

Anatomy of a Steel Girder Bridge System



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Course Description

This course provides an in-depth exploration of the structural, mechanical, and material components that define steel girder bridge systems, a common choice for medium- to long-span bridges in highway and railway infrastructure.

Emphasizing structural engineering principles, this course examines the individual and interconnected roles of girders, bearings, decks, diaphragms, bracing, connections, and support systems. It also addresses fabrication and erection considerations, corrosion protection methods, and maintenance requirements essential to the long-term functionality of steel girder bridges.

Course Objectives

Upon completion of this course, participants will be able to:

- Understand the primary structural components of a steel girder bridge system and their functions
- Analyze the roles of superstructure and substructure elements, including connection and bearing systems
- Identify design considerations related to load transfer, fabrication, erection, and inspection
- Examine corrosion protection techniques and long-term maintenance strategies
- Interpret the influence of design codes, material specifications, and construction practices on bridge system performance

Intended Audience

This course is appropriate for civil engineers, structural engineers, bridge design specialists, transportation infrastructure professionals, and any other licensed engineers engaged in the design, inspection, rehabilitation, or construction of bridge systems. It qualifies for continuing education credit across multiple engineering disciplines.

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Chapter 1: Introduction to Steel Girder Bridge Systems

Steel girder bridge systems have become one of the most widely used structural solutions for medium- to long-span bridge crossings in the modern era of civil and transportation infrastructure. Their utility stems from a combination of strength, versatility, cost-effectiveness, and relative ease of construction compared to alternative materials or systems.

This chapter explores the evolution of steel girder bridges, identifies their typical configurations, and distinguishes between various girder types used in structural practice.

Historical Context and Development

The use of steel in bridge construction dates back to the late 19th century, a period during which advances in metallurgy and manufacturing made steel a reliable and economical material for large-scale structures.

Early bridge designs employed riveted steel components, transitioning over time to welded and bolted systems as design philosophies and construction techniques matured. The widespread adoption of the plate girder bridge was largely driven by its ability to be fabricated in a controlled environment and assembled efficiently in the field.

Steel girder bridges gained dominance in the 20th century through their use in highway and railroad applications, particularly in the post-war era when state departments of transportation sought economical, repeatable bridge designs suitable for mass implementation. Improvements in high-strength low-alloy steels, coupled with advances in welding, led to increased girder spans and reduced section weights without sacrificing structural integrity.

Common Applications and Configurations

Steel girder bridges are commonly employed in the following contexts:

- Highway overpasses and interchanges
- Railroad crossings
- River or channel spans where vertical clearance or navigation is required
- Urban viaducts and elevated expressways
- Pedestrian and bicycle overcrossings (using smaller-scale girders)

The configuration of a steel girder bridge typically consists of a superstructure made up of multiple longitudinal steel girders supporting a deck system, which may be composed of reinforced concrete or open steel grating. The girders are typically parallel and uniformly spaced to distribute loads symmetrically across the span.

Common types of bridge layouts include:

- Simple-span girder bridges, where girders rest on supports at each end
- Continuous-span bridges, where girders are continuous over multiple supports for structural efficiency

- Skewed bridges, where supports are placed at an angle due to geometric constraints
- Curved girder bridges, which require special torsional considerations in both design and detailing

Types of Steel Girders: Plate Girders vs. Rolled Sections

Two primary girder types dominate steel bridge construction: rolled steel beams (commonly W-shapes) and plate girders.

Rolled steel sections are factory-formed shapes produced in standard sizes, such as W14x90, and are used primarily in shorter-span bridges or pedestrian crossings where the required strength and depth can be met using available profiles. Their use is limited by the maximum depth that can be achieved with a rolled section, which is generally around 36 inches.

Plate girders, on the other hand, are custom-fabricated structural members created by welding together steel plates to form an I-shaped cross-section. This fabrication allows for optimized girder depth, variable web thicknesses, and flange proportions tailored to meet the moment and shear demands of longer spans. Plate girders dominate in spans ranging from 40 to 200 feet, and beyond when continuity or composite action with the deck is utilized. Their economy of design and structural efficiency make them a preferred choice in many state and federal bridge projects.

Further distinctions include haunched girders, where the depth of the girder increases near the supports to resist higher bending moments, and box girders, which enclose the structural member and are used when torsional stiffness is critical, such as in curved bridges.

As the foundation of the bridge superstructure, steel girders define not only the load-bearing capacity of the structure but also its aesthetic character and constructability. A clear understanding of the classification and behavior of girder types is essential to designing systems that meet performance, safety, and economic criteria.

Chapter 2: Superstructure Overview

The superstructure of a steel girder bridge encompasses all the components that span between the supports and directly carry the applied loads. This includes the primary steel girders, the bridge deck, intermediate bracing systems such as diaphragms and cross-frames, and other secondary steel members that work collectively to ensure structural integrity, load distribution, and stability under service and environmental conditions. Understanding how these elements function individually and as a system is central to grasping the behavior of steel girder bridge designs.

Main Girders Layout, Spacing, and Profile

The primary load-carrying elements in a steel girder bridge are the longitudinal girders. These girders are typically arranged parallel to one another along the length of the bridge and support the deck system. The number of girders used depends on several factors including span length, roadway width, girder depth, and live load requirements.

Spacing between girders is a critical design parameter. Wider spacing allows for fewer girders, which can reduce material costs but increases the load carried by each girder and the width of the deck slab between supports. Typical girder spacings range from 6 to 12 feet, though wider spacing can be used when deck thickness and reinforcement are sufficient to handle increased bending and shear between girders.

Girders can be of constant depth or variable depth. Constant-depth girders are simpler to fabricate and erect, but variable-depth girders, such as haunched profiles, provide increased moment capacity where bending stresses are highest, typically near midspan or supports. The vertical profile of the girders is coordinated with roadway design to provide the necessary clearances and vertical grades.

Deck Systems Concrete Decks, Steel Grating, and Composite Action

The bridge deck serves as the roadway or pathway surface and is typically composed of reinforced cast-in-place concrete, though open steel grating or orthotropic steel plates are used in specialized applications. The deck is supported by and transfers loads to the longitudinal girders.

In most modern designs, the concrete deck acts compositely with the steel girders, meaning the concrete slab and steel girders work together to resist bending. This composite action is achieved by using shear connectors, usually welded studs, which tie the steel flange to the concrete deck and prevent slippage between the two materials. Composite construction significantly increases the flexural stiffness and strength of the girder system.

Concrete decks are reinforced to control cracking and resist tensile forces. They are often cast in place over formwork supported by stay-in-place panels, such as metal decking or precast concrete planks. Proper curing and drainage are essential to prevent premature deterioration due to moisture and chloride intrusion.

Cross-Frames and Diaphragms: Bracing for Lateral Stability

Cross-frames and diaphragms are transverse members that connect adjacent girders and provide lateral bracing. Their primary purpose is to stabilize the girders against lateral-torsional buckling during both construction and service conditions. They also help distribute live loads transversely, particularly in curved or skewed bridges where torsional forces are non-negligible.

Cross-frames are typically composed of angular or tubular members arranged in a K-frame or X-frame pattern, connecting the webs of adjacent girders at regular intervals. In straight bridges, they primarily serve to prevent girder rotation. In horizontally curved bridges, they also resist warping and twisting induced by eccentric loading.

Diaphragms may be fabricated from rolled shapes or steel plates and are more commonly used in shorter-span bridges. They serve similar bracing functions and are often aligned with intermediate stiffeners on the girder webs.

The spacing of cross-frames or diaphragms varies but is commonly on the order of 15 to 25 feet. In continuous spans, bracing is especially critical near field splices, abutments, and midspan locations where flexural and torsional demands are highest.

Secondary Steel Members and Detailing Practices

Secondary structural members in the superstructure include lateral bracing, lateral restraints, stringers in multi-level systems, and sidewalk brackets or utility supports. These components may not carry primary traffic loads but are essential for stability, utility accommodation, or support of non-structural elements such as railings and lighting systems.

Lateral bracing beneath the deck, especially in shallow girders, adds torsional rigidity and can prevent vibration or flutter under wind loading. In bridges with utilities, supplemental brackets and plates are designed to support conduits, waterlines, or signal cables.

Detailing practices for superstructure members aim to enhance constructability, reduce maintenance needs, and promote durability. This includes avoiding inaccessible welds, providing drainage paths, and minimizing crevices or pockets where debris or moisture can accumulate. Sloped or cambered top flanges promote water runoff, reducing the likelihood of corrosion.

Connection details between girders and cross-frames, and between girders and decks, must also consider fatigue performance, especially in high-cycle environments such as highway bridges. Fillet welds, bolted flange plates, and bearing stiffeners must be detailed according to fatigue category classifications in AASHTO LRFD specifications.

The coordinated interaction between girders, deck, bracing systems, and secondary elements determines not only the structural performance but also the construction sequencing and long-term durability of the bridge system. A detailed understanding of these elements provides the basis for accurate modeling, efficient design, and effective inspection throughout the life cycle of the bridge.

Chapter 3: Substructure Components

The substructure of a steel girder bridge provides the essential vertical support for the superstructure and transfers loads safely to the ground. These components anchor the bridge in place, ensure alignment, and accommodate both static and dynamic loads. While often less visible than the superstructure, the substructure's design is vital to the overall functionality and longevity of the bridge system.

This chapter outlines the primary substructure elements of a steel girder bridge, including abutments, piers, and bearing devices. It also explores how loads are transmitted from the superstructure to the foundation, as well as detailing considerations that impact performance and maintenance.

Pier and Abutment Systems

The abutments and piers form the structural base of the bridge. Abutments are located at the ends of the bridge and support the ends of the girders while retaining the earth fill behind them. They often include wing walls that extend outward to hold back the approach embankment. Piers are intermediate supports that transfer loads to deep or shallow foundations between spans in multi-span bridges.

Abutments may be classified as stub, semi-integral, or integral, depending on how they interact with the superstructure. Stub abutments are independent from the bridge deck, typically supported by piles or spread footings. Integral and semi-integral abutments are designed to interact with the superstructure, accommodating thermal expansion and minimizing the need for deck joints.

Piers are typically designed as solid walls or column bents. Wall piers are robust and resist loads along their entire length, while column bents—consisting of one or more vertical columns connected by a cap beam—are more commonly used in urban and highway applications where clearance is a concern.

The configuration of abutments and piers is influenced by soil conditions, seismic risk, hydraulic considerations, and span arrangement. Substructure elements must resist not only vertical loads from the superstructure but also lateral earth pressures, impact forces, and thermal or seismic displacements.

Bearing Devices and Articulation

Bearings are interface devices located between the superstructure and substructure that allow controlled movement and transfer of loads. They are essential to the articulation of the bridge, accommodating structural deflections, thermal expansion and contraction, shrinkage, and creep.

Types of bridge bearings include:

- **Elastomeric bearings**, made of layered rubber and steel shims, which allow rotation and limited translation. These are common in short- to medium-span steel girder bridges due to their simplicity and durability.

- **Pot bearings**, which use confined elastomeric pads within a steel pot to permit large rotations. These are used in heavier or longer-span bridges.
- **Disc bearings**, which incorporate a polyurethane disc for high-rotation flexibility.
- **Rocker and roller bearings**, older designs that allow large displacements, although they have fallen out of favor due to maintenance complexity.

Fixed bearings are typically placed at one abutment or pier to restrain longitudinal movement, while expansion bearings are used at other support points to accommodate movement. The articulation scheme must ensure that thermal movement is absorbed without generating excessive stresses or binding within the structure.

The proper selection, alignment, and maintenance of bearings are crucial. Misaligned bearings or neglected bearing replacements can lead to deck cracking, excessive vibration, or even girder misalignment over time.

Load Path Considerations Between Superstructure and Foundation

A critical function of the substructure is to channel the complex set of loads originating in the superstructure down to the soil or bedrock.

This load path includes:

- **Dead load**, from the self-weight of the superstructure
- **Live load**, including vehicles, pedestrians, and temporary loads
- **Thermal and shrinkage effects**, inducing horizontal displacements
- **Seismic and wind loads**, often acting laterally or torsionally
- **Braking and acceleration forces**, particularly on highway bridges
- **Hydraulic pressures**, including scour and buoyancy in submerged piers

Load transfer begins with the bridge deck and girders, which distribute vertical and horizontal forces to the bearings. The bearings transfer these forces to the piers or abutments, which in turn distribute them to the foundation—whether piles, drilled shafts, caissons, or spread footings.

Foundations must be carefully engineered based on geotechnical investigation. The load-bearing capacity, settlement characteristics, and susceptibility to scour or liquefaction must be accounted for. Proper foundation selection also affects how the bridge responds to differential movement and long-term settlement.

Structural redundancy in the load path is critical for resilience, particularly in the event of localized damage or extreme events. Design practices increasingly emphasize robustness in substructure-to-superstructure connections to ensure continued functionality even if an element becomes compromised.

Ultimately, the substructure serves as the invisible yet indispensable partner of the superstructure, enabling the full function of the bridge by ensuring that all loads are safely and reliably carried into the ground. Its design, detailing, and execution are critical to the bridge's structural integrity and long-term serviceability.

Chapter 4: Material Selection and Steel Properties

The performance, durability, and economy of a steel girder bridge system are heavily dependent on the quality and characteristics of the steel used in its construction. Material selection must account not only for structural strength but also for fabrication compatibility, fatigue resistance, corrosion performance, and behavior under service and environmental conditions.

This chapter explores the types of structural steel typically used in bridge construction, their mechanical properties, and how they influence the design and long-term reliability of girder systems.

Grades of Structural Steel Used in Girders

The selection of steel grade for bridge girders is governed primarily by the requirements for strength, ductility, weldability, and resistance to environmental degradation.

Structural steel used in bridges must conform to standards established by the American Association of State Highway and Transportation Officials (AASHTO) and the American Society for Testing and Materials (ASTM).

Commonly used steel grades include:

- **ASTM A709 Grade 50:** A widely used high-strength, low-alloy structural steel with a minimum yield strength of 50 ksi. This grade is often the default choice for standard bridge applications due to its balance of strength and ductility.
- **ASTM A709 Grade 50W:** A weathering steel variant that forms a protective oxide layer when exposed to the atmosphere, reducing the need for painting. It is used where corrosion resistance is needed and aesthetics or cost limitations prohibit frequent recoating.
- **ASTM A709 Grade HPS 70W:** A high-performance steel with a minimum yield strength of 70 ksi and improved weldability, fracture toughness, and weathering resistance. HPS steels are used in longer spans and critical structures where enhanced performance is necessary.
- **ASTM A709 Grade 100 or 100W:** Ultra-high-strength grades used selectively in major infrastructure projects, though less commonly due to their fabrication complexity.

Engineers must select steel grades based on span length, loading conditions, fabrication preferences, and environmental exposure. Factors such as the presence of de-icing salts, humidity, and freeze-thaw cycles also influence the choice of steel.

Welding and Bolting Considerations

The fabrication of steel girders involves numerous connections, either through welding or bolting. Material compatibility and mechanical behavior during and after welding or bolting are critical to the structural performance of the system.

Welded connections are commonly used in shop-fabricated plate girders, especially in flange-to-web junctions and flange splices. Modern bridges rely on submerged arc

welding (SAW), flux-cored arc welding (FCAW), and shielded metal arc welding (SMAW) techniques. Steel selected for welding must exhibit adequate toughness and low susceptibility to cracking under high heat input.

Fracture toughness is evaluated using Charpy V-notch (CVN) impact tests at specified temperatures to ensure performance in cold weather and high-stress environments. HPS grades are engineered to provide superior toughness, reducing the risk of brittle fracture.

Bolted connections, using high-strength bolts such as ASTM A325 or A490, are used for field splices, cross-frame attachments, and bracing systems. Bolted connections are either slip-critical (friction-type) or bearing-type, depending on the design intent. Slip-critical connections prevent slip under service loads, while bearing-type connections permit minor deformations.

Bolt spacing, hole tolerance, and pretensioning procedures must adhere to established codes and inspection protocols. Improper bolt installation or insufficient torque can lead to premature connection failures or fatigue cracking.

Fatigue, Fracture Toughness, and Performance in Temperature Extremes

Steel bridges are subjected to millions of load cycles over their service life. Fatigue behavior becomes a dominant design consideration, particularly at welded and bolted details where stress concentrations are highest.

Fatigue-prone locations include:

- Weld terminations
- Stiffener-to-web connections
- Flange cutouts
- Bolted splice plates

AASHTO classifies fatigue details according to their susceptibility to cracking. Category A details have excellent fatigue resistance, while Category E and below are discouraged or require special treatment.

Fracture toughness is critical in cold climates, where steel may become brittle and susceptible to sudden cracking under tensile stress. Charpy testing ensures that steel exhibits ductile behavior at service temperatures. The selection of fracture-critical members (FCMs) requires detailed inspection protocols, often including ultrasonic testing, to verify defect-free welds and materials.

Thermal performance is another vital concern. Steel expands and contracts with temperature changes, inducing stresses at connections and bearings. Differential movement can lead to joint distress, cracking, and misalignment. Bridges must be designed with adequate articulation and expansion devices to accommodate thermal effects without overstressing structural elements.

Environmental exposure can also affect material performance. Corrosive environments accelerate steel degradation, especially in the presence of chlorides or sulfates.

Weathering steels may be used to reduce maintenance, though they must be detailed to allow uniform oxidation and avoid moisture entrapment.

Material behavior must be evaluated over the full expected lifespan of the bridge, typically 75 years or more. Proper steel selection, fabrication control, and protective measures together form the foundation of a durable and resilient girder system.

Chapter 5: Connection Systems and Load Path Continuity

The effectiveness of a steel girder bridge system is critically dependent on the integrity of its connection systems. These connections ensure that the various components of the bridge function together as a single, unified structure, capable of efficiently transferring loads and resisting external forces. Proper detailing, fabrication, and installation of connection elements are essential to achieving structural continuity, minimizing stress concentrations, and maintaining service performance over the lifespan of the bridge.

This chapter explores the primary connection systems used in steel girder bridges, including shear connectors, splices, and joints, and evaluates their role in structural performance.

Shear Connectors and Composite Action

In modern girder bridge systems, composite action between the steel girders and the concrete deck is essential for structural efficiency. Composite behavior allows the concrete deck to resist compressive stresses while the steel girders handle tensile forces, significantly increasing the flexural capacity of the bridge system.

Shear connectors are the mechanical devices that ensure the bond between the steel and concrete components. These are typically **headed shear studs**, welded directly to the top flange of the steel girder before concrete placement. The studs protrude into the concrete deck and resist horizontal slippage through bearing and interlock.

The number, spacing, and placement of shear connectors are determined by composite section analysis and are governed by AASHTO LRFD Bridge Design Specifications. The design must ensure that sufficient longitudinal shear capacity is provided to prevent slip under all service and ultimate load conditions. Additional detailing is required around regions of concentrated loads, changes in deck geometry, or where the girder curvature increases the potential for uplift or rotation.

In bridges where composite action is not desired—either due to construction sequence or maintenance requirements—shear connectors may be omitted, and the girders are designed as non-composite elements. This is less common in modern practice due to the reduced efficiency of non-composite sections.

Field Splices and Shop Splices

Due to limitations in transportation and handling, girders are often fabricated in segments and spliced together either in the fabrication shop or at the bridge site. These splices serve a structural function and must be designed to develop the full moment, shear, and axial capacity of the member at the splice location.

Shop splices are typically welded and executed under controlled conditions, allowing for high-quality, continuous welds with precise alignment. These are generally placed in lower-stress regions of the girder to minimize fatigue risk.

Field splices are most often **bolted connections**, using high-strength bolts in either slip-critical or bearing-type configurations. These connections must be carefully detailed and assembled in the field to ensure alignment and structural integrity. Field splices are usually located at points of lower moment to reduce the demand on the connection and to ease construction.

The splice plates used in bolted field connections must be detailed to avoid eccentricities and to maintain the continuity of the flanges and web. Flange splices are particularly critical, as they carry the bulk of the bending forces. Web splices, while generally less demanding, must still transfer shear effectively.

Inspection of field splices includes verifying bolt torque, alignment, plate dimensions, and presence of corrosion inhibitors. Improper assembly can lead to localized stresses, fatigue cracks, or misalignment of the girder system.

Expansion Joints and Movement Allowances

Steel bridges are subject to significant thermal expansion and contraction, as well as movements induced by creep, shrinkage, and live loads. Expansion joints are critical elements that accommodate this movement without causing damage to the deck or superstructure components.

Expansion joints are typically placed at abutments or between spans in continuous bridges.

Common types include:

- **Strip seal joints**, consisting of a neoprene seal compressed between steel edge rails
- **Finger joints**, using interlocking steel plates that slide over one another
- **Modular expansion joints**, designed for larger movements and incorporating multiple support bars and elastomeric elements

The type of joint selected depends on the anticipated movement range, expected traffic loading, and environmental exposure. Joints must be carefully designed to prevent leakage, which can introduce moisture and deicing salts to the substructure and bearing areas, accelerating corrosion.

Improperly functioning joints are one of the most common sources of long-term maintenance problems in steel bridges. They must be accessible, replaceable, and designed to accommodate not just movement, but also rotation, skew, and vibration.

In addition to deck joints, **movement allowances** must be provided at bearings and expansion devices. Bearings are typically designed with fixed and expansion configurations to guide movement in controlled directions. Restraints such as keeper plates, guides, and anchors are employed to manage movement and maintain system stability.

Load Path Continuity and Structural Behavior

Continuity in the load path is essential for efficient structural performance. Bridges may be designed as simple-span systems or as **continuous-span systems**, where girders span over intermediate supports. Continuity improves structural efficiency, reduces mid-span moments, and enhances redundancy.

For continuous spans, the connection details over piers must be carefully considered to develop negative moment capacity and ensure rotation compatibility. Cast-in-place continuity diaphragms, continuity plates, and reinforcement bars embedded into the deck are often used to achieve moment continuity.

Redundant load paths enhance the resilience of the bridge system by providing alternative routes for load transfer in the event of localized damage. This is especially important in fracture-critical locations, where failure of a single member could lead to system-wide collapse.

Designing for continuity requires precise alignment of girders, tight fabrication tolerances, and proper field assembly. Inadequate execution can result in unintended load concentrations, excessive deflections, or even instability.

In summary, connection systems are not merely mechanical junctions—they are integral to the structural concept of the bridge. They influence how loads are distributed, how forces are resisted, and how the system performs under service and extreme conditions. High-quality connection design and construction are central to achieving a safe, efficient, and durable steel girder bridge.

Chapter 6: Erection and Construction Considerations

The process of erecting a steel girder bridge involves complex planning, precise execution, and coordination among designers, fabricators, contractors, and inspectors. Successful construction requires attention to temporary stability, sequencing, quality control, and safety.

This chapter covers key factors influencing the fabrication, transport, lifting, placement, and alignment of steel girders and associated components, as well as field quality assurance procedures critical to the long-term performance of the bridge.

Fabrication Tolerances and Cambering

Steel girders are fabricated off-site under controlled conditions. To meet design intent, fabricators must adhere to strict dimensional tolerances regarding length, depth, flange and web thickness, and hole placement for connections. Deviations beyond tolerance can lead to misalignment, connection difficulties, or increased stresses in the field.

Girder cambering—the intentional vertical curvature introduced during fabrication—compensates for dead load deflections once the bridge is in service. Camber is calculated based on predicted dead load deflections and erection procedures and is typically applied by controlled heating or cold bending.

Accurate cambering is essential to achieve a smooth finished deck profile and proper drainage slopes. Over- or under-cambering may result in uneven deck thickness, increased construction difficulty, or long-term performance issues.

Lifting, Placement, and Alignment Strategies

Due to their size and weight, steel girders require specialized equipment and careful handling during transport and erection. Cranes, barges, or heavy-haul trailers may be employed depending on site constraints.

Erection plans must address:

- Proper lifting points to avoid damaging the girder or inducing unwanted stresses
- Temporary bracing during lifting and placement to prevent lateral-torsional buckling
- Sequential erection to maintain structural stability at all times
- Alignment procedures using laser surveying, total stations, or optical instruments

Temporary bracing and lateral support are critical throughout erection to prevent instability caused by incomplete structural systems. Bracing locations and sequences are typically specified in erection drawings and must be strictly followed.

Girders must be placed accurately on bearings with vertical and horizontal alignment within specified tolerances to ensure proper load transfer and fit of subsequent components such as the deck and cross-frames. Misalignment can induce secondary stresses and complicate joint detailing.

Field Quality Control and Tolerances

Field inspections and quality control are indispensable to verify conformance with design and fabrication specifications.

Inspections include:

- Dimensional checks of girder placement and alignment
- Verification of bearing installation and leveling
- Inspection of bolt torques and weld quality at splices and connections
- Examination of temporary bracing and stability measures
- Documentation of deviations and corrective actions

Non-destructive testing (NDT), such as ultrasonic or magnetic particle inspection, may be performed on critical welds and connections to detect flaws.

Tolerance limits for elevation, lateral position, and rotation are typically defined by design codes and project specifications, often in the range of $\pm 1/4$ inch vertically and horizontally for girder placement.

Quality assurance must also address surface preparation and protective coating application following erection to prevent corrosion initiation in exposed or disturbed areas.

Temporary Bracing and Stability

Before the deck and cross-bracing are installed, girders are susceptible to lateral-torsional buckling due to their slenderness and the absence of full restraint. Temporary bracing systems, including lateral supports and diagonal bracing between girders, must be installed according to erection plans.

Properly designed temporary bracing maintains girder stability throughout lifting, placement, and deck construction. Failure to provide adequate bracing has historically caused catastrophic collapses during erection.

Bracing must be removed carefully once the superstructure gains full structural integrity through deck and cross-frame installation.

This chapter underscores that construction is an integral part of the bridge's life cycle, with decisions made in the field having long-lasting implications for safety and durability. Meticulous planning, adherence to tolerances, and quality assurance are essential pillars of successful steel girder bridge erection.

Chapter 7: Corrosion Protection and Surface Treatments

Steel, while offering excellent strength and versatility for bridge construction, is inherently susceptible to corrosion when exposed to moisture, oxygen, salts, and other environmental agents. Corrosion not only reduces the structural capacity of steel components but also accelerates deterioration and increases maintenance costs. Protecting steel girders and associated elements from corrosion is therefore a critical aspect of bridge design, fabrication, and maintenance.

This chapter reviews common corrosion mechanisms affecting steel girder bridges and the principal methods employed to prevent or mitigate corrosion throughout the structure's service life.

Corrosion Mechanisms in Steel Bridges

Corrosion of steel typically results from electrochemical reactions between iron in the steel and environmental elements. The most common form is uniform corrosion, where the metal surface gradually oxidizes and thins. However, other localized corrosion forms such as pitting, crevice corrosion, and galvanic corrosion can cause severe structural damage more rapidly.

Steel bridges in environments subject to moisture, chlorides from deicing salts or marine atmospheres, and pollutants experience accelerated corrosion. Areas with poor drainage, trapped moisture, and shielded joints are especially vulnerable. Temperature fluctuations also contribute to condensation cycles that exacerbate corrosion.

Galvanizing and Weathering Steels

One widely used corrosion protection method is **hot-dip galvanizing**, where steel components are coated with a layer of zinc. Zinc acts as a sacrificial anode, corroding preferentially to protect the underlying steel. Galvanizing provides long-term corrosion resistance and is often applied to smaller components such as bolts, fasteners, and some fabricated elements.

Weathering steels, such as ASTM A709 Grade 50W, contain alloying elements like copper, chromium, and nickel that form a stable, adherent oxide patina on the steel surface. This patina acts as a protective barrier, significantly slowing further corrosion without the need for paint systems.

Weathering steel is often used in bridge girders where aesthetic appearance and reduced maintenance are priorities. However, it requires careful detailing to avoid moisture entrapment and should not be used in continuously wet or chloride-rich environments.

Paint Systems and Coatings

Protective paint coatings remain the most common corrosion mitigation method for steel bridges.

Paint systems typically include multiple layers:

- **Surface preparation:** Removal of mill scale, rust, and contaminants by abrasive blasting to achieve a clean, roughened profile for paint adhesion
- **Primer layer:** Provides adhesion and initial corrosion barrier
- **Intermediate coats:** Build thickness and improve barrier properties
- **Topcoat:** Provides ultraviolet resistance, weather protection, and aesthetic finish

Common coating types include epoxy primers, polyurethane topcoats, and zinc-rich primers. The selection depends on environmental exposure, expected service life, and maintenance considerations.

Paint systems require periodic inspection and maintenance. Damage from traffic, weathering, and mechanical impacts can breach coatings, necessitating localized or full repainting to prevent corrosion initiation.

Maintenance Protocols for Protection Longevity

Routine inspection and maintenance of corrosion protection systems are critical to extending bridge life.

Protocols typically include:

- Scheduled visual inspections to identify coating damage, rust spots, and drainage issues
- Cleaning to remove dirt, salts, and debris that can trap moisture
- Prompt repair of damaged coatings using compatible materials
- Monitoring corrosion rates using ultrasonic thickness measurements or corrosion sensors in critical areas
- Replacement of corroded fasteners, bearings, and other vulnerable components

Design detailing that facilitates inspection and maintenance—such as accessible surfaces, drainage paths, and minimal crevices—significantly improves protection effectiveness.

Emerging Technologies

Innovations such as **cathodic protection**, where electrical currents reduce corrosion rates, and advanced coating materials with self-healing or anti-fouling properties, are gaining traction in bridge engineering. These technologies promise to further reduce lifecycle costs and improve durability, particularly for structures exposed to severe marine or industrial environments.

Understanding corrosion processes and protective strategies is fundamental to the sustainable management of steel girder bridges. The choice and implementation of corrosion protection measures directly affect structural safety, serviceability, and economic efficiency throughout the bridge's lifespan.

Chapter 8: Inspection, Monitoring, and Maintenance

Steel girder bridges, like all infrastructure, require ongoing inspection, monitoring, and maintenance to ensure continued safe operation and to extend service life.

This chapter outlines the practices and techniques used to assess the condition of steel girder bridges, detect deterioration early, and implement effective maintenance strategies. Proactive management reduces the risk of structural failure and costly rehabilitation.

Inspection Types and Intervals

Bridge inspections are typically classified into several categories based on purpose and thoroughness:

- **Routine inspections** are visual assessments performed at intervals generally ranging from 1 to 2 years. Inspectors examine accessible elements for signs of corrosion, cracking, deformation, joint condition, bearing movement, and paint deterioration. Routine inspections are crucial for identifying emerging problems before they escalate.
- **Detailed inspections** involve closer examination, often requiring specialized equipment such as scaffolding, lift platforms, or drones. These are conducted every 5 years or when routine inspections reveal issues. Detailed inspections may include non-destructive testing (NDT) such as ultrasonic thickness gauging, magnetic particle inspection, or dye penetrant testing of welds and connections.
- **Special inspections** are performed following extreme events such as earthquakes, floods, or vehicle impacts. These inspections focus on damage assessment and the need for immediate repairs or load restrictions.
- **Underwater inspections** evaluate submerged components of piers and foundations for scour, corrosion, and damage, typically performed by certified divers or remotely operated vehicles.

Common Deterioration Modes

Steel girder bridges are susceptible to several deterioration mechanisms:

- **Corrosion** of girders, connections, and bearings due to coating failure or moisture intrusion
- **Fatigue cracking** at weld terminations, splice plates, and high-stress details, particularly under repetitive traffic loads
- **Bearing deterioration** including loss of elastomeric properties, corrosion of steel components, or seizing of movable bearings
- **Deck deterioration** leading to water infiltration and subsequent steel damage
- **Impact damage** from over-height vehicles or vessel collisions

Early identification of these modes is critical to prevent structural degradation and preserve load-carrying capacity.

Strategies for Retrofitting and Rehabilitation Aging Girder Bridges

When inspection reveals significant deterioration or deficiencies, retrofit and rehabilitation become necessary to restore or enhance performance.

Common interventions include:

- **Steel section repair or replacement**, using bolted or welded plate additions to restore section properties
- **Strengthening with external steel plates, fiber-reinforced polymers (FRP), or post-tensioning** to increase load capacity
- **Bearing replacement or refurbishment**, including elastomeric pad replacement or upgrading to more advanced bearing types
- **Application of corrosion protection systems**, repainting, or installation of cathodic protection
- **Deck replacement or overlay** to restore the riding surface and protect girders from water ingress

Rehabilitation design must consider compatibility with existing materials, structural effects, constructability, and minimizing traffic disruption.

Monitoring Technologies

Advancements in structural health monitoring (SHM) enable continuous or periodic assessment of bridge conditions using sensors and data analytics.

Techniques include:

- **Strain gauges and displacement sensors** for measuring stresses and deflections under live loads
- **Accelerometers and vibration sensors** to detect changes in dynamic response indicative of damage
- **Corrosion sensors** embedded in coatings or attached to steel surfaces to track corrosion rates
- **Acoustic emission sensors** to identify crack initiation and propagation
- **Remote monitoring using drones or cameras** to supplement visual inspections

SHM systems provide valuable data that can predict maintenance needs, optimize inspection schedules, and enhance safety.

Regular, comprehensive inspection and maintenance of steel girder bridges are essential to prevent failures, maximize lifespan, and ensure public safety. The integration of traditional inspection methods with modern monitoring technologies offers a pathway toward more resilient and cost-effective bridge management.

Chapter 9: Design Code Frameworks and Regulatory Standards

The design, fabrication, and construction of steel girder bridge systems are governed by a comprehensive set of codes and standards developed to ensure safety, serviceability, and durability. These frameworks incorporate empirical research, best practices, and lessons learned from past bridge performance and failures.

Understanding and applying these regulations is fundamental for engineers responsible for bridge projects. This chapter provides an overview of key design codes and regulatory standards that guide steel girder bridge engineering in the United States, with emphasis on structural design, materials, and inspection requirements.

AASHTO LRFD Bridge Design Specifications

The American Association of State Highway and Transportation Officials (AASHTO) publishes the Load and Resistance Factor Design (LRFD) Bridge Design Specifications, which serve as the primary guideline for bridge design in the U.S. These specifications apply a limit state design approach incorporating safety factors to account for uncertainties in loads and resistance.

Key features include:

- **Load modeling:** Comprehensive consideration of dead loads, live loads (vehicular, pedestrian), impact factors, wind, seismic loads, thermal effects, and special loads such as construction or overweight vehicles. Load combinations ensure worst-case scenarios are evaluated.
- **Material resistance:** Use of calibrated resistance factors for steel, concrete, bearings, and connections. Material strengths are based on ASTM standards and include considerations for fatigue, fracture, and corrosion.
- **Structural analysis:** Emphasis on load paths, redundancy, and continuity. LRFD encourages the use of advanced modeling techniques, including finite element analysis, to predict behavior under complex loading.
- **Fatigue design:** Detailed guidance on classifying details according to fatigue category and designing for the anticipated number of load cycles.
- **Serviceability and durability:** Requirements for deflection limits, crack control, corrosion protection, and maintenance accessibility.
- **Seismic design:** Provisions for ductility, redundancy, and detailing in seismic regions, including design of special seismic systems.

State Departments of Transportation (DOTs) typically adopt AASHTO LRFD as their design standard, sometimes with supplemental requirements to address local conditions such as climate, seismicity, or materials availability.

State DOT Adaptations and Federal Guidance

While AASHTO specifications provide a national framework, individual states may modify or supplement these requirements based on regional needs.

These adaptations can include:

- More stringent seismic design criteria in high-risk zones
- Additional durability requirements in marine or cold climates
- Customized load factors or live load models based on traffic patterns
- Enhanced inspection intervals or rehabilitation protocols

Federal agencies such as the Federal Highway Administration (FHWA) also publish manuals and guidelines that supplement AASHTO standards, particularly for federal-aid projects. These may address environmental compliance, bridge management systems, and innovative technologies.

Load Rating, Serviceability, and Redundancy Requirements

Bridges must be evaluated not only for ultimate strength but also for serviceability under normal traffic and environmental conditions. Load rating procedures assess whether existing bridges can safely carry current or anticipated traffic loads and help determine posting requirements or restrictions.

Serviceability criteria include deflection limits, vibration control, and fatigue life considerations. Redundancy provisions ensure that bridges retain sufficient load-carrying capacity even if some components fail or degrade, thereby preventing progressive collapse.

Engineers must document compliance with these requirements through detailed calculations, drawings, and inspection reports to satisfy regulatory authorities and obtain project approvals.

Adherence to design codes and regulatory standards is essential for ensuring that steel girder bridge systems meet contemporary safety, durability, and performance expectations. Familiarity with these frameworks enables engineers to design bridges that are not only structurally sound but also economically viable and maintainable throughout their service lives.

Chapter 10: Case Study and System-Level Behavior

Understanding the behavior of a steel girder bridge system as a whole is essential for appreciating how individual components interact to achieve structural performance and safety.

This chapter presents an overview of system-level load transfer, redundancy, and failure mechanisms through the lens of a case study. The lessons drawn illuminate practical challenges and inform improved design, inspection, and maintenance strategies.

Full-System Load Transfer

In a steel girder bridge, loads applied on the deck—such as vehicular traffic, pedestrians, and environmental forces—are transferred through a hierarchical path. The concrete deck distributes loads transversely to the steel girders via composite action, significantly increasing the girder stiffness. Longitudinal girders then channel these loads to bearings, which transmit forces to the piers and abutments.

Intermediate members like diaphragms and cross-frames provide lateral stability and distribute torsional and lateral loads between girders. Secondary elements such as bracing and stiffeners prevent local buckling and maintain geometric integrity.

At the substructure, load paths extend to foundations and the soil, with consideration for soil-structure interaction effects. Understanding this flow is vital for analyzing the response of the bridge to various loading conditions, including overloads, impacts, and environmental loads.

System Redundancy and Failure Mechanisms

Redundancy refers to the ability of a structure to continue to perform adequately even if some components fail. In steel girder bridges, redundancy is achieved through multiple girders, continuous spans, and multiple load paths. This means that if one girder or connection is compromised, others can share the load to prevent catastrophic failure.

Failure mechanisms in steel girder bridges commonly include:

- **Fatigue-induced cracking** at welds or bolted connections
- **Corrosion weakening**, reducing cross-sectional area and load capacity
- **Buckling** of slender components under compression
- **Overloading**, causing excessive deflections or yielding
- **Impact or collision damage**

Design and inspection protocols emphasize early detection of these issues and incorporation of redundant load paths to avoid sudden collapse.

Lessons Learned from Real-World Failures

Historical bridge failures underscore the importance of thorough design, inspection, and maintenance.

For example:

- The **Silver Bridge collapse (1967)** resulted from a failure of a single eyebar, highlighting the dangers of fracture-critical members lacking redundancy.
- Fatigue cracking at weld details has caused failures in many steel girder bridges, emphasizing the need for fatigue-resistant detailing and periodic inspections.
- Corrosion-related collapses often occur due to neglect of protective coatings and inadequate drainage, stressing preventive maintenance.

These incidents have driven code enhancements, increased focus on redundancy, and more rigorous inspection regimes.

System-Level Behavior Modeling

Advanced analytical techniques, including finite element modeling, allow engineers to simulate the full behavior of steel girder bridge systems under varied loads and scenarios. Such models incorporate material nonlinearities, geometric imperfections, and load combinations to predict response, identify vulnerabilities, and optimize designs.

System-level modeling supports decisions on retrofit necessity, emergency load postings, and response planning following damage or extreme events.

By studying system-level behavior and learning from past failures, engineers can design steel girder bridges that are robust, resilient, and reliable. Integrating these insights into design, inspection, and maintenance ensures safety and longevity of critical transportation infrastructure.

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