Sustainability and Durability Considerations for Design and Preservation of Highway Bridges

7th JCI-ACI Joint Seminar 2025
Innovations and New Developments in Concrete Structures

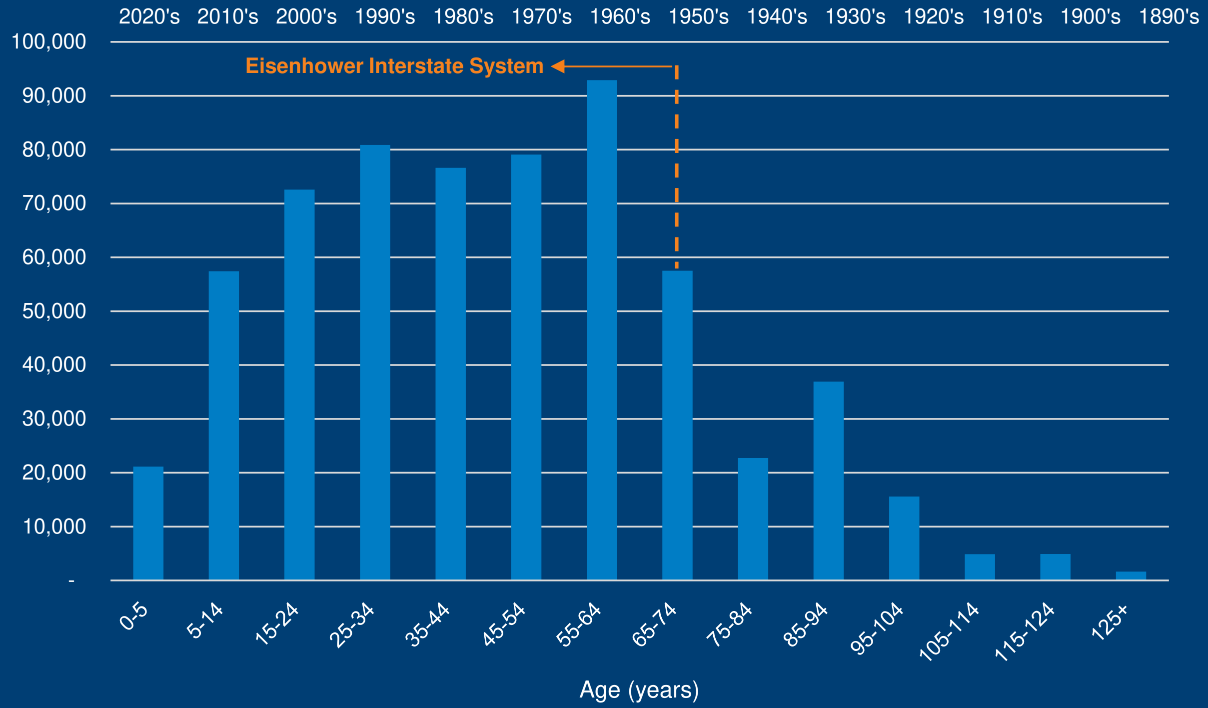
American Concrete Institute

Michael C. Brown, PhD, PE, FACI
Wiss, Janney, Elstner Associates

Highway Bridges in United States

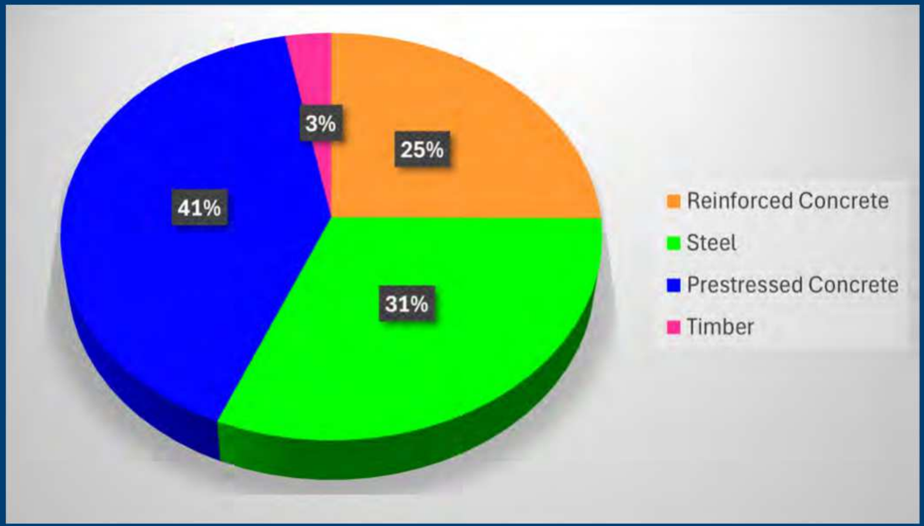
- About 625,000 bridges (National Bridge Inventory, 2024)
- Owned and managed by:
  - State Departments of Transportation
  - Counties and Municipalities
  - Federal Agencies (FHWA, NPS, DoD, BIA, etc.)

U.S Highway Bridges and Culverts



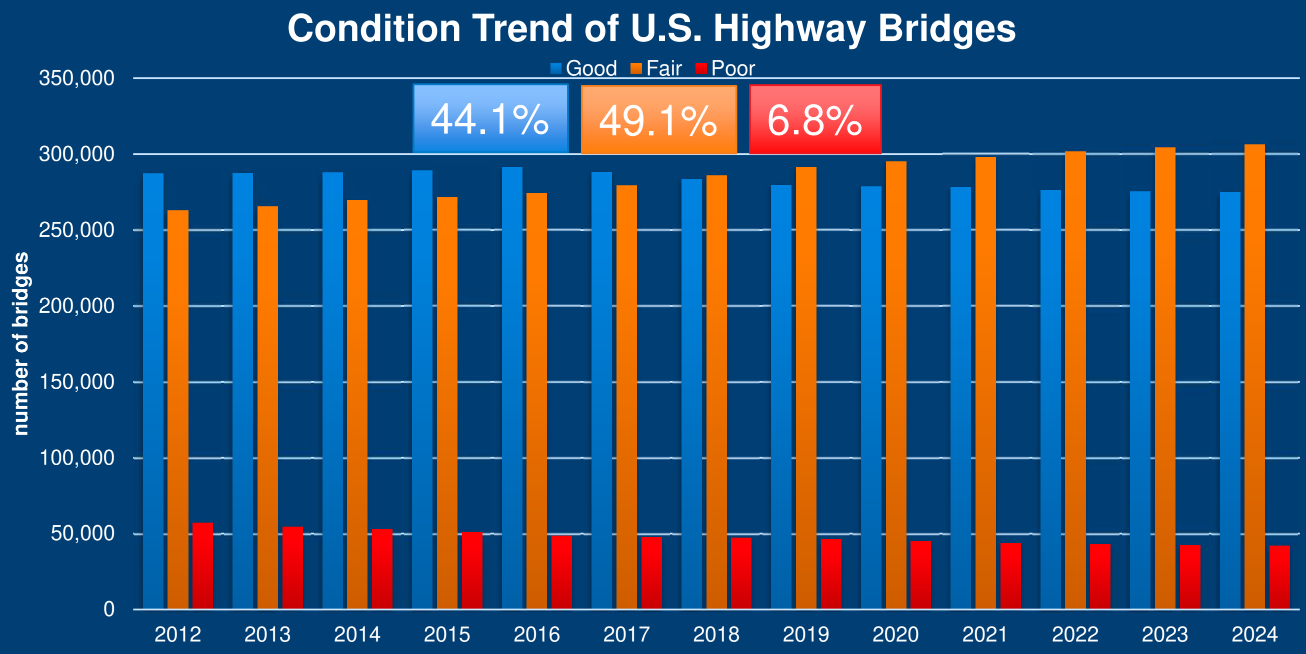
Source: Bridges by Year Built, Year Reconstructed and Material Type
https://www.fhwa.dot.gov/bridge/nbi/no10/yrblt_yrreconst13.cfm

Percentage of in-service bridges for main span superstructure material types from 1950 to 2022



Source: Market Use and Condition Report for US Concrete Bridges
https://nationalconcretebridge.org/resources/ConcreteBridgesMarketShareAndPerformance-ePub.pdf

Condition of U.S. Highway Bridges and Culverts



Bridge Condition

lowest of National Bridge Inventory (NBI) condition ratings 0-9 for:

Item 58 (Deck),
Item 59 (Superstructure),
Item 60 (Substructure), or
Item 62 (Culvert).

If lowest rating is ≥ 7, then Good;
if lowest rating = 5 or 6 , then Fair;
if lowest rating ≤ 4, then Poor.

Source: Condition of U.S. Highway Bridges | Bureau of Transportation Statistics, https://www.bts.gov/content/condition-us-highway-bridges

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Sustainability

- "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

  - United Nations World Commission on Environment and Development
- Sustainability is addressed in all life stages, from planning, design, and construction, through management and preservation.
- Maximize the positive effect on equity (social or people), ecology (environment), and economy

Source: Primer on The Sustainability Considerations for Bridges
https://www.tac-atc.ca/wp-content/uploads/primer-scbg-e.pdf

Sustainability Objectives

- Reduce virgin material use
- Optimize waste stream
- Reduce energy use
- Reduce emissions to air
- Maintain or improve hydrologic characteristics
- Maintain biodiversity
- Engage community values and sense of place
- Improve safety
- Improve access and mobility
- Improve local economy
- Increase lifecycle efficiency
- Promote innovation

Sustainability Practice of State DOTs

- Some DOTs, (e.g., TxDOT), use performance measurement-based frameworks to evaluate and enhance sustainability. This involves assessing factors such as congestion, safety, alternative travel modes, and air quality to align with strategic planning goals.
- Agencies use Green Infrastructure solutions in transportation projects. For stormwater management, infiltration, evapo-transpiration, and reuse of stormwater help maintain or restore natural hydrologies and improve water quality, buffer climate change impacts, and conserve water resources.

Service Life and Life Cycle Design

Service Life – The period of time that a structure is expected to be in operation, over which a structure is intended to perform its function without major repair

Design Life – "Period of time on which the statistical derivation of transient loads is based, which is 75 years for these Specifications." (AASHTO LRFD 9th Ed., 2020)

Codes usually define design life that *implies* a particular service life regarded by society as acceptable

Design life, specific or implied, is used to guide design and construction, often by defining *limit states:*

Service LS, Ultimate LS, *…and now Durability LS*

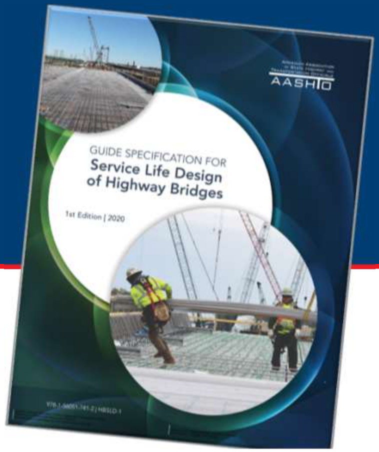
"The limit states specified herein are intended to provide for a buildable, serviceable bridge, capable of safely carrying design loads for a specified lifetime." (AASHTO LRFD 9th Ed., 2020)

American Association of State Highway and Transportation Officials (AASHTO) www.transportation.org

Service Life and Life Cycle Design

AASHTO Guide Specification for Service Life Design of Highway Bridges, 1st Edition, 2020

- select/specify **materials** to withstand deterioration through the design service life
- provide **protective systems**
  (e.g. reinforcement coating, membranes, overlays, steel coatings, joints, and drainage)
- provide **dimensions and details** to reduce the rate of deterioration
  (e.g. cover dimension, reinforcement size, and reinforcement spacing)
- specify **shorter service life for specific elements** and plan for their replacement
  (e.g. joints, bearings, scuppers, and traffic barriers)
- **Remove vulnerability** of a structure to deterioration by avoidance



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Durability Aspects of Sustainability

Eco-Friendly Materials: Using materials like recycled steel and high-performance concrete reduces the environmental impact. Some bridges even incorporate recycled plastics, helping to reduce waste and pollution.

DOTs adopt materials and design techniques that extend the lifespan of bridge assets.

- high-performance and ultra-high-performance concrete
- corrosion-resistant materials
- advanced construction methods

Evolving Cementitious Systems

- Traditionally portland cement per ASTM C150 (Type I/II, III, IV)
- Supplementary cementitious materials (i.e., pozzolans) gained common use since early 1990s — "high-performance concrete"
  - Slag cement, silica fume (microsilica), fly ash
- Now predominately ASTM C595, Blended Hydraulic Cements
  - Type IL — Portland-limestone cement
  - Type IS — Portland blast-furnace slag cement
  - Type IP — Portland-pozzolan cement
- Emerging are Limestone Calcined Clay Cements (LC3)

Trends in Cementitious Systems and Mixtures

Low-carbon concretes

- Increasing range of types and proportions of permissible SCMs
- Increasing age of acceptance testing
- Optimizing cementitious contents and w/cm
  - High strength may not be needed in every component
  - Richer mixtures have larger carbon footprint
  - Richer mixtures often have greater shrinkage and cracking
- Use locally quality aggregates and efficient gradations

Lightweight Concrete

Coarse and fine aggregate of expanded slates, shales, or clays

Typically 90-115 lb/ft^3 unit weight; f'_c can exceed 10,000 psi

Benefits include:

- Reduces dead load
- Increase span lengths
- Fewer substructure components
- Lower transportation weight, cost and energy use
- Promote internal curing to control shrinkage and cracking

Ultra-High-Performance Concrete (UHPC)

- Compressive strengths up to 30,000 psi
- Tensile Strength from 1.5 to 2.5 ksi
- Very low permeability and porosity
- Lighter, thinner, and more durable structural sections
- High shear capacity in bending

Material	Amount (lb/yd^3)	Percent by Weight
Portland Cement	1200	28.5%
Fine Sand	1720	40.8%
Silica Fume	390	9.3%
Ground Quartz	355	8.4%
Super Plasticizer	51.8	1.2%
Accelerator	50.5	1.2%
Steel Fibers	263	6.2%
Water	184	4.4%

Corrosion-resistant materials

Reinforcement

Selected based on structural and environmental demands

Includes:

- Organic and inorganic coated steel
- Low-carbon chromium
- Austenitic and duplex solid stainless steels
- Fiber-reinforced polymer and non-metallics

Corrosion-resistant materials

Prestressing Reinforcement

- Stainless Steel strand

	AASHTO M 203	Stainless Steel
Steel type	1080 carbon	2205 stainless
Grade	250 and 270	250
Total elongation	> 3.5%	1.2% to 2.0%
Relaxation: 1000 hours @ 80% GUTS	< 3.5%	< 3.5%
Modulus of elasticity	28,500 ksi*	24,500 ksi*

Corrosion-resistant materials

Prestressing Reinforcement

- Fiber-reinforced polymer (FRP)

Carbon-fiber composite cable (CFCC) by Tokyo Rope

Advanced Construction Methods

- Modular Construction - reduced construction waste, minimized time on-site, smaller ecological footprint.
- Accelerated Bridge Construction (ABC) - rapid replacement of bridges with minimal traffic disruption, by constructing large sections offsite and quick installation.
  - Precast deck panels and girder systems
  - Precast pier systems
  - Precast modular abutment systems
  - Modular superstructure systems

Quality Control and Assurance

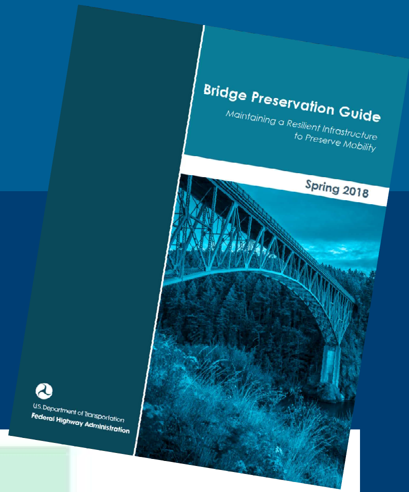
Construction QC/QA role is critical in ensuring concrete material quality and to avoid compromising the design

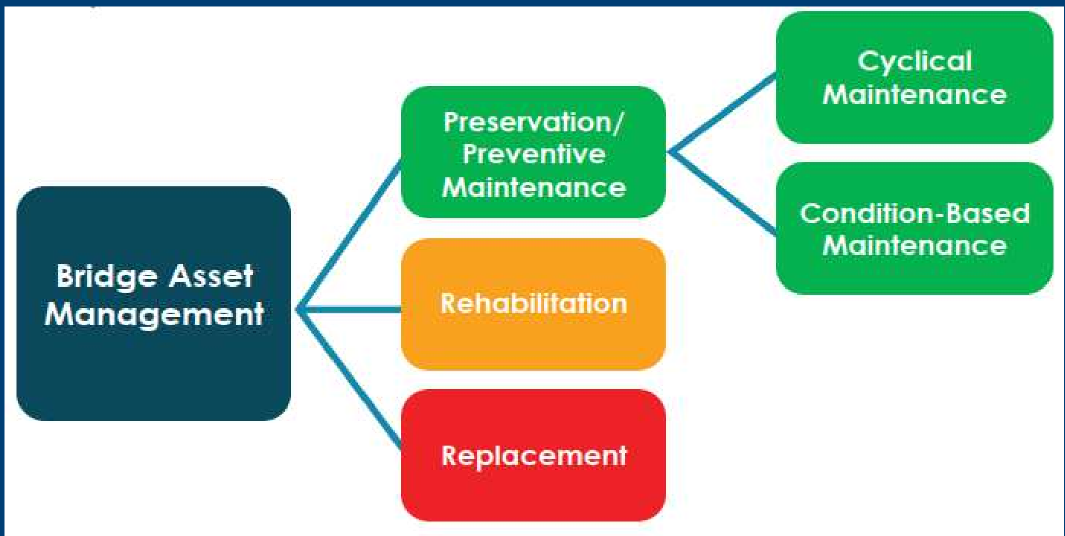
…beyond slump/flow, air content and compressive strength, factors include:

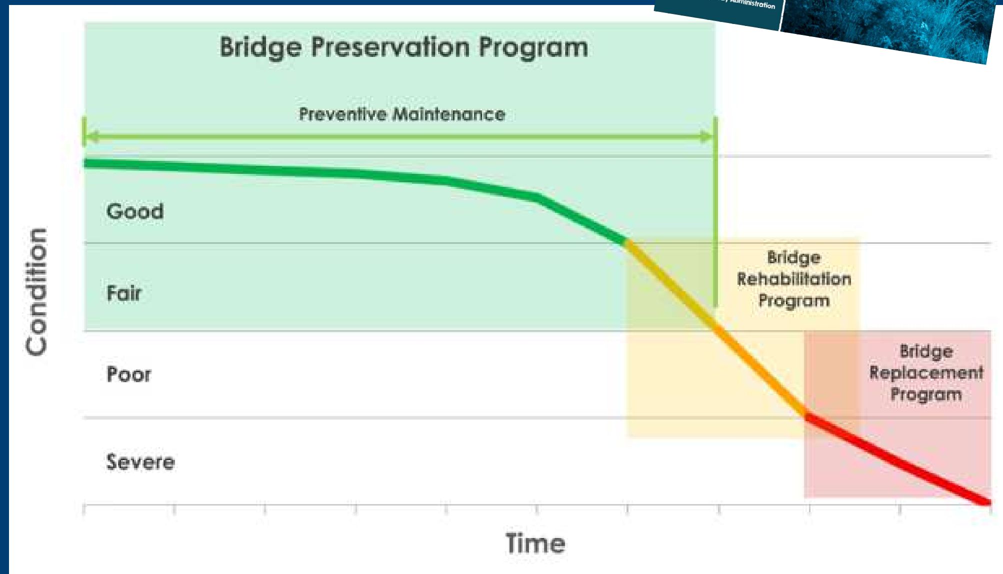
- Permeability (resistivity as surrogate)
- Shrinkage and creep (control w/cm & paste content)
- Heat of hydration / Thermal stress (cooling/low heat mix)
- Consolidation and Finishing
- Proper curing (method and duration, accelerated curing)

Preservation and Maintenance

- FHWA Bridge Preservation Guide (2011; revised 2018)







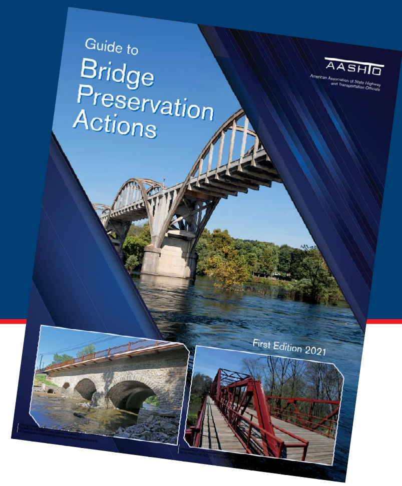
Preservation and Maintenance

- AASHTO Guide to Bridge Preservation Actions

  Identifies criteria for candidate bridges for preservation,

  Lists preservation actions, costs of actions, and time intervals

  Preservation-Cycle Cost Analysis (PCCA) used to compute monetized benefits of preservation



Preservation and Maintenance

Cyclical Activities

- Clean/Wash Bridge Deck and/or Super/Substructure
- Clean and Flush Deck Drains
- Clean Deck Joints
- Deck/Parapet/Rail Sealing and Deck Crack Sealing
- Seal Concrete Super/Substructure

Condition-Based Activities

- Repair/Replace Deck Drains
- Replace/Eliminate Deck Joint
- Deck Overlays
- Seal/Patch/Repair Concrete
- Coating Concrete/Steel
- Fatigue Crack Mitigation
- Bearing Restoration
- Pile jackets/wraps/CP
- Scour Countermeasure

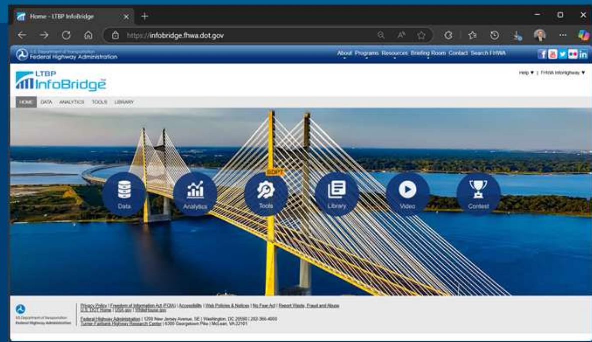
Preservation and Maintenance

FHWA Bridge Deck Preservation Tool

For reinforced concrete bridge decks where:

- deck general condition (GCR) rating ≥ 5.
- deterioration is chloride-induced corrosion
- analysis of strategies using InfoBridge data is sufficient

- Need at a minimum:
  - deck GCR must be known
  - deterioration model to forecast deck GCR



https://infobridge.fhwa.dot.gov/

Preservation and Maintenance

FHWA Bridge Deck Preservation Tool (continued)

Users can also provide:

- element-level data,
- detailed inspection data (e.g., crack maps)
- their own cost estimates maintenance actions

Tool compares preservation strategies for a bridge deck based on initial costs, service life benefits, life cycle costs, and risk

Sustainability and Resiliency

- Approximately 22,420 bridges across the US are susceptible to **extreme storm events**, resulting in:
  - **Flooding and scour**
  - **Overtopping**
  - **Washout**
- Present and future designs must consider impacts of **global warming** and sea-level rise
- Resistance to seismic events

Summary

For bridges in our transportation networks, involves

- Meeting the needs of the present without compromising the future
- A continuous process throughout life of a project/structure
- Strategies that are seamless with goals for safety and mobility

Concrete will continue to be a fundamental part of infrastructure

Continually adapt and improve to design, construct and maintain bridges with attention to equity, ecology, and economy.

Thank you

Michael C. Brown, PhD, PE, FACI <MBrown@WJE.com>

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