

STRUCTURAL DYNAMICS

Rose School, Fall 2017

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COURSE OUTLINE

1. Introduction

- 1.1. Dynamic response
- 1.2. Dynamic loading
- 1.3. Dynamic degrees of freedom
- 1.4. Modeling a dynamic problem
- 1.5. Dynamic analysis of structures

Part 1 - Single Degree of Freedom

2. Equation of Motion

- 2.1. Dynamic load
- 2.2. Effect of gravity forces
- 2.3. Motion of the support

3. Free Response

- 3.1. Characteristic equation
- 3.2. Undamped free response
- 3.3. Conservation of energy
- 3.4. Damped free response
- 3.5. Coulomb damping
- 3.6. Logarithmic decrement and free vibration test

4. Forced Response to Harmonic Loading

- 4.1. Forced response of conservative systems
- 4.2. Forced response of dissipative systems
- 4.3. Resonance
- 4.4. Dynamic amplification factors
- 4.5. Complex frequency response
- 4.6. Vibration measurement instruments
- 4.7. Vibration isolation

- 5. **Measurement of Damping**
 - 5.1. Free-decay method
 - 5.2. Amplification method
 - 5.3. Half-power bandwidth method
 - 5.4. Energy dissipated by damping
- 6. **Forced Response to Periodic Loading**
 - 6.1. Representation of a periodic function as a Fourier series
 - 6.2. Fourier spectrum
 - 6.3. Response to periodic loading
- 7. **Response to Arbitrary Loading in the Time Domain**
 - 7.1. Response to an impulse loading
 - 7.2. Dirac impulse or delta function
 - 7.3. Response to a Dirac impulse
 - 7.4. Duhamel integral
 - 7.5. Convolution integral
 - 7.6. Numerical evaluation of the Duhamel integral
 - 7.7. Response to a step loading
 - 7.8. Response to a linearly increasing force
 - 7.9. Response to a constant force applied slowly
 - 7.10. Response to impulse loads
- 8. **Forced Response to Arbitrary Loading in Frequency Domain**
 - 8.1. Fourier transform
 - 8.2. Discrete Fourier transform
 - 8.3. Fast Fourier transform : Cooley-Tukey algorithm
 - 8.4. Calculation of the inverse fast Fourier transform
- 9. **Direct Time Integration of Linear Systems**
 - 9.1. Exact numerical integration for piecewise linear loading functions
 - 9.2. Central difference method
 - 9.3. Newmark method
- 10. **Direct Time Integration of Nonlinear Systems**
 - 10.1. Incremental equation of dynamic equilibrium
 - 10.2. Newmark's methods
 - 10.3. Error reduction with Newton method
- 11. **Generalized Elementary Systems**
 - 11.1. Rigid-body assemblies

- 11.2. Flexible system
- 11.3. Elementary generalized system
- 11.4. Rayleigh method

12. **Response to Earthquake Excitation**

- 12.1. Earthquake response in the time domain
- 12.2. Response spectrum
- 12.3. Design spectrum
- 12.4. Earthquake intensity
- 12.5. Fourier spectrum, relative velocity and energy
- 12.6. Response of a generalized SDOF system
- 12.7. Nonlinear response
- 12.8. Inelastic response spectrum

Part 2 - Multi-Degrees of Freedom Systems

13. **Equations of Motion**

- 13.1. Simplified model of a building
- 13.2. Equation of dynamic equilibrium
- 13.3. Stiffness influence coefficients
- 13.4. Static condensation
- 13.5. Support motions

14. **Finite Element Method**

- 14.1. Global formulation using the principle of virtual works
- 14.2. Local formulation using the principle of virtual work
- 14.3. Coordinate transformations
- 14.4. Generalized displacements, strains and stresses
- 14.5. Two-node truss element
- 14.6. Beam finite element
- 14.7. Beam-column element
- 14.8. Geometric stiffness matrix
- 14.9. Rules for assembling element matrices
- 14.10. Properties of the stiffness matrix
- 14.11. Numerical solution
- 14.12. Post-processing

15. **Free Response of Conservative Systems**

- 15.1. Physical significance of eigenvalues and eigenvectors
- 15.2. Evaluation of vibration frequencies
- 15.3. Evaluation of mode shapes

- 15.4. Influence of axial forces
- 15.5. Orthogonality of mode shapes
- 15.6. Comparing prediction and measured data
- 15.7. Influence of the mass matrix
- 16. Free Response of Non-conservative Systems**
 - 16.1. Proportional damping matrix
 - 16.2. Superposition of modal damping matrices
 - 16.3. Damping measurement by harmonic excitation
 - 16.4. Non-proportional damping matrix
- 17. Response to Arbitrary Loading by Modal Superposition**
 - 17.1. Normal coordinates
 - 17.2. Uncoupled equations of motion
 - 17.3. Modal superposition method
 - 17.4. Error due to the use of a truncated eigenvector base
 - 17.5. Harmonic amplification
 - 17.6. Static correction
- 18. Modal Superposition Response to Earthquake Excitation**
 - 18.1. Modal superposition
 - 18.2. Effective modal mass
 - 18.3. Error due to the use of a truncated modal base
 - 18.4. Superposition of spectral responses
- 19. Properties of Eigenvalues and Eigenvectors**
 - 19.1. Fundamental properties
 - 19.2. Generalized symmetric eigenvalue problem
 - 19.3. Spectral shift
 - 19.4. Zero masses
 - 19.5. Transformation of generalized eigenvalue problems to standard form
 - 19.6. Rayleigh quotient
 - 19.7. Properties of characteristic polynomials
 - 19.8. Sylvester's law of inertia
- 20. Reduction of Coordinates**
 - 20.1. Kinematic constraints
 - 20.2. Static condensation
 - 20.3. Rayleigh analysis
 - 20.4. Rayleigh-Ritz analysis
 - 20.5. Load-dependant Ritz vectors

20.6. Guyan-Irons reduction method

21. Numerical Methods for Eigenproblems

21.1. Iterative methods

21.2. Transformation methods

21.3. Subspace iterations

22. Direct Integration of Linear Systems

22.1. Central difference method

22.2. Newmark methods

22.3. Estimation of the highest eigenvalue

22.4. Analysis of the accuracy

22.5. Selection of a numerical direct integration method

COURSE INFORMATIONS

1. Teaching :

- a) Lecture : 3 hours per day from Monday to Thursday.
- b) Recitation/Tutorial : 3 hours every day.

2. Evaluation :

- a) 14 homeworks (70%).
- b) 1 final exam (30%).

COURSE MATERIALS

- 1. **Textbook** : *Dynamics of Structures*, P. Paultre.
- 2. **Software** : LAS (will be distributed to all students).