DEP613E – Seismic Isolation of Structures

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Objective

This course aims to develop a theoretical foundation for modeling, analysis and design of structures with seismic isolation.

Course Format

Main part of the course comprised of mathematical theory, which can be implemented in computer programming. Therefore, course will be accompanied by a set of MATLAB exercises and regular homework assignments. Depending on the capacity of the students, some MATLAB functions will be given to the student for easy programming. In addition, a research project that would make use of the programs developed during the semester will be assigned to students.

Textbook

There is no textbook for the course. Students will be asked to follow research papers and reports published in the seismic isolation field. Following references are suggested as a starting point.

1. Skinner RI, Robinson WH and McVerry GH (1993) "An Introduction to Seismic Isolation," John Wiley and Sons.
2. Naeim F and Kelly JM (1999) "Design of Seismic Isolated Structures," John Wiley and Sons.
3. Buckle I, Constantinou M, Dicleli M and Ghasemi H (2006) "Seismic Isolation of Highway Bridges," Special Report MCEER-06-SP07, MCEER, SUNY, Buffalo.
4. Komodromos, P. (2000) "Seismic Isolation for Earthquake Resistant Design," WIT Press.
5. AASHTO Guide Specifications to Seismic Isolation Design.

Grading

Grading will mostly depend on the project, programming and homework assignments. There will be one midterm. Tentative grading policy is as follows:

- Midterm: %20
- Homework: %40
- Project: %40

Contents

The following is a broad coverage of the course. Depending on the alignment of the course, some of the topics will receive higher attention and some of them will not be covered.

1. Essential Mathematics, Structural Dynamics and Earthquake Engineering for Seismic Base Isolation

   (a) Matrix Theory, Notation, Basic Matrix Algebra.

   (b) Differential Equations, Analytical and Numerical Solution Methods

   (c) Stiffness Forces, Damping Forces, Free-body diagrams, Kinematic diagrams, Equations of Motion

   (d) SDOF Systems, Linear Systems, Viscous Damping, Nonlinear Systems, Bilinear Nonlinearity, Hysteretic Energy Dissipation, Linearization, Equivalent Stiffness and Equivalent Damping, Frequency Domain Analysis, Numerical Solution of Linear and Nonlinear Systems, Stochastic Aspects of Linear and Bilinear SDOF systems

   (e) 2-DOF Systems, Equations of Motion, Modal Analysis, Damping, Irregular Systems, Low-Mass Secondary Systems, Classical and Nonclassical Damping Matrix. Frequency Domain Analysis

   (f) MDOF Systems, Modal Analysis, Damping, Classical and Non-classical Damping, Generalized SDOF systems, Response Spectrum Analysis, Modal Time History Analysis, Direct Time History Analysis, State-Space Representation

   (g) Seismic Design, Seismic Hazard, Intensity Measures, Scaling of Time Histories, Performance Levels, Performance Based Design

2. Introduction to Seismic Isolation

   (a) Fundamentals of Seismic Base Isolation, Purpose, Difference between Conventional Structures and Isolated Structures. Fundamental Characteristics of Isolated Structures.

3. Analysis and Behavior of Base Isolated Structures

   (a) Buildings with Linear Base Isolation, Mathematical Modeling and Equations of Motion, FE-Based Modeling, Super and Substructure Modeling, Modal Analysis, Mode Shapes, Natural Frequencies, Isolation with Viscous Damping, Analysis for Classical and Non-classical Damping, Response Characteristics

   (b) Buildings with Bilinear Isolation, Numerical Solution, Equivalent Linearization for Stiffness and Damping, Response Characteristics

   (c) Analysis of 3D Buildings, Linear and Nonlinear Isolation, Torsional Behavior

   (d) Bridges with Isolation, Modeling and Analysis, Response Characteristics.

   (e) Analysis Methods, Equivalent Linear Analysis, Response Spectrum Analysis and Direct Time History Analysis.

4. Mechanical Properties, Behavior and Modeling of Isolators

   (a) Types of Isolators

(b) Laminated Rubber Bearings

- Mechanical Properties, Stiffness, Damping and Period, Stress-Strain Relations, Maximum Strains, Interaction, Stability, Design, Constitutive Modeling, Continuous Analytical Models, Piecewise Linear Models. Design Considerations, Temperature Effects, Aging

(c) High Damping Rubber Bearings

- Mechanical Properties, Design Considerations, Constitutive Modeling

(d) Lead-Rubber Bearings

- Mechanical Properties, Design Considerations, Constitutive Modeling

(e) Sliding Isolators, Friction Pendulums, Double and Triple Friction Pendulum

- Mechanical Properties, Period Properties, Design Considerations, Temperature Effects, Aging

(f) Comparison of Isolators

- Performance
- Cost
- Application

5. Design of Base Isolated Buildings

(a) Design Stages, Preliminary Design of Isolated Bridges

(b) Design of Isolators for Displacements, Axial Loads and Buckling

(c) Design of Substructure and Superstructure

(d) Analysis Methods

- Equivalent Static Force Procedure
- Response Spectrum Procedure
- Nonlinear Time-History Analysis

(e) Code Base Requirements

(f) Anchorage and Base Plate Design

(g) Detailing and Construction

6. Design of Isolated Bridges

(a) Design Stages, Preliminary Design of Isolated Bridges

(b) Design of Isolators for Displacements, Axial Loads and Buckling

(c) Design of Substructure and Superstructure

(d) Analysis Methods

- Equivalent Static Force Procedure
- Response Spectrum Procedure
- Nonlinear Time-History Analysis

(e) Code Base Requirements

   (f) Anchorage and Base Plate Design
   (g) Detailing and Construction

7. Testing of Isolators

   (a) Prototype and QC testing
   (b) Code Requirements.

8. Practical Applications

   (a) Sample Buildings and Bridges

9. Isolation Systems with Dampers

   (a) Types of Dampers
      - Viscous Dampers
      - Viscoelastic Dampers
      - Yielding Metal Dampers
      - Friction Dampers
   (b) Modelling, Analysis and Design with Dampers

10. Computer Implementation

   (a) Commercial Programs
   (b) Research-oriented Programs

Computer Applications

1. Essential Mathematics, Structural Dynamics and Earthquake Engineering for Seismic Base Isolation

   (a) Basic Matrix Operations
   (b) Linear Time History Analysis of SDOF Systems
      - Numerical Solution
      - MATLAB "`lsim`" function
      - Simulink
   (c) Modeling Bilinear Nonlinearity
      - Piecewise Linear
      - Continuous Models
   (d) Nonlinear Time History Analysis of SDOF Systems

2. Analysis and Behavior of Base Isolated Structures:

   (a) Analysis of Linear MDOF Systems
      i. Modal Time History Analysis

        ii. Discrete Time History Analysis
    (b) Linear Models with Equivalent Viscous Damping
3. Mechanical Properties, Behavior and Modeling of Isolators
    (a) Modelling of Lead Rubber Bearing Isolators
    (b) Modeling of Sliding Isolators
4. Design of Base Isolated Buildings
    (a) Development of Iterative Procedure for Preliminary Design

Project Topics

1. Analysis of Isolated Building Structures with Bilinear Nonlinearity
2. Frequency Domain Analysis of Isolated Structures
3. Simplified 3D Analysis of Base Isolated Buildings
4. Simplified Analysis of Isolated Bridges
5. Analysis with Dampers