Bridge Design - Structural Modeling and Analysis

Course Number: CE-02-402

PDH: 5

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Module 4: Structural Modeling and Analysis

Learning Objectives

By the end of this section, you will be able to:

- **Select** appropriate element types and discretization levels for complex bridge geometries based on structural behavior.
- **Evaluate** the differences between linear, nonlinear, static, and dynamic analysis methods to predict internal forces and deformations.
- **Calculate** Live Load Distribution Factors (LLDF) using both approximate AASHTO methods and refined 3D Finite Element Analysis.

Executive Summary: Structural modeling serves as the essential mathematical bridge between physical laws and predicted structural behavior. For the Professional Engineer, this chapter provides the framework for establishing structural, material, and load models. It details the transition from basic discretization to advanced 3D vehicle live load analysis, ensuring that the predicted responses—internal forces, stresses, and deformations—accurately reflect the physical prototype under service and extreme event limit states.

Introduction

Structural analysis is the process of predicting responses and behaviors of a structural system using physical laws and mathematical equations. The primary objective is to determine internal forces, stresses, and deformations under various load effects.

Structural modeling establishes three critical mathematical components:

1. **Structural Model**: Members, joints (nodes), and boundary conditions (supports/foundations).
2. **Material Model**: Stress-strain relationships.
3. **Load Model**: Applied forces and effects.

Structure Modeling

General Design Fundamentals

For new designs, connection details and support conditions **shall** be made as close to the computational models as possible. For existing structure evaluation, the model **shall** reflect actual as-built conditions. The choice of analysis method depends on the importance of the structure, the purpose of the analysis, and the required accuracy.

Types of Elements

Elements are categorized by their principal structural actions:

- **Truss Element**: A two-force member subjected only to axial loads (tension or compression).
- **Beam Element**: A slender member subjected to lateral loads and moments; typically possesses **six degrees of freedom (DOF)** at each node.
- **Frame Element**: Often called a beam-column element, it combines truss and beam properties, including biaxial bending, torsion, and axial/shear deformations.
- **Plate Element**: A 2D solid element modeling plate-bending behavior (out-of-plane rotations and normal displacement).
- **Shell Element**: A 3D solid element (where thickness is relatively small) that carries bending, shear, and membrane loadings.
- **Plane Element**: A 2D solid capable of supporting forces but not moments; includes **plane stress** (thin plates) and **plane strain** (thick sections/walls) variants.
- **Solid Element**: An eight-node element for modeling complex 3D structures and evaluating principal stress states.
- **NlLink Element**: An element used to model structural nonlinearities, such as grounded springs or two-joint links.

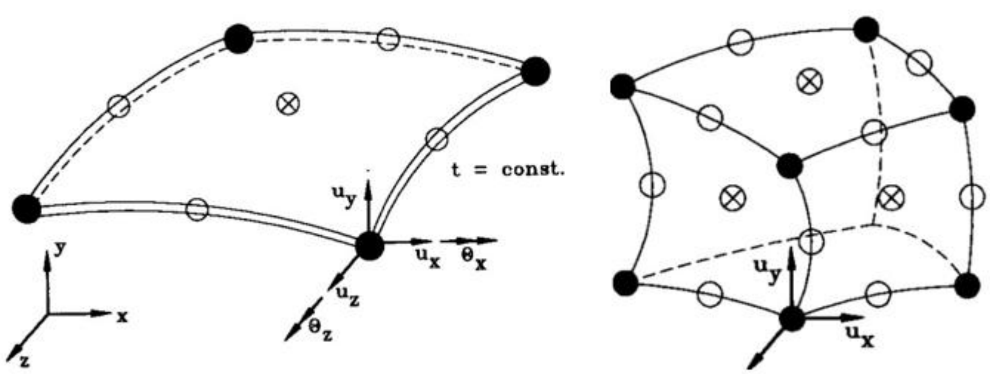

Figure 4.2-1: Shell and Solid Elements

Types of Boundary Elements

Effective modeling of support conditions at bearings and expansion joints is critical.

- **Static Analysis**: Often uses simplified assumptions (fixed, pinned, roller).
- **Dynamic Analysis**: Representation of soil/foundation stiffness (typically a **[6x6] stiffness matrix**) is essential.

Types of Materials

Material properties used for elastic analysis include: modulus of elasticity, shear modulus, Poisson's ratio, coefficient of thermal expansion, and density.

- **Homogeneous**: Properties are independent of coordinates.
- **Isotropic**: Properties are independent of axis rotation at any point.

Types of Loads

- **Permanent Loads**: Constant forces such as self-weight, wearing surface, and earth pressure.
- **Transient Loads**: Varying forces such as vehicular/pedestrian traffic, wind, water, and earthquakes.

Modeling Discretization

Discretization is the formulation of the mathematical model using discrete elements.

- **Joints/Nodes**: Points where displacements are of interest.
- **Elements**: Interconnect at joints to represent physical members.
- **Mass and Loads**: Applied to elements and transferred to joints.

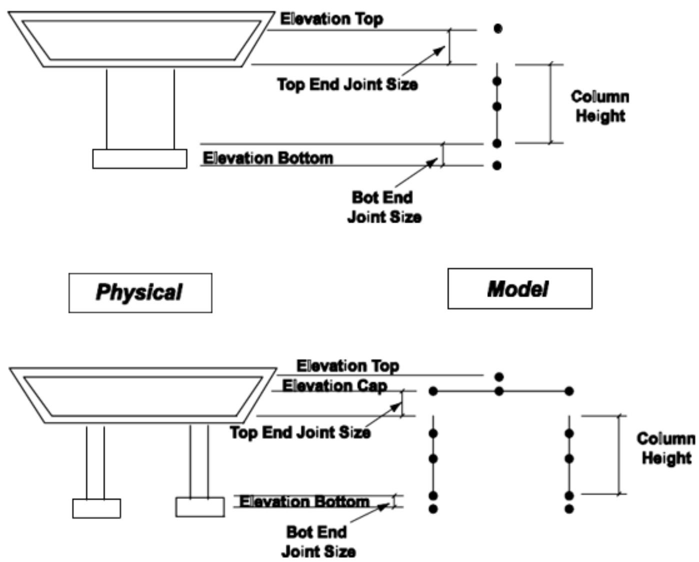

Figure 4.2-2: Model Discretization for Monolithic Connection

Structural Modeling Guidelines

- **Lumped-Parameter Models (LPMs)**: Mass, stiffness, and damping are combined at discrete locations.
- **Structural Component Models (SCMs)**: Idealized subsystems based on geometry. **Gross moment of inertia** is standard for non-seismic concrete column modeling; **effective moment of inertia** is used for thermal or prestressing effects.
- **Finite Element Models (FEMs)**: Detailed discretization where characteristics are derived from constituent materials.

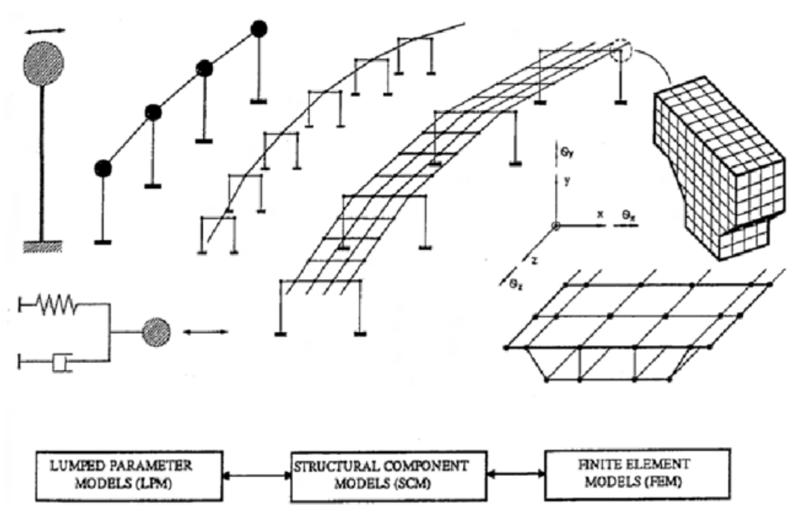

Figure 4.2-3. Levels of Modeling for Seismic Analysis of Bridge (Priestley, et al 1996)

Material Modeling Guidelines

A material is **elastic** if it returns to its original shape upon load release; otherwise, it is **inelastic**. Linear elastic materials follow **Hooke's Law**: **Equation 4-1:** $\sigma = E\varepsilon$

Where:

- **σ** = Stress
- **E** = Modulus of Elasticity
- **ε** = Strain

Types of Bridge Models

- **Global Bridge Models**: Includes the entire structure to capture irregular geometry, curves, and frame interactions.
- **Tension and Compression Models**: Capture nonlinear responses at expansion joints. Tension models capture out-of-phase movement; compression models capture in-phase movement.
- **Frame Models**: Assess dynamic responses of standalone portions between expansion joints.
- **Bent Models**: Focus on transverse moments and shears along the bent cap and columns.

Slab-Beam Bridges

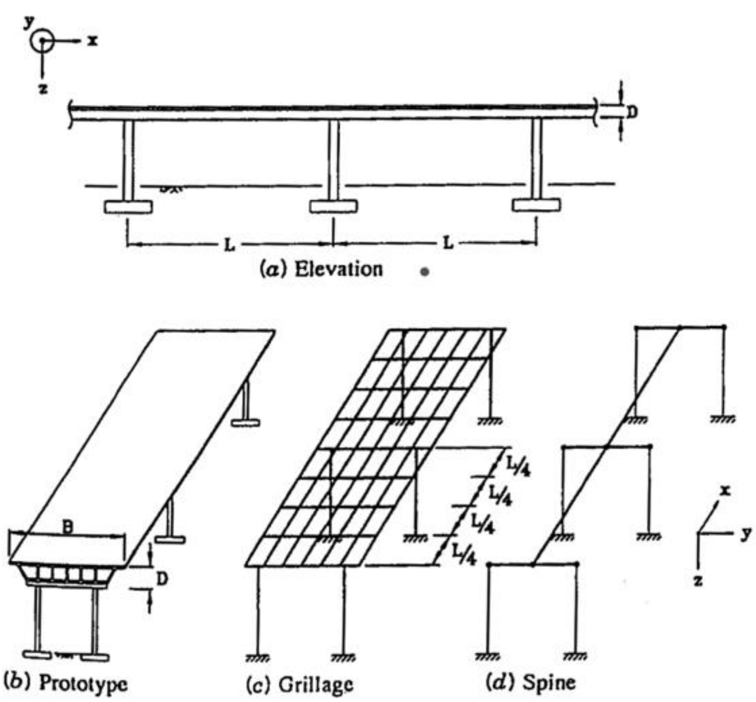

Figure 4.2-4: Superstructure Models (Priestley, et al 1996).