

Prestressing Optimization Using ANN in Box-Girder Bridges

Enhancing Efficiency and Structural Integrity with AI



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Introduction



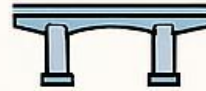
Bridges

- 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

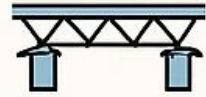


Classification

- Based on Structural Form



Beam Bridges



Truss Bridges

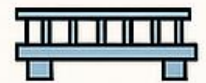


Arch Bridges



Cable-Stayed
Bridges

- Based on Function



Highway Bridges



Railway Bridges

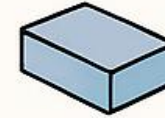


Pedestrian
Bridges



Aqueduct Bridges

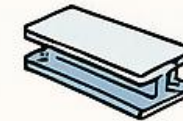
- Based on Material



Concrete Bridges



Steel Bridges

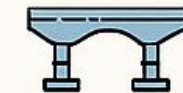


Composite Bridges



Timber Bridges

- Based on Construction Method



Cast-in-Situ Bridges



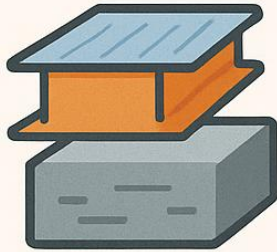
Precast Bridges



Segmental Bridges



Factors Influencing Economic Span Length



Material Availability & Cost

The choice of materials (concrete, steel, composite) impacts both initial and long-term expense



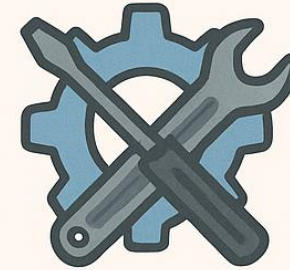
Construction Method

Techniques such as cast-in-situ, precast, or incremental launching influence overall cost and efficiency



Loading Conditions

Traffic demands, environmental factors (wind, seismic forces), and design standards affect the required structural capacity



Maintenance & Durability

While longer spans reduce the number of piers, they require stronger materials, influencing maintenance costs



Bridges Span Ranges

SHORT SPANS (Up to 50m)

Reinforced concrete slab bridges and simple beam bridges



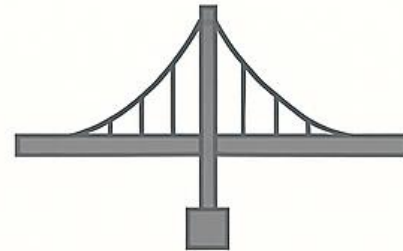
MEDIUM SPANS (50m–200m)

Prestressed concrete girders, box girders, Truss

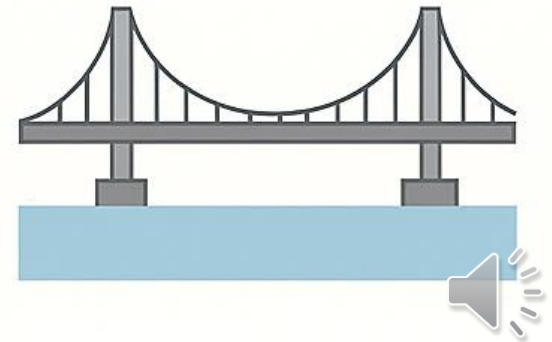


LONG SPANS (200m–1,000 m)

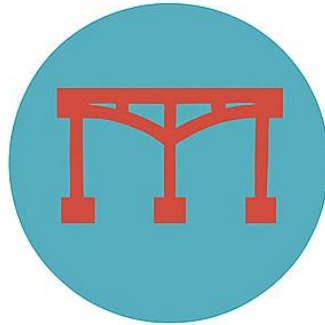
Cable-stayed bridges



SUSPENSION BRIDGES

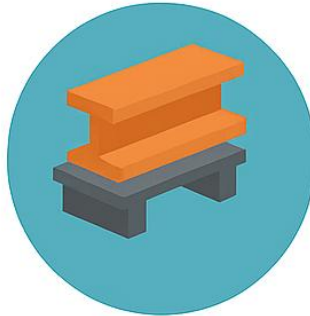


Bridges Cost Optimization Strategies



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



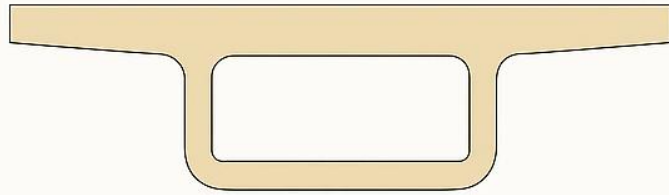
Overview of Concrete Box Girder Bridges

- 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.

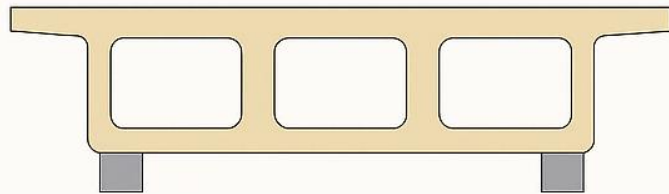


Types of Box Girder Configurations

By Cross-Section

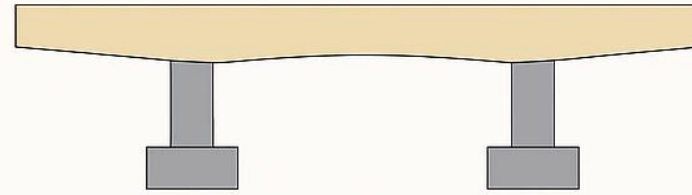


Single-Cell

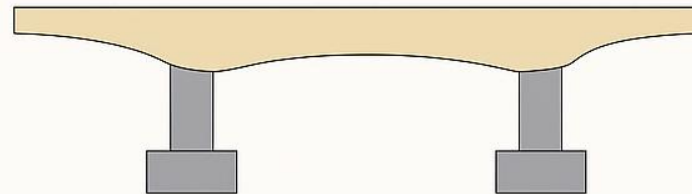


Multi-Cell

By Depth Profile



Constant-Depth



Variable-Depth



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

CSI Bridge Models

Directories

Attach to an Open Insedent: ☐ Yes ☐ No

Save Path

Bridge Geometry

Span Range: : m / Inc. m

Radius Range: : m / Inc. m

Width Range: : m / Inc. m

No. Spans:

Get Arrays

Spans:

Radii:

Width:

0

0

0

Get Models List

Delete

Delete

Delete

Modify

Modify

Modify

Add

Add

Add

Concrete

fc': MPa Ec: 36878.60 MPa

yc: 24.70 MPa ft: 4.46 MPa

RH: % Age: days

Design Code: AASHTO LRFD 2020

Cement Type: Cem 42.5N

Prestressing

Strand #:

Area: 140 mm²

Yield Stress: 1676 MPa

Jacking Force: 260.7 kN

Diameter: 15.24 mm

Weight: 1.102 kg/m

Tension Strength: 1860 MPa

Young's Modulus: 195000 MPa

Loading Data

Lane Width: m

Parapet Width: m

ywearing: m

Temp. Inc.: m

Utility Loading: kN/m

Super Elevation: %

Vehicle Load: AASHTO LRFD 2020

Parapet Weight: kN/m

twearing: mm

Temp Dec.: mm

Grad. Temp: AASHTO Zone 1

Coeff. Lateral Fric.:

Prestressing Losses:

Anchorage: m

Wobble: 1/m

Curvature: 1/rad

Geometric Data:

Span/Depth:

Cant. Length (min): m

tmin (Top Slab): m

tmin (Cant End): m

Svent/tts:

Sides V:H:

No. Vents:

Wps/Vconc (min): kg/m³

PS Min. Radius: m

PS Top Cover: m

PS Side Cover: m

Cant/Width:

Cant. Length (max): m

tmin (Bot Slab): m

tmin (Web): m

Llaunch/Svent:

Svent/tbs:

Wps/Vconc (max): kg/m³

Wps/Vconc (Inc): kg/m³

No Profile Trials: m

PS Bot Cover: m

Running Models

Models List:

Start Model #:

End Model #:

Start

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.

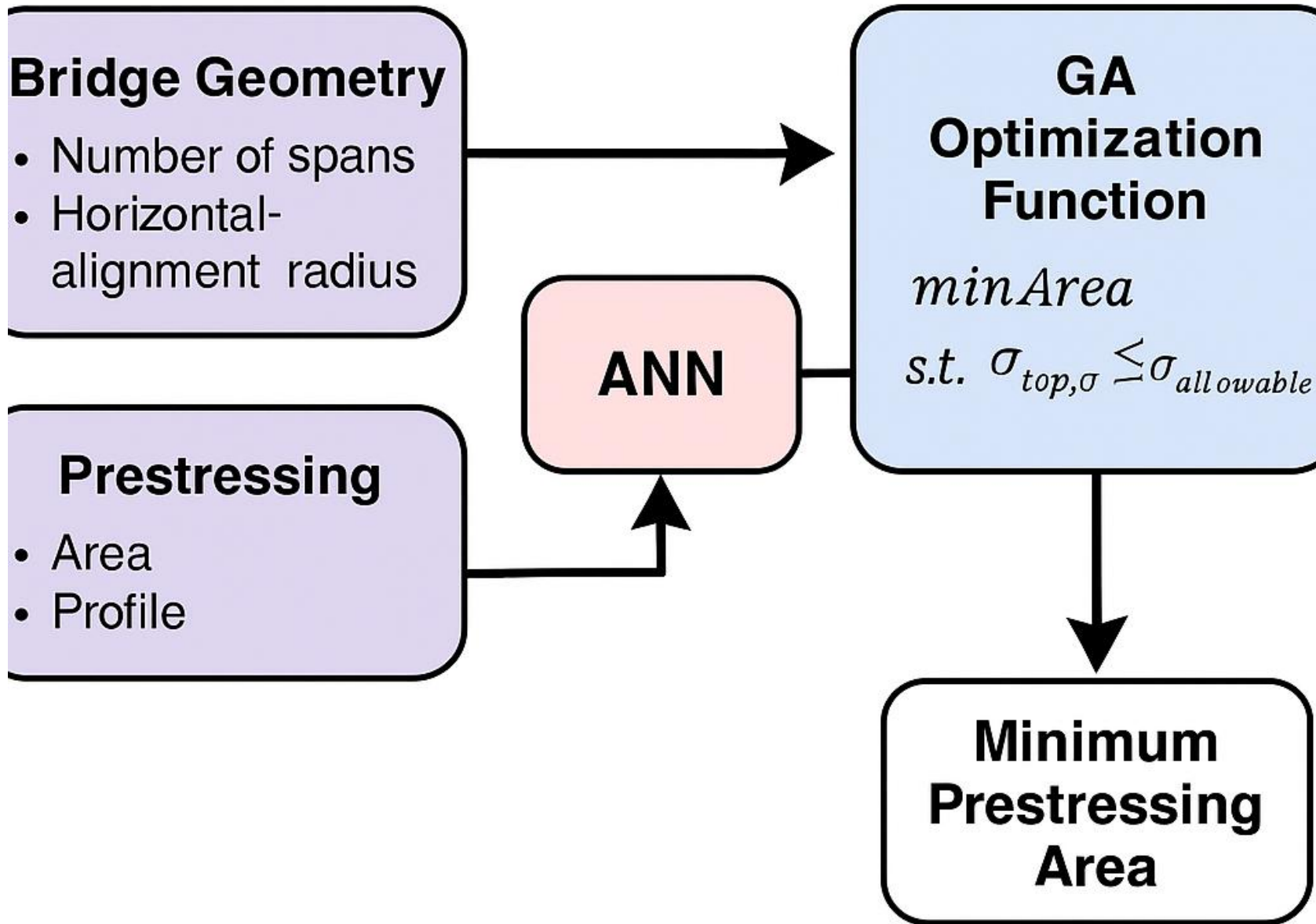
- Objective Function:

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

- GA Advantages

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





Any Questions ???

