

Contents

| | | |
|----------|---|----------|
| 1 | Introduction to Earthquake with Explanatory Data | 1 |
| 1.1 | Earthquake or Seismic Analysis and Design | |
| | Considerations | 1 |
| | 1.1.1 Introduction. | 1 |
| 1.2 | Plate Tectonic and Inner Structure of Earth | 1 |
| 1.3 | Types of Faults | 6 |
| 1.4 | Seismograph And Seismicity | 7 |
| 1.5 | Seismic Waves. | 8 |
| 1.6 | Magnitude of the Earthquake | 9 |
| | 1.6.1 Seismic Magnitude | 10 |
| 1.7 | The World Earthquake Countries and Codes of Practices . . . | 11 |
| 1.8 | Intensity Scale. | 23 |
| | 1.8.1 Earthquake Intensity Scale | 24 |
| | 1.8.2 Intensity Distribution | 25 |
| | 1.8.3 Abnormal Intensity Region. | 31 |
| | 1.8.4 Factors Controlling Intensity Distribution | 31 |
| 1.9 | Earthquake Intensity Attenuation | 32 |
| | 1.9.1 Epicentral Intensity and Magnitude | 32 |
| 1.10 | Geotechnical Earthquake Engineering. | 32 |
| 1.11 | Liquefaction | 33 |
| | 1.11.1 Introduction. | 33 |
| | 1.11.2 Types of Damage. | 34 |
| 1.12 | Earthquake-Induced Settlement. | 34 |
| 1.13 | Bearing Capacity Analyses for Earthquakes | 35 |
| 1.14 | Slope Stability Analysis for Earthquakes. | 35 |
| 1.15 | Energy Released in an Earthquake | 36 |
| 1.16 | Earthquake Frequency | 37 |
| 1.17 | Impedance Contrast | 40 |
| 1.18 | Glossary of Earthquake/Seismology | 41 |
| 1.19 | Artificial Generation of Earthquake | 45 |
| 1.20 | Net Result. | 45 |
| | Bibliography | 46 |

| | |
|---|-----|
| 2 Existing Codes on Earthquake Design with and Without Seismic Devices and Tabulated Data..... | 51 |
| 2.1 Existing Codes on Earthquake Design..... | 51 |
| 2.1.1 Algeria: RPA (1989) | 51 |
| 2.1.2 Argentina : INPRES-CIRSOC 103 (1991) | 53 |
| 2.1.3 Australia: AS11704 (1993)..... | 57 |
| 2.1.4 China: TJ 11-78 and GBJ 11-89 | 60 |
| 2.1.5 Europe: 1-1 (Oct 94); 1-2 (Oct 94); 1-3 (Feb 95); Part 2 (Dec 94); Part 5 (Oct 94); Eurocode 8..... | 64 |
| 2.1.6 India and Pakistan: IS-1893 (1984) and PKS 395-Rev (1986)..... | 75 |
| 2.1.7 Iran: ICRD (1988)..... | 77 |
| 2.1.8 Israel: IC-413 (1994) | 79 |
| 2.1.9 Italy: CNR-GNDT (1986) and Eurocode EC8 is Implemented..... | 83 |
| 2.1.10 Japan: BLEO (1981) | 84 |
| 2.1.11 Mexico: UNAM (1983) M III (1988) | 88 |
| 2.1.12 New Zealand: NZS 4203 (1992) and NZSEE (1988) | 92 |
| 2.1.13 USA: UBC-91 (1991) and SEAOC (1990) | 95 |
| 2.1.14 Codes Involving Seismic Devices and Isolation Techniques | 100 |
| Bibliography..... | 136 |
| 3 Basic Structural Dynamics..... | 143 |
| 3.1 General Introduction | 143 |
| 3.2 Structural Dynamics..... | 143 |
| 3.2.1 General Introduction to Basic Dynamics | 143 |
| 3.2.2 Single-Degree-of-Freedom Systems – Undamped Free Vibrations | 144 |
| 3.2.3 Summary and Conclusions | 149 |
| 3.2.4 Multi-Degree-of-Freedom System..... | 152 |
| 3.2.5 Dynamic Response of Mode Superposition | 159 |
| 3.3 Examples of Dynamic Analysis of Building Frames and Their Elements Under Various Loadings and Boundary Conditions | 162 |
| 3.3.1 Example 3.1 | 163 |
| 3.3.2 Example 3.2 | 165 |
| 3.3.3 Example 3.3 | 167 |
| 3.3.4 Example 3.4 | 169 |
| 3.3.5 Example 3.5 | 172 |
| 3.3.6 Example 3.6 | 179 |
| 3.3.7 Example 3.7 | 181 |
| 3.3.8 Example 3.8 | 182 |
| 3.3.9 Example 3.9 | 184 |

| | |
|---|------------|
| 3.3.10 Example 3.10 | 185 |
| 3.3.11 Example 3.11 | 190 |
| 3.3.12 Generalized Numerical Methods in Structural Dynamics | 195 |
| 4 Earthquake Response Spectra With Coded Design Examples | 207 |
| 4.1 Introduction | 207 |
| 4.2 Fourier Spectrum | 208 |
| 4.3 Combined Spectrum S_d - V - S_a | 218 |
| 4.4 Construction of Response Spectrum | 219 |
| 4.5 Design Examples | 220 |
| 4.5.1 Example 4.1 American Practice | 221 |
| 4.5.2 Example 4.2 American and Other Practices | 224 |
| 4.5.3 Example 4.3 Algeria and Argentina Practices | 229 |
| 4.5.4 Example 4.4 American Practice | 236 |
| 4.5.5 Example 4.5 American Practice | 237 |
| 4.5.6 Example 4.6 American Practice | 242 |
| 4.5.7 Elastic Design Spectrum: Construction of Design Spectrum | 244 |
| 4.6 Earthquake Response of Inelastic Systems | 252 |
| 4.6.1 General | 252 |
| 4.6.2 De-amplification Factors | 254 |
| 4.6.3 Response Modification Factors | 256 |
| 4.6.4 Energy Content and Spectra | 257 |
| 4.6.5 Example 4.7 American Practice | 259 |
| 4.6.6 Example 4.8 American Practice | 261 |
| 4.6.7 Example 4.9 European Practice | 271 |
| 4.6.8 Example 4.10 British Practice | 281 |
| 4.6.9 Yield Strength and Deformation from the Response Spectrum (American Practice) | 284 |
| 4.7 Equivalent Static Force Method Based on Eurocode-8 | 286 |
| 4.7.1 General Introduction | 286 |
| 4.7.2 Evaluation of Lumped Masses to Various Floor Levels | 286 |
| 4.7.3 Response Spectrum Method | 288 |
| 4.7.4 Example 4.12 Step-by-Step Design Analysis Based on EC8 | 293 |
| 5 Dynamic Finite Element Analysis of Structures | 305 |
| 5.1 Introduction | 305 |
| 5.2 Dynamic Equilibrium | 305 |
| 5.2.1 Lumped Mass system | 305 |
| 5.3 Solution of the Dynamic Equilibrium Equations | 306 |
| 5.3.1 Mode Superposition Method | 307 |
| 5.4 Step-By-Step Solution Method | 312 |

| | | |
|---------|--|-----|
| 5.4.1 | Fundamental Equilibrium Equations | 312 |
| 5.4.2 | Supplementary Devices | 313 |
| 5.5 | Runge–Kutta Method | 315 |
| 5.5.1 | Introduction. | 315 |
| 5.6 | Non-linear Response of Multi-Degrees-of-Freedom Systems: Incremental Method | 317 |
| 5.7 | Summary of the Wilson- θ Method. | 320 |
| 5.8 | Dynamic Finite Element Formulation with Base Isolation . . . | 322 |
| 5.9 | Added Viscoelastic Dampers (VEDs) in Seismic Buildings . . . | 323 |
| 5.9.1 | Introduction. | 323 |
| 5.9.2 | Generalized Equation of Motion when Dampers Are Used | 324 |
| 5.9.3 | System Dynamic Equation with Friction Dampers . . | 324 |
| 5.10 | Non-linear Control of Earthquake Buildings with Actuators . . | 327 |
| 5.10.1 | Introduction. | 327 |
| 5.10.2 | Analysis Involving Actuators | 327 |
| 5.11 | Spectrum Analysis with Finite Element | 332 |
| 5.11.1 | Calculation by Quadratic Integration | 334 |
| 5.11.2 | Calculation by Cubic Integration | 334 |
| 5.11.3 | Cubic Integration. | 334 |
| 5.11.4 | Mode Frequency Analysis using Finite Element. | 335 |
| 5.11.5 | Dynamic Analysis: Time-Domain Technique | 338 |
| 5.12 | Sample Cases | 350 |
| 5.12.1 | Plastic Potential of the Same Form as the Yield Surface. . . | 350 |
| 5.12.2 | von Mises Yield Surface Associated with Isotropic Hardening | 351 |
| 5.12.3 | Dynamic Local and Global Stability Analysis | 360 |
| 5.13 | Dynamic Analysis of Buildings in Three Dimensions | 362 |
| 5.13.1 | General Introduction. | 362 |
| 5.13.2 | Finite Element Analysis of Framed Tubular Buildings Under Static and Dynamic Load Influences. | 364 |
| 5.14 | Finite Element Modelling of Building Structures – Step by Step Formulations Incorporating All Previous Sections | 365 |
| 5.14.1 | Introduction. | 365 |
| 5.14.2 | Solid Isoparametric Element Representing Concrete . . | 366 |
| 5.14.3 | The Shape Function | 368 |
| 5.14.4 | Derivatives and the Jacobian Matrix | 368 |
| 5.14.5 | Determination of Strains | 370 |
| 5.14.6 | Determination of Stresses | 371 |
| 5.14.7 | Load Vectors and Material Stiffness Matrix | 371 |
| 5.14.8 | The Membrane Isoparametric Elements | 375 |
| 5.14.9 | Isoparametric Line Elements. | 379 |
| 5.14.10 | Element Types, Shape Functions, Derivatives, Stiffness Matrices for Finite Element | 387 |

| | | |
|----------|---|------------|
| 5.15 | Criteria for Convergence and Acceleration | 393 |
| 5.15.1 | Introduction. | 398 |
| 5.15.2 | Hallquist et al. Method | 398 |
| | Bibliography | 400 |
| 6 | Geotechnical Earthquake Engineering and Soil-Structure Interaction | 405 |
| 6.1 | General Introduction | 405 |
| 6.2 | Concrete Structures – Seismic Criteria, Numerical Modelling of Soil–Building Structure Interaction and Isolators. | 406 |
| 6.2.1 | Structural Design Requirements for Building Structures. | 406 |
| 6.2.2 | Structure Framing Systems | 407 |
| 6.3 | Combination of Load Effects. | 413 |
| 6.4 | Deflection and Drift Limits | 414 |
| 6.5 | Equivalent Lateral Force Procedure | 415 |
| 6.5.1 | General | 415 |
| 6.5.2 | Seismic Base Shear. | 415 |
| 6.5.3 | Period Determination | 416 |
| 6.5.4 | Vertical Distribution of Seismic Forces. | 417 |
| 6.6 | Horizontal Shear Distribution | 418 |
| 6.6.1 | Torsion. | 418 |
| 6.6.2 | Overturning (determined by all codes) | 419 |
| 6.7 | Drift Determination and $P-\Delta$ Effects. | 419 |
| 6.7.1 | Storey Drift Determination (determined by all codes) | 419 |
| 6.7.2 | $P-\Delta$ Effects (determined according to all codes) | 420 |
| 6.8 | Modal Analysis Procedure: Codified Approach | 420 |
| 6.8.1 | Introduction. | 420 |
| 6.8.2 | Modal Base Shear as by Codified Methods | 421 |
| 6.8.3 | Modal Forces, Deflection and Drifts | 422 |
| 6.8.4 | Soil–Concrete Structure Interaction Effects | 423 |
| 6.9 | Methods of Analysis Using Soil-Structure Interaction | 426 |
| 6.9.1 | General Introduction. | 426 |
| 6.9.2 | Response-Spectrum Analysis. | 426 |
| 6.9.3 | Time-History Analysis. | 427 |
| 6.9.4 | Characteristics of Interaction | 427 |
| 6.10 | Site Response – A Critical Problem in Soil-Structure Interaction Analyses for Embedded Structures | 430 |
| 6.10.1 | Vertical Earthquake Response and $P-\Delta$ Effect | 430 |
| 6.10.2 | $P-\Delta$ Effects. | 430 |
| 6.10.3 | Frequency Domain Analysis of an MDF System | 433 |
| 6.10.4 | Some Non-linear Response Spectra | 434 |
| 6.10.5 | Soil–Structure Interaction Numerical Technique | 435 |
| 6.10.6 | Substructure Method in the Frequency Domain. | 436 |

| | | |
|----------|--|------------|
| 6.11 | Mode Superposition Method – Numerical Modelling..... | 438 |
| 6.12 | Mass Moments of Inertia..... | 439 |
| 6.12.1 | Energies | 441 |
| 6.13 | Modelling of Isolators with Soil–Structure Interaction..... | 441 |
| 6.13.1 | Introduction..... | 441 |
| 6.13.2 | Isolation System Components..... | 443 |
| 6.13.3 | Numerical Modelling of Equations of Motion with Isolators..... | 443 |
| 6.13.4 | Displacement and Rotation of Isolation Buildings.... | 444 |
| | Bibliography | 451 |
| 7 | Response of Controlled Buildings – Case Studies..... | 455 |
| 7.1 | Introduction | 455 |
| 7.2 | Building With Controlled Devices | 457 |
| 7.2.1 | Special Symbols with Controlled Devices..... | 459 |
| 7.2.2 | Seismic Waveforms and Spectra | 460 |
| 7.2.3 | Maximum Acceleration and Magnification | 462 |
| 7.2.4 | Three-Dimensional Simulation of the Seismic Wave Field..... | 462 |
| 7.3 | Evaluation of Control Devices and the Response-Control Technique..... | 462 |
| 7.3.1 | Initial Statistical Investigation of Response-Controlled Buildings | 462 |
| 7.3.2 | Permutations and Combinations..... | 469 |
| 7.4 | Permutations and Combinations of Devices | 472 |
| 7.5 | Seismic Design of Tall Buildings in Japan – A Comprehensive Study..... | 523 |
| 7.5.1 | General Introduction..... | 523 |
| 7.5.2 | Resimulation Analysis of SMB Based on the Kobe Earthquake Using Three-Dimensional Finite Element Analysis..... | 523 |
| 7.5.3 | Data I. | 529 |
| 7.5.4 | Data II..... | 530 |
| 8 | Seismic Criteria and Design Examples Based on American Practices | 555 |
| 8.1 | General Introduction | 555 |
| 8.2 | Structural Design Requirements for Structures..... | 555 |
| 8.2.1 | Introduction to the Design Basis..... | 555 |
| 8.3 | Drift Determination and $P - \Delta$ Effects..... | 556 |
| 8.3.1 | Storey Drift Determination | 556 |
| 8.4 | $P - \Delta$ Effects | 556 |
| 8.5 | Modal Forces, Deflection and Drifts..... | 557 |
| 8.6 | Soil–Concrete Structure Interaction Effects..... | 557 |
| 8.6.1 | General | 557 |

| | | |
|-----------|--|------------|
| 8.7 | Equivalent Lateral Forces Procedure..... | 557 |
| 8.7.1 | Base Shear | 558 |
| 8.7.2 | Effective Structural Period | 559 |
| 9 | Design of Structural Elements Based on Eurocode 8 | 565 |
| 9.1 | Introduction | 565 |
| 9.2 | Existing Codes | 565 |
| 9.2.1 | Explanations Based on Clause 4.2.3 of EC8 Regarding Structural Regularity. A Reference is Made to Eurocode 8: Part 1 – Design of Structures for Earthquake Resistance | 567 |
| 9.2.2 | Seismological Actions (Refer Clause 3.2 of EC8) | 567 |
| 9.3 | Avoidance in the Design and Construction in Earthquake Zones: Contributing Factors Responsible for Collapse Conditions | 568 |
| 9.4 | Superstructure and Structural Systems | 569 |
| 9.4.1 | Regularity | 569 |
| 9.4.2 | Structural Systems..... | 569 |
| 9.5 | Response Spectra Based on EU Code 8..... | 572 |
| 9.5.1 | The Behaviour Factor q | 574 |
| 9.6 | Seismic Design Philosophy of Building Frames Using Eurocode 8..... | 575 |
| 9.6.1 | General Introduction..... | 575 |
| 9.7 | Load Combinations and Strength Verification | 578 |
| 9.7.1 | Design Strength..... | 578 |
| 9.7.2 | Capacity Design Effects: Method Stated in the Eurocode-8 | 578 |
| 9.7.3 | Design Provisions for Earthquake Resistance of Structures | 580 |
| 9.7.4 | Second-Order Effects..... | 581 |
| 9.7.5 | Resistance Verification of Concrete Sections | 581 |
| 9.8 | Analysis and Design of a Steel Portal Frame under Seismic Loads. A Reference is Made to Fig. 9.6. | 596 |
| 9.8.1 | Data on Loadings | 596 |
| 9.8.2 | Bending Moments, Vertical and Horizontal Reactions | 597 |
| 9.8.3 | Ultimate Design Moments and Shears (Moment- Capacity Design) | 597 |
| 10 | Earthquake-Induced Collision, Pounding and Pushover of Adjacent Buildings | 601 |
| 10.1 | General Introduction | 601 |
| 10.2 | Analytical Formulation for the Pushover | 604 |
| 10.3 | Linear Response | 605 |
| 10.3.1 | Post-contact Conditions | 609 |

| | | |
|--------|--|------------|
| 10.4 | Calculation of Building Separation Distance..... | 612 |
| 10.4.1 | Minimum Separation Distance Required to Avoid Structural Pounding..... | 612 |
| 10.5 | Data for Buildings | 614 |
| 10.6 | Discussion on Results..... | 614 |
| | Bibliography | 618 |
| | Additional Extensive Bibliography..... | 623 |
| | Appendix A Subroutines for Program ISOPAR and Program F-Bang .. | 645 |
| | Appendix B KOBE (Japan) Earthquake Versus Kashmir (Pakistan) Earthquake | 705 |