Prestressing Optimization Using ANN in Box-Girder Bridges

Enhancing Efficiency and Structural Integrity with AI

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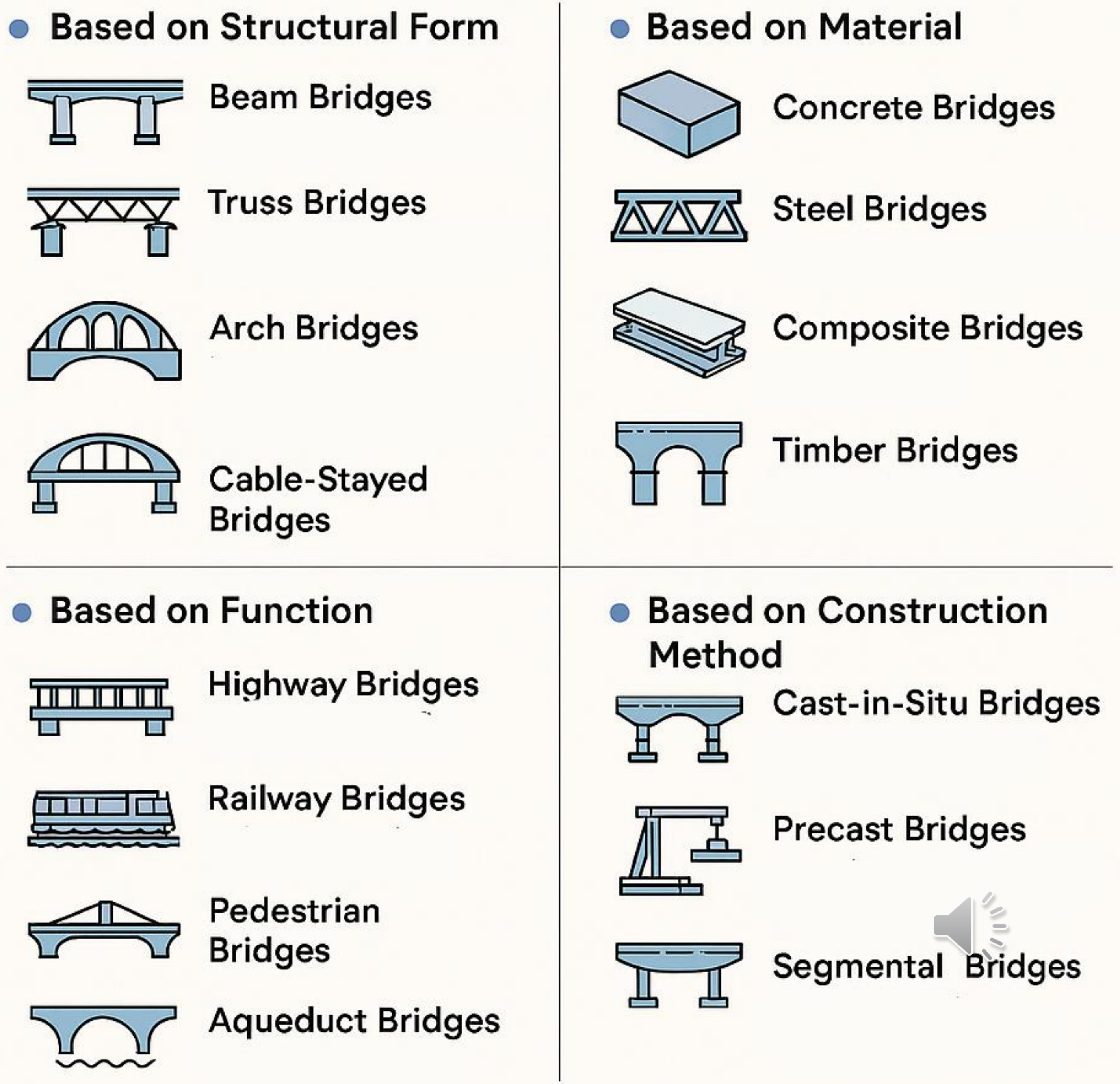
Contents

Introduction

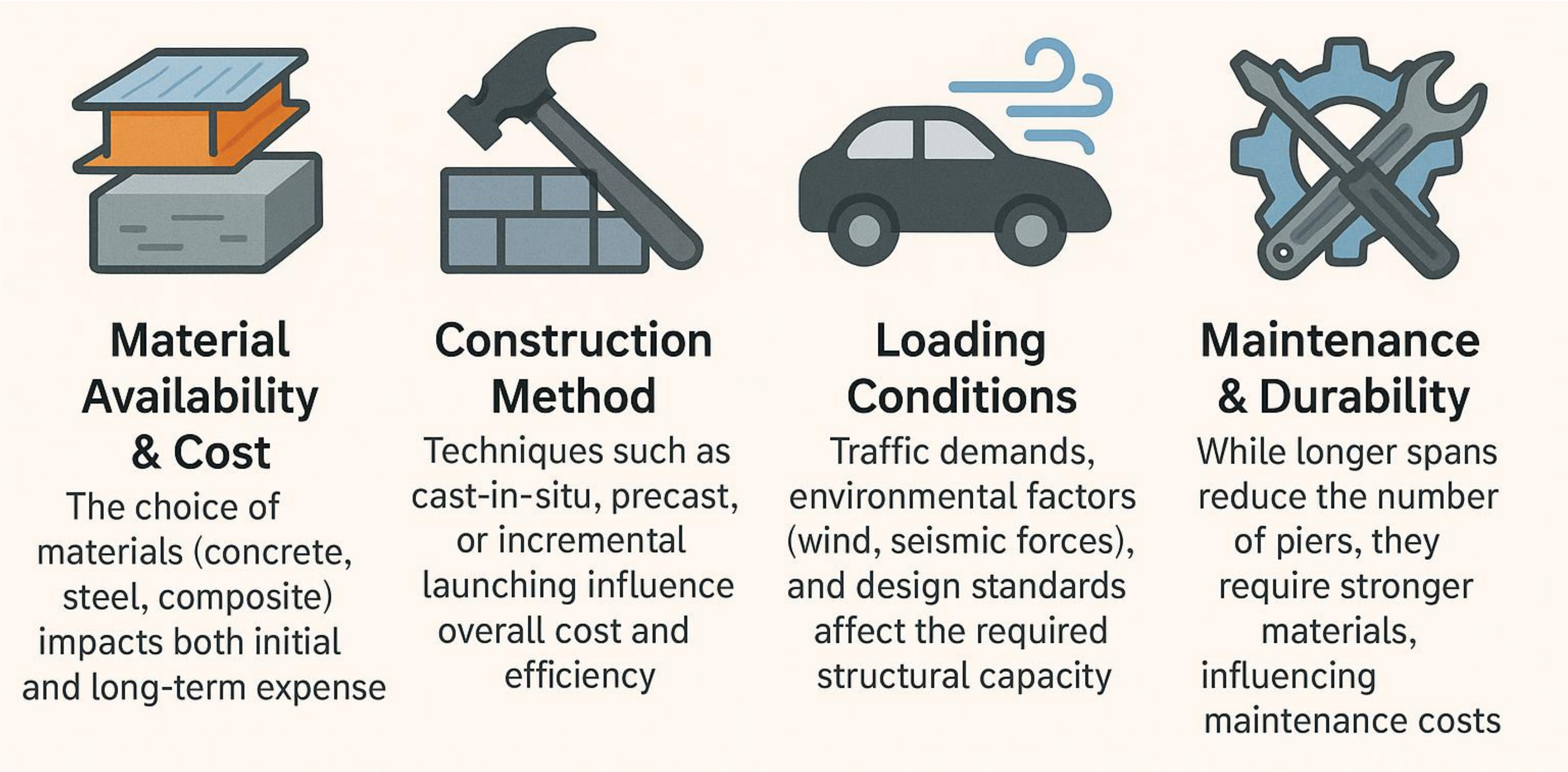
Bridges

- Bridges are vital infrastructure for connectivity and transport.
- Enable passage over obstacles (rivers, roads, railways, canals, etc.).
- Support various traffic types:
  - Pedestrians
  - Vehicles
  - Trains
  - Utility
  - pipelines (water, gas)
  - Waterways

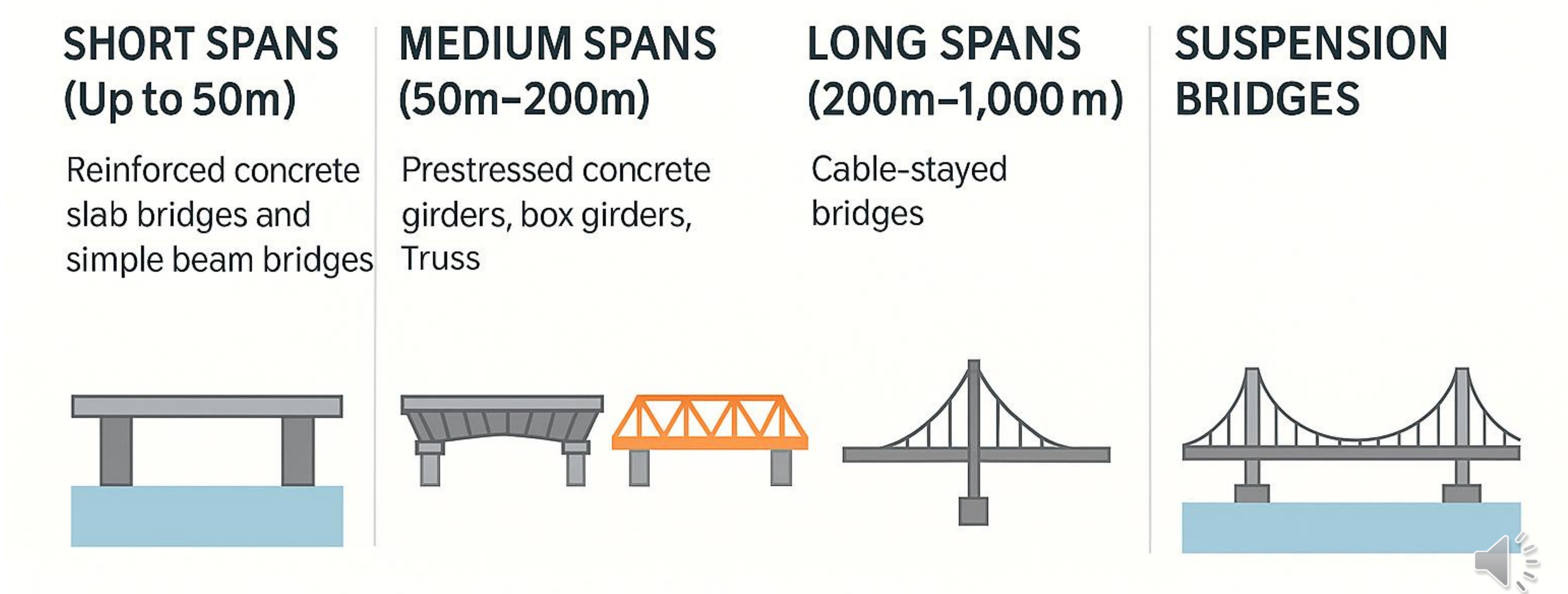
Classification



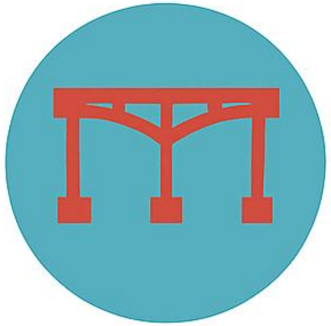
Factors Influencing Economic Span Length



Bridges Span Ranges

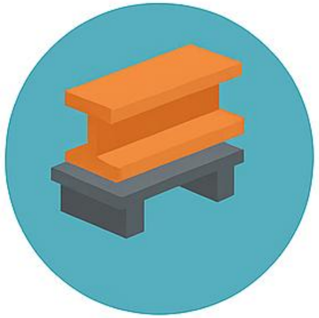


Bridges Cost Optimization Strategies



Optimize pier placement

Reducing the number of piers minimizes foundation costs, particularly in difficult terrain



Select efficient construction techniques

Precast, segmental, and incremental launching reduce costs

Consider life-cycle costs

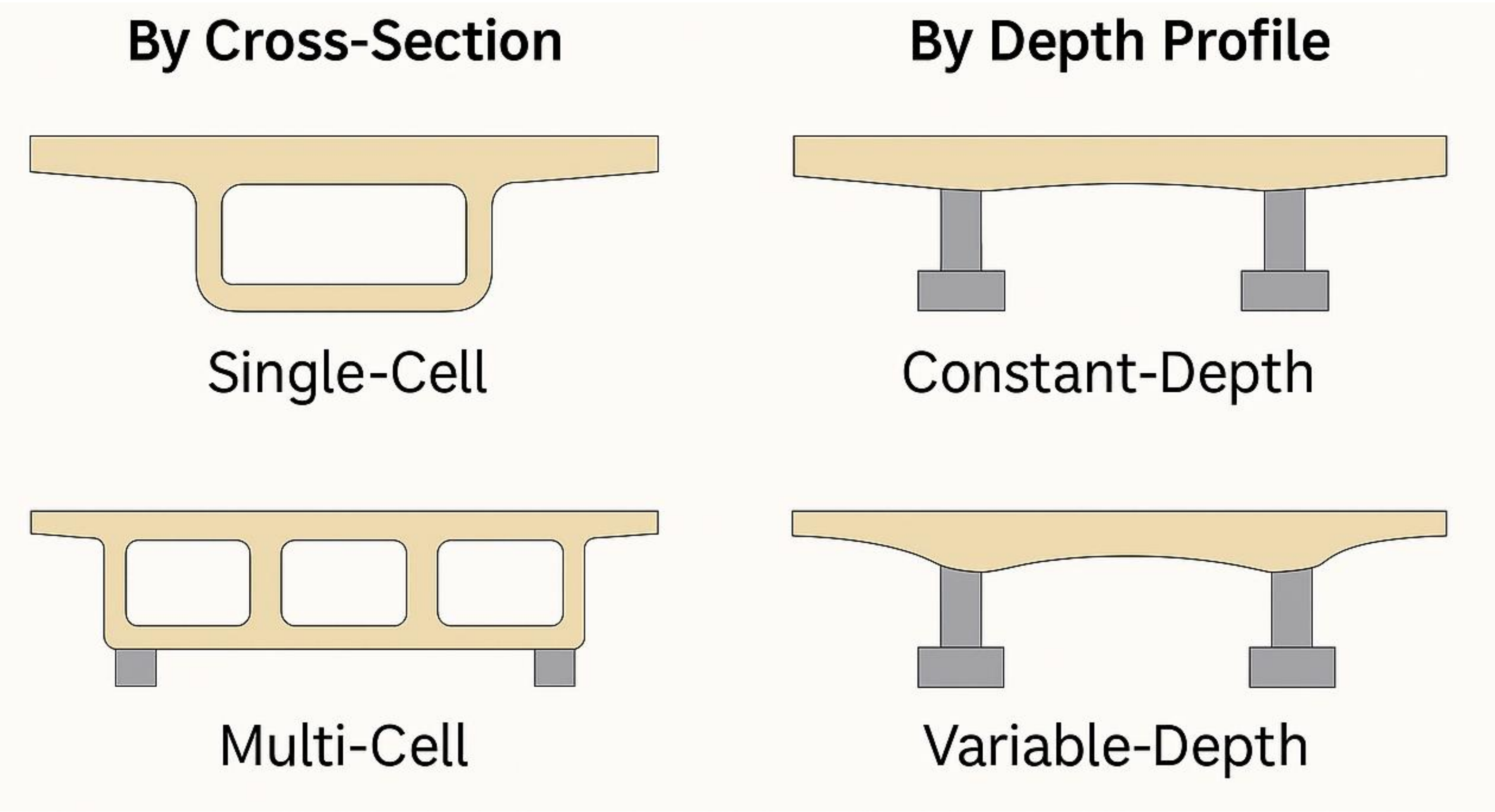
Factoring in maintenance and durability ensures long-term economic benefits

Box Girder Bridges

Overview of Concrete Box Girder Bridges

- Popular for modern highway, railway, and urban applications.
- Hollow box-shaped cross-section offers:
  - High torsional rigidity
  - Efficient load distribution
  - Long-span capabilities with fewer supports
- Durable and structurally efficient design.

Types of Box Girder Configurations



Construction Methods

- Cast-in-situ:
  - Built on-site using formwork; suitable for short/medium spans.
- Balanced cantilever:
  - Segments cast from piers outward; ideal for medium–long spans.
- Segmental construction:
  - Precast segments, match-cast and post-tensioned; fast and efficient for constrained sites.

Design Considerations & Advancements

- Factors influencing design:
  - Span length
  - Site conditions
  - Material availability
  - Environmental constraints
- Ongoing developments enhance:
  - Speed of construction
  - Sustainability
  - Resilience and lifecycle cost-efficiency

Design Challenges

The Optimization Challenge

- Prestressed concrete box girders are widely used for their efficiency and span capacity.
- Optimizing prestressing is complex due to:
  - Structural behavior
  - Material properties
  - Construction constraints
- Design must meet stress limits while minimizing cost and materials.

Structural & Loading Complexity

- Ideal tendon layout must counteract:
  - Dead loads, live loads, … etc.
- Multi-cell and variable-depth sections introduce:
  - Complex stress distributions

Impact of PS Profile

- With changing PS profiles, the following are affected:
  - Long-term Losses:
    - Creep & shrinkage
    - PS Steel Relaxation
  - Short-term Losses:
    - Friction & Wobble
    - Anchorage slip
    - Elastic Shortening
  - Secondary PS effect in continuous structures

Need for a Systematic Approach

- Current designs often rely on empirical or conservative methods.
- Consequently time & effort is consumed to reach the optimum PS arrangement.
- Goal of research: Develop an ANN-based optimization approach to efficiently achieve an optimized PS configuration, enhancing both structural performance and design productivity.

Acquiring Training Data

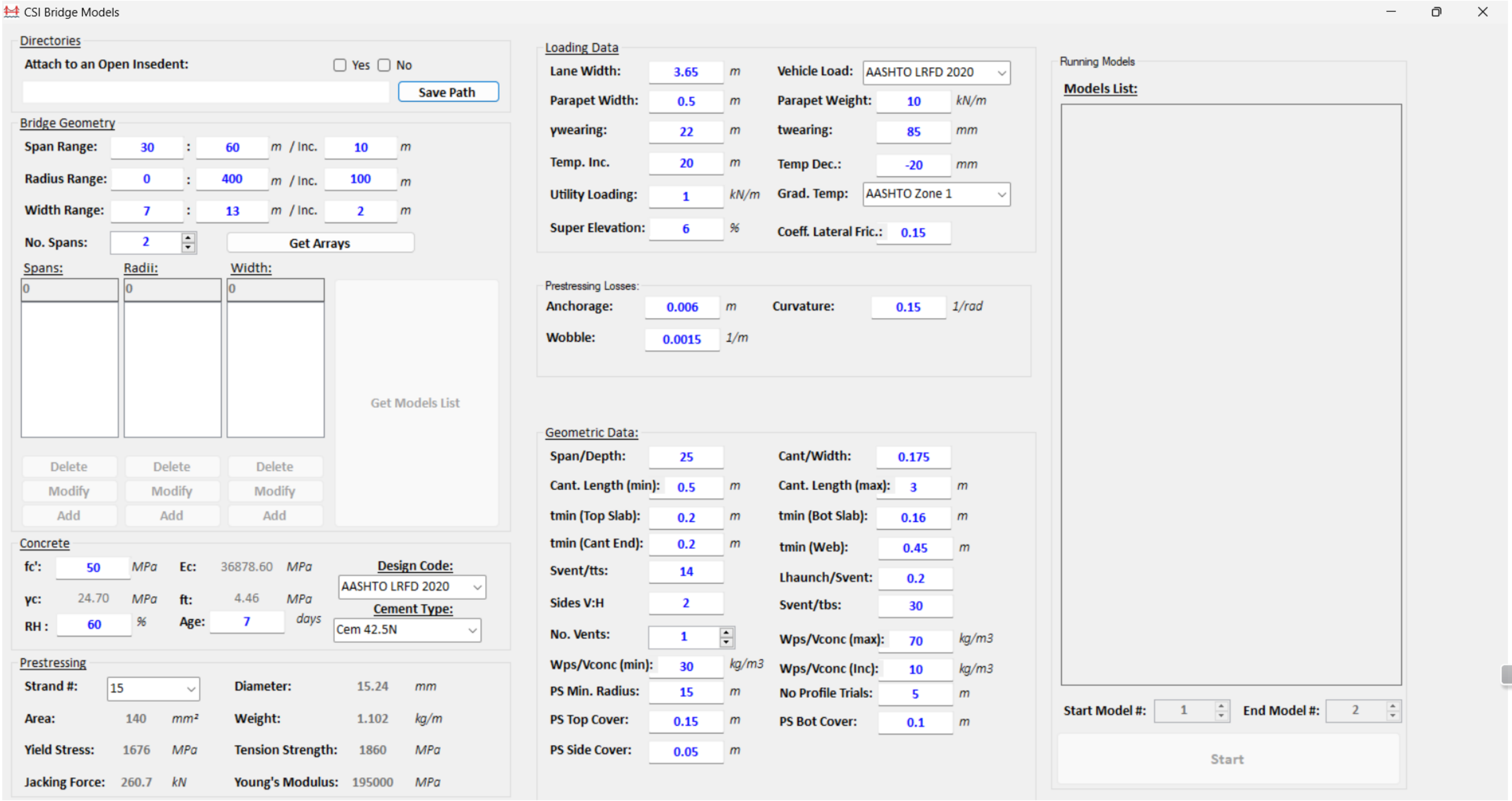
Training Dataset Requirement

- ANNs require large, verified datasets to learn meaningful structural behavior patterns.
- In bridge engineering, such data must reflect:
  - Realistic geometry
  - True boundary conditions
  - Accurate loading combinations

Why Automated Data Generation is Essential

- Challenge: This kind of data isn't readily available in design manuals or literature.
- Solution:
  - Use CSI Bridge software to generate thousands of validated analysis cases.
  - Ensures high-fidelity inputs and outputs for robust ANN training.
- Outcome: A data-driven foundation rooted in actual engineering analysis.

Data Generation Tool



Step 1: Parametric Model Initialization

- Input Parameters:
  - Span configuration
  - Girder type (single / multi cell)
  - Geometry: span lengths, widths, alignment radius
  - Tendon layout variables (eccentricities & area ratios ranges)
- Code Logic:
  - Define bridge superstructure template
  - Assign cross-section properties
  - Generate geometry using CSI Bridge objects

Step 2: Load Definition & Prestress Input

- Automated Load Case Generation:
  - Dead load (self-weight, parapet)
  - Live load (HL-93 or specified moving load)
  - Temperature gradient loads
  - Prestress load (short term losses coefficients)
- Load Combination Generation

Step 3: Result Extraction & Dataset Assembly

- Data Extracted per Run:
  - Stress at top and bottom fibers at key sections
- Storage Format:
  - CSV or txt format with tagged input-output pairs
  - Includes geometric and tendon parameters with resulting stresses
- Final Output: High-quality dataset ready for ANN training

Overview

Validating GA-Enhanced ANN Optimization

- Aim: Demonstrate that a Genetic Algorithm (GA) coupled with a nonlinear objective function can reliably fine-tune prestressing (PS) design when driven by pretrained ANNs.
- Target Structure: Concrete box-girder bridges.
- Key Deliverable: Minimum-area PS layout that meets design-code tensile-stress limits along the entire span.

ANN Training Framework

- Inputs to ANN
  - Geometry:
    - number of spans
    - horizontal-alignment radius
    - number of cells.
  - Prestressing:
    - total PS area
    - cable-profile eccentricities.
- Outputs from ANN
  - Maximum top & bottom-fiber stresses along each span.
- Training Platform: MATLAB® ANN Toolbox.
- Dataset: Automatically generated CSI Bridge models covering wide parametric ranges.

Three-Stage ANN Parametric Study

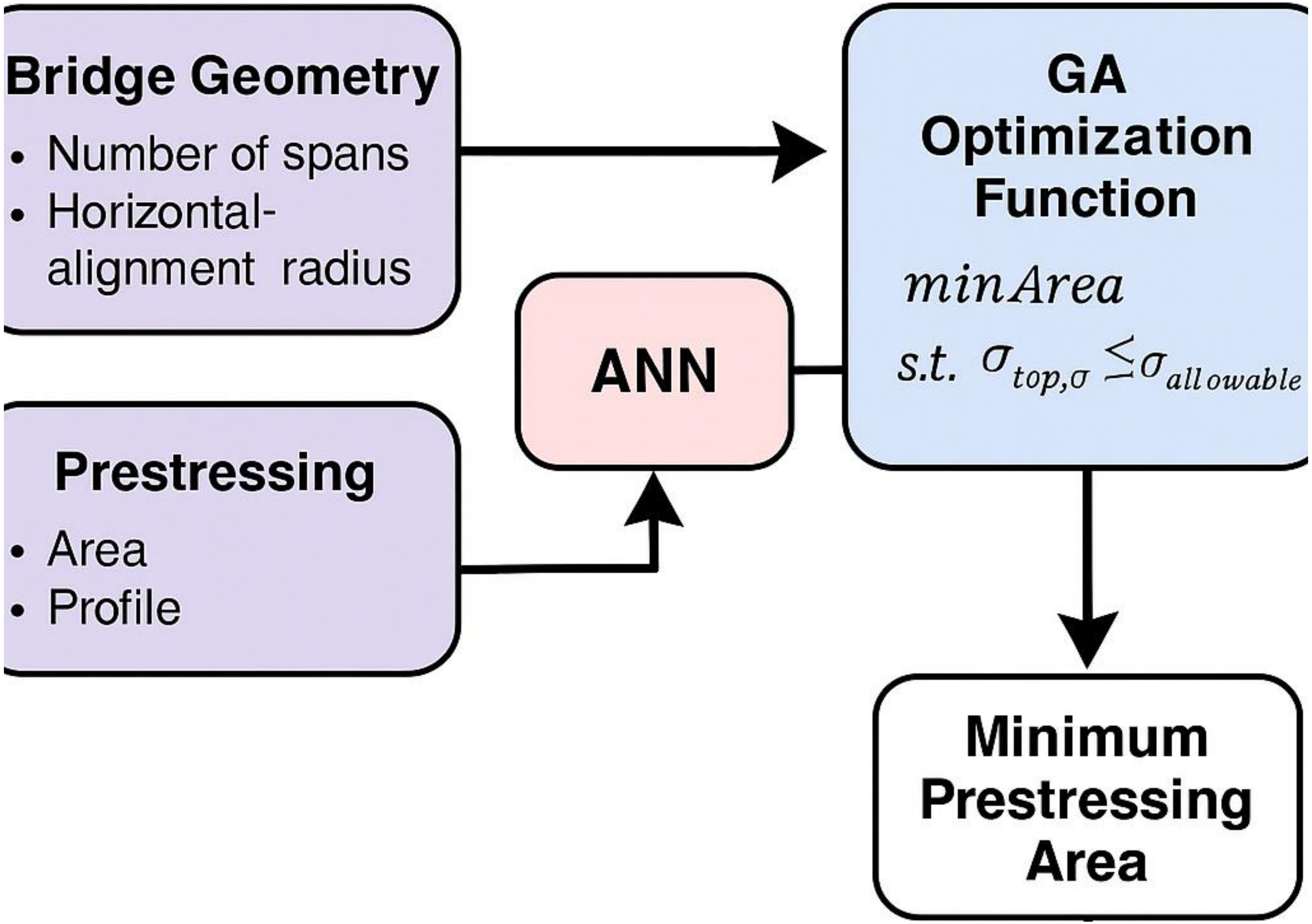
- Network-Type Selection
  - Tested: FFBPNN, CFBPNN, LRNN, Elman, NARX, RBFNN, GRNN → pick best performer.
- Training-Function Tuning
  - Compared TRAINLM, TRAINBR, TRAINBFG, CG variants, GD variants, TRAINRP, TRAINOSS, TRAINSCG → select best convergence / generalization.
- Architecture Optimization
  - Systematic sweep of hidden-layer count & neurons per layer to minimize validation MSE.

GA-Driven Prestress Optimization

- Decision Variables: PS area + eccentricity profile fed into trained ANN.
- Objective Function:

$$\min(A_{PS}) \rightarrow \sigma_{top\,\&\,bot} \approx \sigma_{allowable}$$

- GA Advantages
  - Robust global search for single-objective problems.
  - Minimum PS area–profile combinations the ANN alone cannot guarantee.


Bridge Geometry
• Number of spans
• Horizontal-alignment radius
Prestressing
• Area
• Profile
ANN
GA Optimization Function
$\min Area$
s.t. $\sigma_{top,\sigma} \leq \sigma_{allowable}$
Minimum Prestressing Area

Any Questions ???