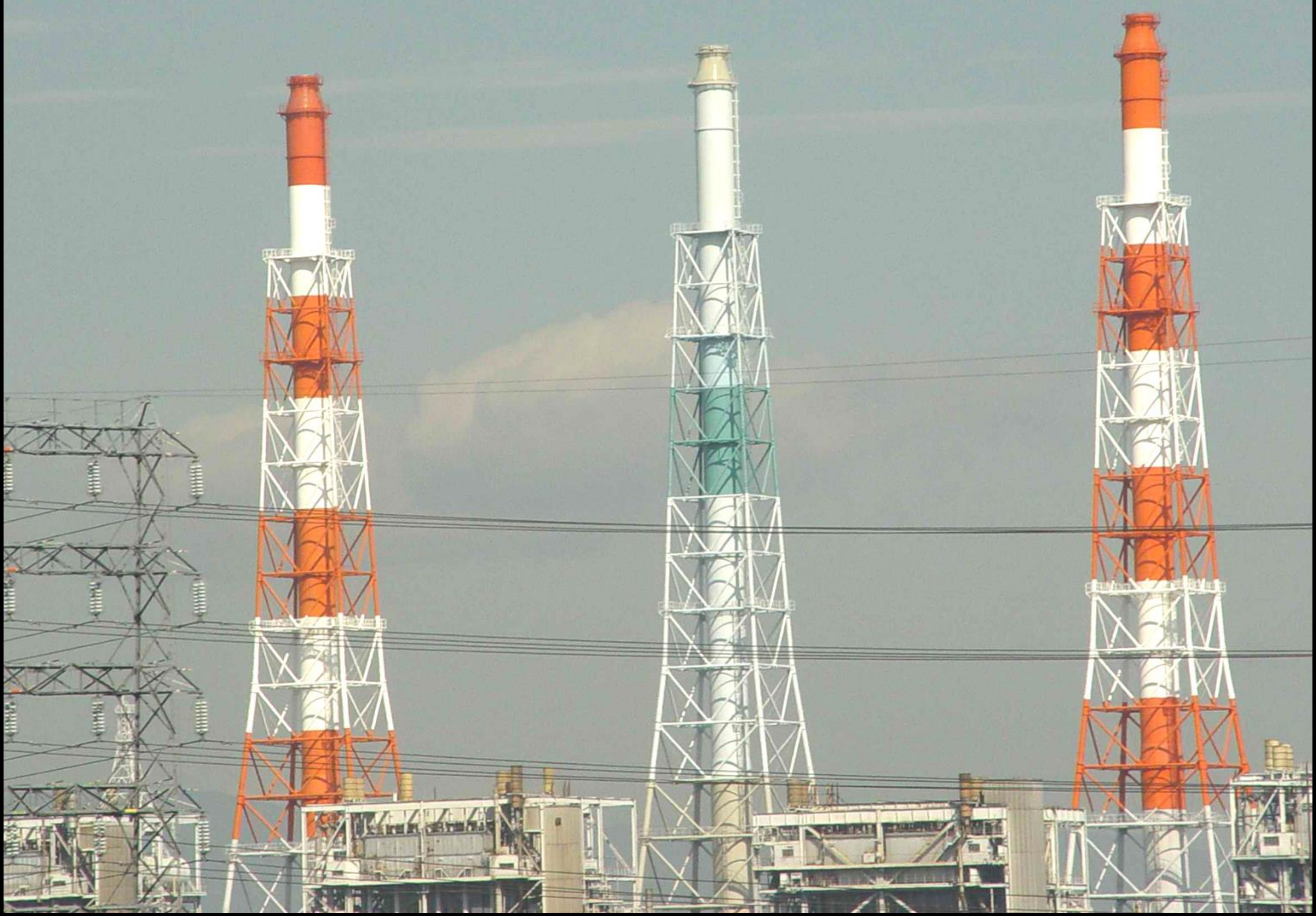
ABCB

Standards Australia

STANDARDS NEW ZEALAND

A Steel Stack

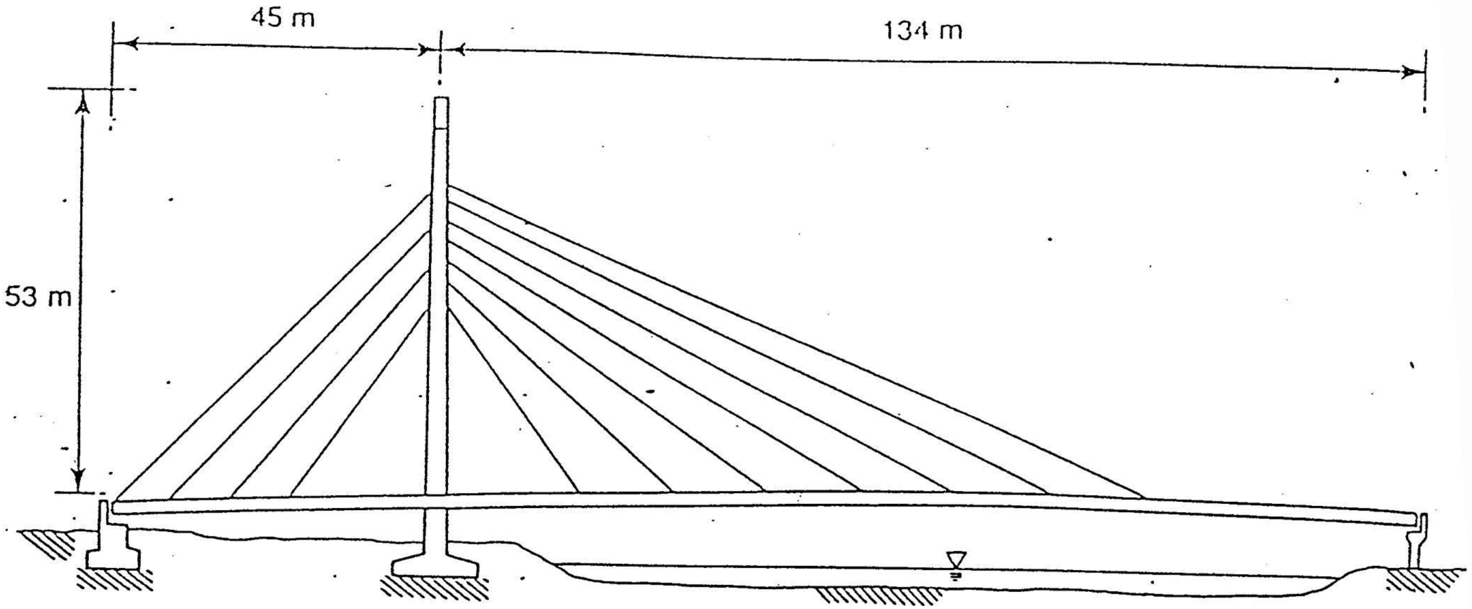
A Steel Stack

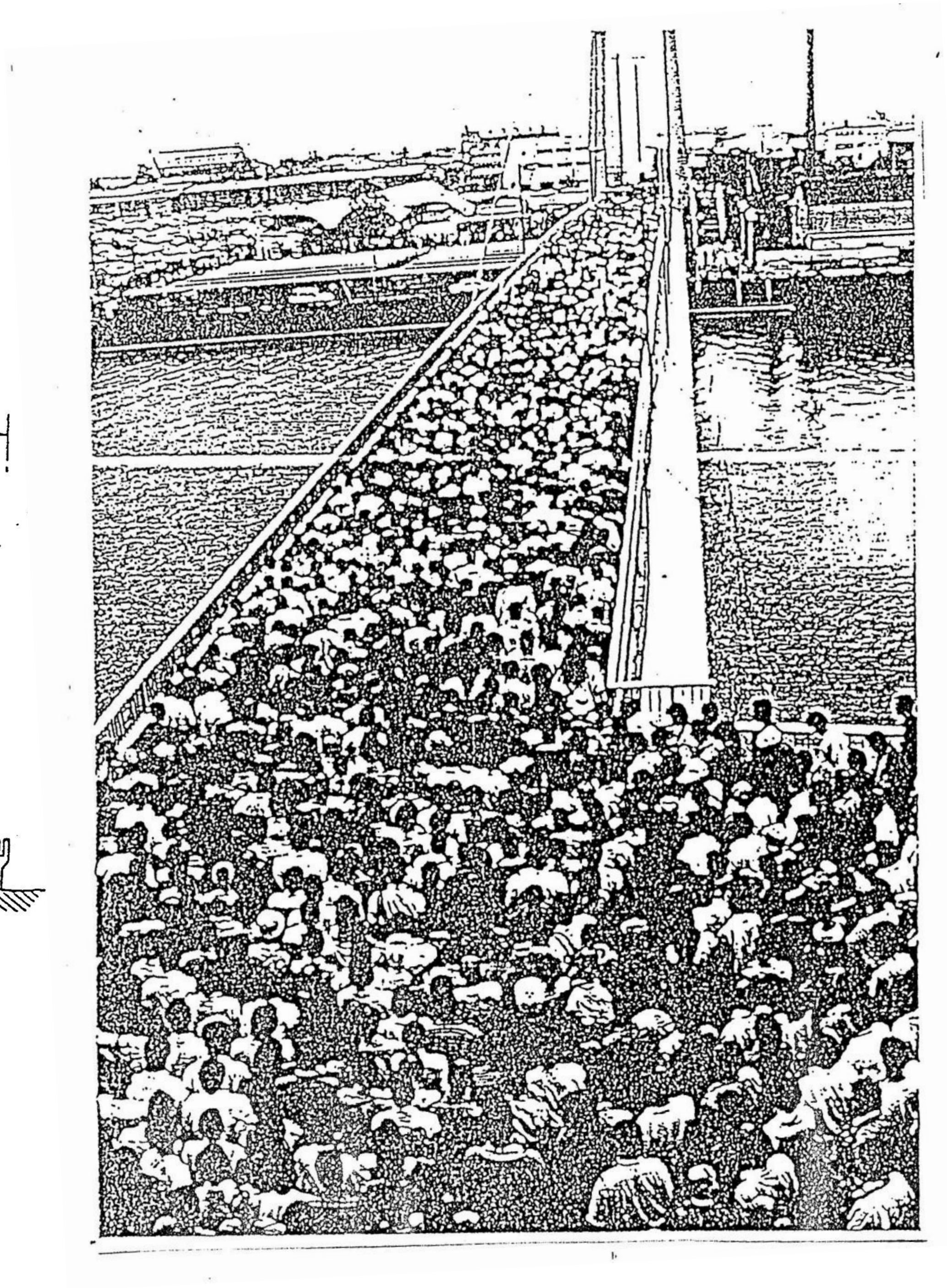


Pendulum Tuned Mass Damper


Suspended Wire Rope
Steel Ring
Viscous Damper

A Pedestrian Bridge





A Pedestrian Bridge

- 2000 pedestrians walk across the bridge in the same time.
- The bridge is subjected to human-induced force in both vertical and horizontal directions.
- The bridge girder vibrates laterally, and the stay cables also vibrate with very large lateral vibration amplitudes, says up to 50 cm.
- The dynamic stresses are so low that the structure will never fail.
- And the vibrations are too low to cause any difficulty on the walking mode of pedestrians.
- But many pedestrians are afraid to walk. Many people complain about the vibration, and many of them think that the bridge was poorly designed and constructed.
- Problem of ‘human perception of vibration’

Why This Course? - Course Objectives

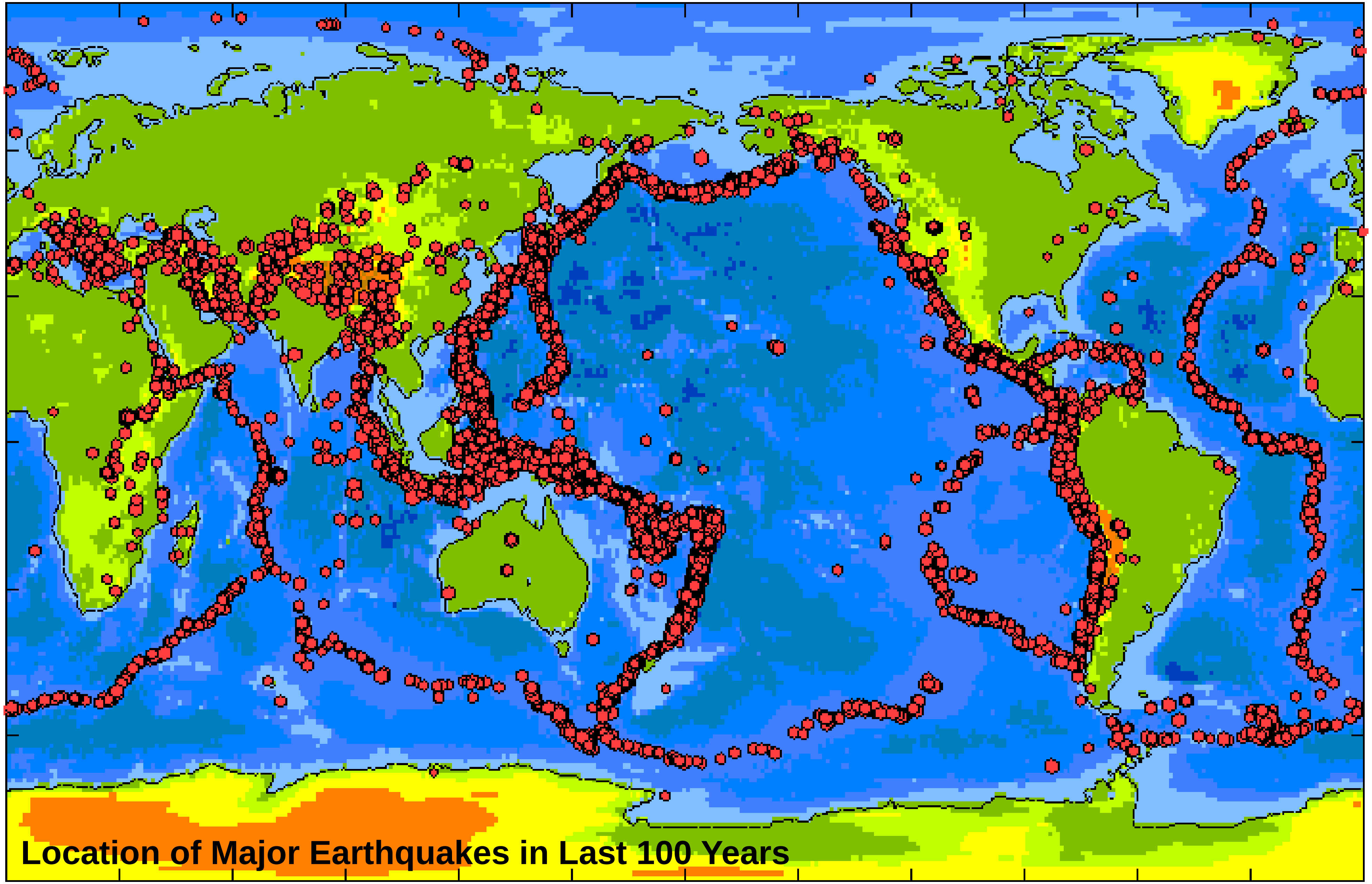
- As modern structures are becoming slender and light, they are also becoming more susceptible to dynamic loadings.

- Various examples of real-life dynamic problems that frequently confront civil engineers include:
  - *Aerodynamic stability of long-span bridges*
  - *Earthquake response of multi-story buildings*
  - *Impact of moving vehicles on highway structures, etc.*

- The traditional engineering solutions to these problems, based on "static force" and "static response", are no longer valid in most cases.

- Many of these problems have to be tackled by applying the knowledge of structural dynamics. Thus, a basic understanding of the dynamic behavior of structures as well as the underlying principles is essential for structural engineers.

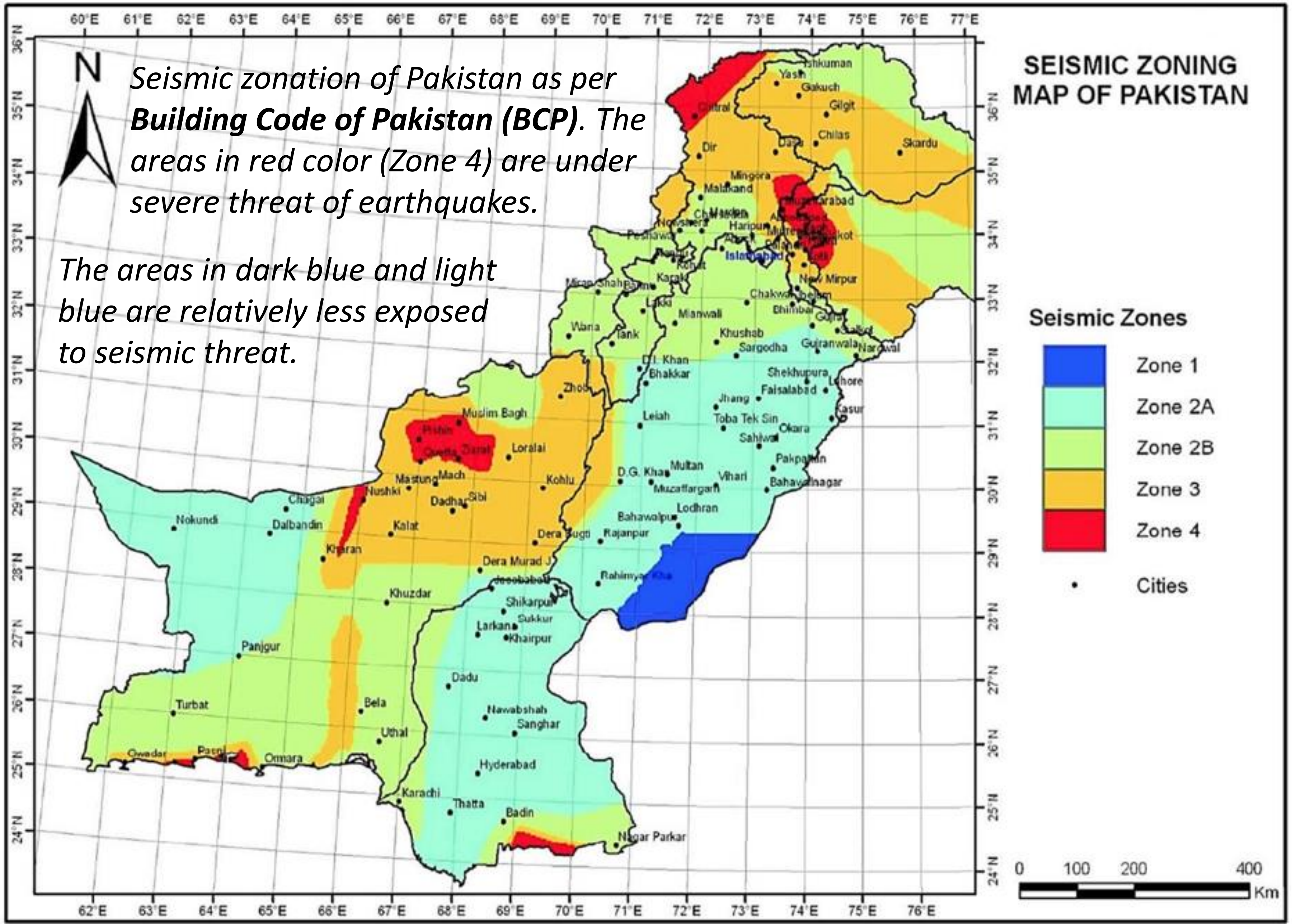
Why This Course?



Why This Course?

Seismic zonation of Pakistan as per ***Building Code of Pakistan (BCP)****. The areas in red color (Zone 4) are under severe threat of earthquakes.*

The areas in dark blue and light blue are relatively less exposed to seismic threat.



Learning Outcomes

- Develop the basic understanding of principles of structural dynamics
- Develop the ability to integrate the principles of structural dynamics in structural design of buildings and structures
- Develop the ability to analyze and solve problems in dynamic response and behavior of buildings and structures

Course Outline

1) Dynamics of Simple Structures (single-degree-of-freedom systems)
    a. *Equation of motion*
    b. *Free vibrations*
    c. *Response to harmonic force*
    d. *Response to periodic force*
    e. *Response to arbitrary dynamic force*
    f. *Nonlinear dynamic response*

2) Multi-Degree-Of-Freedom Structures
    a. *Formulation of matrix equations of motion*
    b. *Analysis of free vibrations*
    c. *Modal analysis and forced vibrations*
    d. *Nonlinear dynamic response*

Course Outline

3) Continuous Structures
   a. *Partial differential equations of motions (for strings, bars, beams)*
   b. *Modal analysis*
   c. *Wave propagation analysis*

4) Earthquake Response
   a. *Response spectrum concept*
   b. *Application to earthquake engineering*

3) Random Vibrations
   a. *Probability theory, random processes*
   b. *Correlation and spectral density functions*
   c. *Response to stationary random excitations*
   d. *Crossing, peak distributions, extreme value analysis, evaluation of fatigue life*
   e. *Application to wind engineering*

Course Outline

6) Control of Dynamic Response
   a. *Overview of vibration control*
   b. *Tuned Mass Dampers*
   c. *Active vibration control*

Reference Books

- A. K. Chopra, (2017): **Dynamics of Structures-Theory and Applications to Earthquake Engineering**, ISBN 0134555120, 9780134555126, Prentice Hall international series, Pearson, 2017.

- R. W. Clough, and J. Penzien, (2003): **Dynamics of Structures**, Computers and Structures, Incorporated, ISBN 0923907505, 9780923907501.

- Roy R. Craig, (2010): **Structural dynamics: An introduction to computer methods**, ISBN 0471044997, Wiley.

- J. W. Smith, (1988): **Vibration of Structures: Applications in Civil Engineering Design**, Chapman and Hall, London.

- T. R. Tauchert, (1974): **Energy Principles in Structural Mechanics**, McGraw-Hill, ISE.

- H. Bachmann, and W. Ammann, (1987): **Vibrations in Structures-Induced by Man and Machines**, Series: Structural Engineering Documents. Vol. 3e. International Association for Bridge and Structural Engineering (IABSE), Zurich, Switzerland.

Reference Books

- D. E. Newland, (1993): **An Introduction to Random Vibrations**, Spectral and Wavelet Analysis, Longman, 3rd Edition, London.

- S. H. Crandall, and W. D. Mark, (1963): **Random Vibration in Mechanical Systems**, Academic Press, New York.

Journals and Magazines

- Earthquake Engineering and Structural Dynamics, Wiley
- Engineering Structures, Elsevier
- Structural Design of Tall and Special Buildings, Wiley
- Journal of Structural Engineering, ASCE
- Soil Dynamics and Earthquake Engineering, Elsevier
- Journal of the engineering mechanics division, ASCE
- Magazine of Concrete Research, ICE
- Structures and Buildings, ICE

Evaluation Scheme

- The final grade will be computed according to the following weight distribution:
  - *Mid-Semester Exam: 30%*
  - *Assignments: 10%*
  - *Quizzes: 10%*
  - *Final Exam: 50%*

- Dropbox link for downloading course material.

https://www.dropbox.com/sh/45yxjw98i06z0xv/AABgaADBnaEl6PcWsZTb0TQKa?dl=0

Thank you