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**NJDOT Multi-Hazard Design of Highway Bridges  
Recommendations**

**FINAL REPORT**

January 2026

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New Jersey  
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And  
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## **EXECUTIVE SUMMARY**

This document provides an integrated multi-hazard framework for the design of highway bridges in New Jersey exposed to multiple hazards, rather than a stand-alone, print-ready design guideline. These hazards include natural events such as earthquakes, floods, hurricanes, scour, and wind, as well as man-made threats such as vessel collisions, vehicle collisions, blast, and fire. New Jersey's geographic location exposes its bridge infrastructure to a broad range of environmental and anthropogenic risks. Historical events such as Hurricane Sandy and the Philadelphia I-95 fire collapse underscore the urgent need for resilient, adaptive, and performance-based bridge design. Existing standards often address individual hazards in isolation, which does not fully account for compound or cascading risks. To address this gap, the document outlines a holistic multi-hazard framework for how New Jersey Department of Transportation (NJDOT) may progressively incorporate these concepts into its existing manuals, policies, and procedures so that bridges remain serviceable and safe during extreme events.

The document identifies various hazards such as earthquakes, flooding, storm surge, scour, wind, collisions, fire, blast, and site-specific risks, and characterizes the hazards that affect New Jersey bridges. Site-specific evaluation is addressed conceptually by referencing mapping tools, Federal Emergency Management Agency (FEMA) flood requirements, and Climate Adjusted Flood Elevation (CAFE)-related criteria, and by describing how these tools can be leveraged within NJDOT's existing project development processes. The design philosophy emphasizes both probability-based and performance-based approaches, balancing safety, economy, and long-term resilience, and highlights where current practice may not fully capture multi-hazard or climate-related effects.

Rather than prescribing detailed design criteria or specific language to be directly reprinted in the NJDOT Design Manual, this document points to relevant American Association of State Highway and Transportation Officials (AASHTO), Federal Highway Administration (FHWA), NJDOT, and New Jersey Department of Environmental Protection (NJDEP) provisions and identifies where additional refinement, coordination, or clarification for seismic, flood and storm surge, bridge scour, wind load, vehicle collision, vessel collision, blast load, and fire may be warranted. It also discusses multi-hazard interactions and load combinations, as well as considerations for structural systems, superstructures, substructures, foundations, connections, bearings, and energy-dissipation devices to improve safety, durability and resilience. Climate change impacts, such as sea-level rise, increased flooding, and changes in storm intensity and rainfall, are addressed in terms of adaptive strategies and potential future updates to NJDOT practice.

By consolidating multi-hazard considerations into a single strategic framework, this document offers NJDOT, designers, engineers, and decision-makers a framework to guide future policy choices, pilot projects, and selective revisions to existing standards. It is intended to inform and support the evolution of NJDOT's design manuals and procedures so that New Jersey's bridges are robust, adaptable, and prepared for both current and future challenges, while preserving NJDOT's flexibility to determine the timing, level of detail, and format of any formal design standards updates.

## **INTRODUCTION**

New Jersey's geographical setting subjects its bridge infrastructure to diverse environmental and anthropogenic risks, including coastal storms, sea-level rise, storm surge, riverine flooding, scour, extreme temperatures, and hazards associated with dense urban development, aging industrial corridors, and heavy freight traffic. Historical events such as Hurricane Sandy and the Philadelphia I-95 fire collapse underscore the necessity for resilient, adaptive, and performance-based bridge design, demonstrating that damage to a single structure can trigger widespread disruptions to mobility, emergency response, supply chains, and the regional economy. Existing standards often treat hazards in isolation, which may not reflect the actual compound and cascading risks bridges face when events such as storm surge, wave action, debris impact, scour, fire, or collision occur together or in rapid succession. Therefore, NJDOT is adopting a holistic multi-hazard framework that explicitly considers these interactions, aligns design decisions with defined performance objectives, and supports the long-term safety, functionality, and resilience of New Jersey's bridge infrastructure.

### **Purpose and Scope**

The purpose of this research project is to provide a discussion and a possible framework for consideration in developing more comprehensive and integrated recommendations for the design, assessment, and retrofitting of highway bridges in New Jersey exposed to multiple hazards. These hazards include natural events, such as earthquakes, floods, hurricanes, scour, and wind, and man-made threats, such as vessel collisions, vehicle collisions, blast, and fire.

These guideline recommendations are intended to supplement existing AASHTO and NJDOT requirements by highlighting how these hazards may interact and by encouraging a coordinated, multi-hazard approach rather than treating each threat in isolation. It applies to both new and existing highway bridges within New Jersey, with emphasis on structures whose continued functionality is critical to regional mobility, emergency response, and economic activity. The framework presented here is not a prescriptive standard, but a resource to inform future NJDOT policies, guide project-specific decision-making, and support the development of resilient, performance-based bridge designs and retrofits in a multi-hazard environment.

## **Applicability and Limitations**

The guideline recommendations are intended to develop guidance and apply to the planning, design, evaluation, and major rehabilitation of highway bridges that are owned, operated, or maintained by NJDOT, and to other bridges where NJDOT criteria are adopted by agreement. The provisions are intended projects where multi-hazard performance is an explicit objective.

This research report as a framework is to be used in conjunction with the AASHTO LRFD Bridge Design Specifications (BDS), applicable AASHTO Guide Specifications and related documents, FHWA related documents, and NJDOT Bridge Design Manual (BDM) and their policies. It provides supplemental, MH-focused guidance and does not replace or supersede those governing documents. Where requirements in this guideline differ from AASHTO or NJDOT standard specifications, the controlling specification or policy identified and approved by NJDOT shall govern, unless project-specific direction is provided by the Owner.

Hazard characterizations, load combinations, and climate-related assumptions contained in this document reflect current knowledge and regulations at the time of publication. As scientific understanding, regulatory requirements, and design standards evolve, designers shall verify that the latest NJDOT policies, AASHTO provisions, and applicable federal and state regulations are consulted and, where necessary, update the analyses and design criteria accordingly.

## LITERATURE REVIEW, HAZARD IDENTIFICATION AND CHARACTERIZATION

### Overview of Multi-Hazard Environment in New Jersey

New Jersey's geographic location, dense population, aging infrastructure, and proximity to both inland and coastal environments expose its bridge network to a wide array of natural and man-made hazards. These hazards must be systematically addressed in both new bridge designs and renovation projects to ensure safety, service continuity, and long-term resilience.

- **Seismic Risk:** While not in a high seismic zone, New Jersey falls within a low to moderate seismic risk area, particularly along the Ramapo Fault. Seismic design for life safety and functional resilience is required for critical lifeline and long-span structures.
- **Flooding and Storm Surge:** New Jersey experiences frequent intense rainfall events that result in flash flooding, riverine overflow, and urban drainage failures. Changes in precipitation intensity due to climate change have made historical hydrologic models inadequate. Bridges located in flood-prone areas require elevation, larger hydraulic openings, and robust scour protection.
- **Coastal Storm Surge and Sea-Level Rise:** Bridges along the coastlines and tidal waterways face threats from storm surges driven by hurricanes and nor'easters. Superstructures are vulnerable to uplift, debris impact, and foundation scour. Sea-level rise projections necessitate designing for future elevations and resilient substructures.
- **Wind and Extreme Weather:** Bridges in exposed areas are subject to sustained high winds and gusts during tropical storms and extratropical cyclones. Extreme wind loads affect structural design related to superstructure stability, dynamic responses, and appurtenances, e.g. signs and barriers.
- **Scour and Erosion:** Foundation scour is one of the leading causes of bridge failure nationwide. In New Jersey, a significant number of bridges are built over water bodies prone to shifting streambeds, high flow velocities, and sediment transport. Scour analysis and mitigation (e.g., deep foundations, riprap) are essential.
- **Vehicle and Vessel Collision:** Bridges crossing major highways or navigable waterways are susceptible to impact from errant vehicles or maritime traffic. Protection measures such as crash barriers, pier protection, fender system, and collision analysis are vital for structural integrity and public safety.
- **Blast and Fire:** Although infrequent, incident like the 2023 I-95 bridge collapse in Philadelphia or terrorism attack, etc. highlights the vulnerability of steel and concrete bridge components to intense fire and explosive forces. Accidental fuel spills, tanker fires, or intentional acts (e.g., terrorism) shall be considered, especially in urban areas and near industrial zones.
- **Climate Change & Non-Stationary Conditions:** New Jersey's bridges should now be designed with the recognition that historical data may no longer predict future conditions. This includes increased rainfall, storm frequency, higher temperatures, and changing freeze-thaw cycles, all affecting material durability, loadings, and risk scenarios.

The following section describes each hazard with their definition, characteristics as well as the design implications. Detailed discussion will be given in the following Sections.

## **Seismic**

Earthquakes produce ground motions that can generate significant inertial forces in bridge superstructures and substructures, leading to damage or collapse if not properly designed for. In New Jersey's low to moderate seismic risk environment, seismic design should focus on providing adequate load paths, seat widths and restraints, and ductile detailing so that forces and deformations can be accommodated without catastrophic failure.

### Design Implications:

- **Seismic Analysis:**
  - Perform detailed seismic analysis to determine the expected ground accelerations and forces on the structure.
- **Base Isolation and Dampers:**
  - Implement base isolation systems and dampers to reduce the impact of seismic forces on the structure.
- **Ductile Design:**
  - Design structures with ductile materials and connections that can absorb and dissipate energy, reducing the risk of catastrophic failure.

## **Flood**

A flood is an overflow of water that submerges land that is usually dry. Floods can occur due to various reasons such as heavy rainfall, storm surges, river overflow, or dam breaks. They can cause significant damage to infrastructure, erode foundations, and disrupt transportation networks.

### Design Implications:

- **Hydraulic Analysis:**
  - Perform detailed hydraulic modeling to predict flood levels, flow rates, and the extent of flooding under various scenarios.
- **Elevation of Structures:**
  - Design critical components of infrastructure, such as bridge decks and roadways, to be elevated above the predicted flood levels.
- **Flood-Resistant Materials:**
  - Use materials that can withstand prolonged exposure to water without significant deterioration.
- **Floodplain Management:**
  - Implement measures to manage water flow and storage in flood-prone areas, such as retention basins and levees.
- **Drainage Systems:**
  - Design effective drainage systems to quickly remove excess water and prevent waterlogging.

### Practical Applications in Design:

- **Hydraulic Modeling:**
  - Conduct hydraulic modeling using historical data and predictive tools to estimate the impact of various flood scenarios.

- Use computational models to simulate water flow and determine floodplain extents.
- Elevation and Clearance:
  - Elevate bridge decks, roadways, and other critical infrastructure above the 100-year flood level to ensure functionality during significant flood events.
  - Design adequate vertical and horizontal clearance to accommodate flood flows without obstruction.
- Flood-Resistant Materials:
  - Select construction materials that resist water damage, such as reinforced concrete and corrosion-resistant metals.
  - Use waterproofing techniques and materials to protect vulnerable components.
- Floodplain Management:
  - Incorporate retention basins, levees, and floodwalls to manage and control floodwaters.
  - Design landscape and urban planning features to divert and store floodwaters safely.
- Drainage Design:
  - Implement robust drainage systems to facilitate rapid removal of floodwaters from critical areas.
  - Design culverts, channels, and storm drains with sufficient capacity to handle expected flood flows.

### ***Storm Surge***

A storm surge is a temporary rise in sea level caused by a storm, typically a hurricane or other intense weather system, which can lead to flooding and increased wave action.

#### Design Implications:

- Elevation:
  - Design superstructures to be elevated above the predicted storm surge level to prevent inundation, structure uplift, and sweep off.
- Wave Action:
  - Consider the impact of waves on structures during a storm surge, designing for additional forces and potential erosion.
- Structural Integrity:
  - Ensure that structures can withstand the combined forces of elevated water levels, wave action, and debris impact.

#### Practical Applications in Design:

- Hydraulic Analysis:
  - Perform detailed hydraulic modeling to predict the height and extent of storm surge for the design area.
  - Consider historical data and future climate change scenarios to estimate potential storm surge levels.
- Elevation Setting:

- Elevate critical components of structures, such as bridge decks and abutments, above the predicted storm surge level.
- Ensure that foundations are designed to remain stable under storm surge conditions.
- Wave Protection:
  - Design structures to resist wave forces and prevent erosion, using materials like concrete armor units or wave deflectors.
  - Incorporate breakwaters or other wave-dissipating structures if necessary.

### **Scour**

A scour is the erosion or removal of sediment from around bridge abutments, piers, footings, or foundations due to flowing water. This phenomenon can undermine the foundations of structures, leading to instability or failure.

#### Design Implications:

- Hydraulic Analysis:
  - Perform detailed hydraulic modeling to predict the potential depth and extent of scour around bridge foundations under various flow conditions.
- Scour-Resistant Materials:
  - Use materials such as riprap, gabions, or concrete aprons around foundations to protect against erosion.
- Foundation Design:
  - Design foundations to extend below the maximum predicted scour depth to ensure stability even if a significant scour occurs.
- Monitoring and Maintenance:
  - Implement regular inspection and maintenance plans to monitor for signs of scour and take corrective actions as needed.

#### Practical Applications in Design:

- Scour Analysis:
  - Conduct a scour analysis to determine potential scour depths based on flow velocities and sediment characteristics.
  - Use empirical formulas or computational fluid dynamics (CFD) models to predict scour under different flow conditions.
- Foundation Protection:
  - Install scour protection measures such as riprap, geotextiles, or concrete armor units around bridge piers and abutments.
  - Ensure the foundations extend below the predicted scour depth to maintain structural stability.
- Design Adjustments:
  - Adjust the design of bridge components, such as increasing the depth of foundations or adding scour protection, based on the results of the scour analysis.

### ***Elevation and Discharge Definitions:***

There are several definitions regarding the elevation and discharge in a hazard, such as flood, including Mean High water, Storm Water Elevation, Base Flood Elevation, Design Wave Crest Elevation, and Design Flood (Hydraulic Engineering Circular (HEC)-18, 2012) [1]. These definitions apply to different contexts and are worth discussing. Table 1 summarizes the above-mentioned elevation and discharge definition.

- Mean High Water (MHW), Elevation
  - Definition: The average height of all high tides over a period of time, e.g., 19-year period, at a specific location.
  - Data Source: National Oceanic and Atmospheric Administration (NOAA) tide stations using the National Tidal Datum Epoch (currently 1983–2001 or updated range).
  - Use: Legal/tidal boundary reference, datum for mapping, baseline for sea level rise studies.
- 100-Year Storm Water Elevation, Elevation
  - Definition: The still-water elevation (no waves) during a storm with a 1% annual chance of occurring.
  - Data Source: Coastal storm surge and tide modeling (e.g., ADvanced CIRCulation (ADCIRC), FEMA Flood Insurance Study (FIS) studies).
  - Use: Engineering design, FEMA mapping base; closely approximates Base Flood Elevation (BFE) in many cases.
- Base Flood Elevation (BFE), Elevation
  - Definition: The computed elevation to which floodwaters (including wave effects) are anticipated to rise during a 100-year flood.
  - Data Source: FEMA FIS; includes tide, surge, and sometimes wave setup.
  - Use: Minimum elevation for regulatory compliance, flood insurance rating, building codes.
- 100-Year Design Wave Crest Elevation, Elevation
  - Definition: The highest peak of a wave riding on top of the storm water and surge during a 100-year event.
  - Data Source: Coastal wave modeling (e.g., Storm-induced BEAch CHange model (SBEACH), Steady-State Spectral WAVE model (STWAVE), and Simulating WAVes Nearshore (SWAN)); used in structural design.
  - Use: Engineering of bridges, seawalls, offshore platforms ensures freeboard to avoid wave impact.
- Design Flood (HEC-18), Discharge
  - Definition: a statistically derived flood event with a specified recurrence interval (commonly 100-year or 200-year) used to evaluate hydraulic conditions and scour potential at bridge foundations. It represents the peak discharge (flow rate, cfs or m<sup>3</sup>/s) that a river or stream is expected to carry with a certain probability.
  - Data Source: Hydrologic analysis tools (HEC-HMS), historical gage data (USGS), or FEMA Flood Insurance Studies.
  - Use: Engineering of bridges, seawalls, offshore platforms ensures freeboard to avoid wave impact.

Table 1 – Summary of Elevation and Discharge Definitions

Term	Definition	Data Source	Includes Tide	Includes Surge	Includes Wave Setup*	Includes Wave Crest**	Frequent Use Case
Mean High Water (MHW)	Average height of all high tides over a 19-year period	NOAA tide gauges	Yes	No	No	No	Datum, legal coastal boundary
100-Year Storm Water Elevation	Stillwater elevation during a 100-year storm (tide + surge [+setup])	Storm surge models (e.g., ADCIRC, FEMA FIS)	Yes	Yes	Varies	No	Engineering water level estimate
Base Flood Elevation (BFE)	FEMA flood level during 1% annual chance flood (may include wave setup)	FEMA FIS	Yes	Yes	Depends on FEMA Zone	No	Floodplain management and insurance
100-Year Design Wave Crest	Highest wave peak during 100-year storm (includes tide, surge, setup, crest)	Wave modeling (e.g., SBEACH, SWAN, STWAVE)	Yes	Yes	Yes	Yes	Coastal structure freeboard design

\* Wave setup: Wave setup is the increase in mean water level due to wave breaking. It results from the momentum flux gradient induced by the dissipation of wave energy in the surf zone [2]

\*\* Wave crest: the elevation of the peak of a design wave, computed above the total storm surge level including wave setup. It is used to determine required freeboard for structures [3]

**Tidal Flood Hazard Area**

A coastal zone subject to flooding caused by tides, typically affected by high tides, storm surge, tidal wave setup, and sea level rise. This area experiences regular tidal influences and is at risk during both normal tidal cycles and extreme events like hurricanes. In FEMA and NJDEP terminology, tidal flood hazard areas are:

- Mapped as “V zones” or “AE (coastal) zones” in coastal flood insurance rate maps (FIRMs).
- Usually defined where flooding is driven by ocean tide levels, not by upstream river discharge.
- Found along coasts, bays, tidal rivers, and estuaries.

The comparison of tidal flood hazard area and riverine flood hazard area are described in Table 2.

Table 2 – Tidal Flood Hazard Area and Riverine Flood Hazard Area

Feature	Tidal Flood Hazard Area	Riverine Flood Hazard Area
Cause	Ocean tides, storm surge, wave setup	Rainfall runoff, river flow
Examples	NJ shorelines, tidal rivers like lower Hudson	Inland areas along rivers like the upper Delaware
Mapped by FEMA	FEMA (V Zones, coastal AE)	FEMA (AE, A Zones inland)
Affected by	Sea level rise, lunar cycles, coastal storms	Watershed rainfall and drainage

**Wind**

Wind loads refer to pressure/force exerted by wind on the surface of structures, which can induce significant stresses, affect structural stability and services leading to damage or potential failure if not properly accounted for.

Design Implications:

- Wind Loads:
  - Structures must be designed to withstand the maximum wind speeds expected in the region.
- Structural Reinforcement:
  - Critical structural elements, such as beams and columns, need to be reinforced to resist bending and shear forces caused by high winds.
  - Secondary fabricated structural steel components used in the bridge superstructure, such as wind bracing and diaphragms.
- Aerodynamic Design:
  - Shape and orientation of the structure can be optimized to reduce wind pressure and minimize potential damage.

## ***Vessel Collision***

Vessel collisions involve impact forces from boats or ships striking bridge piers, footings, foundations, overhead structures, or other structures over navigable waterways.

### Design Implications:

- Impact Resistance:
  - Design structures to withstand impact forces from vessel collisions.
- Protective Measures:
  - Implement fender systems or other protective measures to absorb impact energy and protect critical structural elements.
- Redundancy:
  - Ensure redundancy in structural elements to prevent catastrophic failure in case of vessel impact.

### Practical Applications in Design:

- Impact Load Analysis:
  - Conduct impact load analysis based on expected vessel sizes and speeds.
  - Use collision simulation software to model the effects of vessel impacts on structures.
- Protective Fender Systems:
  - Install fender systems to absorb impact energy and protect piers, footings, or foundations.
  - Use materials like rubber or composite materials in fender design for energy absorption.
- Redundant Design:
  - Design redundant load paths to ensure structural stability even if some elements are damaged.
  - Reinforce critical elements to resist impact forces.

## ***Vehicle Collision***

Vehicle collisions involve impact forces from vehicles striking bridge piers, abutments, or other structures, which can cause significant damage.

### Design Implications:

- Impact Resistance:
  - Design structures to withstand impact forces from vehicle collisions.
- Protective Barriers:
  - Implement barriers or guardrails to protect critical structural elements from vehicle impacts.
- Redundancy:
  - Ensure redundancy in structural elements to prevent catastrophic failure in case of impact.

### Practical Applications in Design:

- Impact Load Analysis:
  - Conduct impact load analysis based on expected vehicle sizes and speeds.
  - Use crash simulation software to model the effects of vehicle impacts on structures.
- Protective Barriers:
  - Install barriers or guardrails to absorb impact energy and protect structural elements.
  - Use energy-absorbing materials in barrier design to reduce impact forces.
- Redundant Design:
  - Design redundant load paths to ensure structural stability even if some elements are damaged.
  - Reinforce critical elements to resist impact forces.

### ***Fire and Explosion***

Fire involves the combustion of materials that can produce significant heat, smoke, and structural damage. Fire load represents the severity of a possible fire and is typically quantified as heat energy per unit area (e.g., MJ/m<sup>2</sup>). In structural and fire engineering, fire load is used to evaluate the intensity and duration of a fire that a structure may be exposed to.

### Design Implications:

- Fire Resistance:
  - Design structures with materials and systems that resist fire and prevent structural collapse.
- Protective Measures:
  - Implement fire protection systems such as sprinklers, fireproof coatings, and smoke barriers.
- Redundancy:
  - Ensure redundancy in structural elements to prevent catastrophic failure in case of fire damage.

### Practical Applications in Design:

- Fire Load Analysis:
  - Conduct load analysis due to fire based on potential fire scenarios.
  - Use fire simulation software to model the effects of fire on structures.
- Fire Protection Systems:
  - Install sprinklers, fireproof coatings, and smoke barriers to protect critical elements.
  - Use materials like fire-resistant concrete or steel in structural design.
- Redundant Design:
  - Design redundant load paths to ensure structural stability even if some elements are damaged.
  - Reinforce critical elements to resist fire damage.

## ***Blast***

Blasts involve explosive forces that can cause significant structural damage and potential collapse if not properly designed.

### Design Implications:

- Blast Resistance:
  - Design structures to withstand the forces from explosive blasts.
- Protective Measures:
  - Implement protective measures such as blast walls or barriers to shield critical elements.
- Redundancy:
  - Ensure redundancy in structural elements to prevent catastrophic failure in case of blast damage.

### Practical Applications in Design:

- Blast Load Analysis:
  - Conduct blast load analysis based on potential threat scenarios.
  - Use blast simulation software to model the effects of explosions on structures.
- Protective Measures:
  - Install blast-resistant walls or barriers to shield critical elements.
  - Use materials like reinforced concrete or steel to enhance blast resistance.
- Redundant Design:
  - Design redundant load paths to ensure structural stability even if some elements are damaged.
  - Reinforce critical elements to resist blast forces.

## Site-Specific Hazard Assessment

Designers shall conduct site-specific hazard analyses using the following documents. Probabilistic and deterministic approaches should be employed to capture both known risks and low-frequency, high-impact events.

- FEMA Flood Maps and CAFE guidance
- NJDEP Inland Flood Protection Rules
- ASCE 7-22, AASHTO Risk-Targeted Seismic Design criteria, and USGS Seismic Hazard Maps
- Historical incident data and local traffic/waterway studies

## United States Geological Survey (USGS) Tools

USGS Ground Motions Resources are listed below

- USGS NSHM Uniform-Hazard Ground Motions
  - Unified Hazard Tool Website:
  - <https://earthquake.usgs.gov/hazards/interactive/>
- USGS NSHM Risk-Targeted Ground Motions (RTGM)
  - AASHTO-USGS Seismic Design Web Service:
  - <https://earthquake.usgs.gov/ws/designmaps/aashto-2023/#/>
- RTGM also considered fragility functions (resistance), in addition to hazard curve (load).

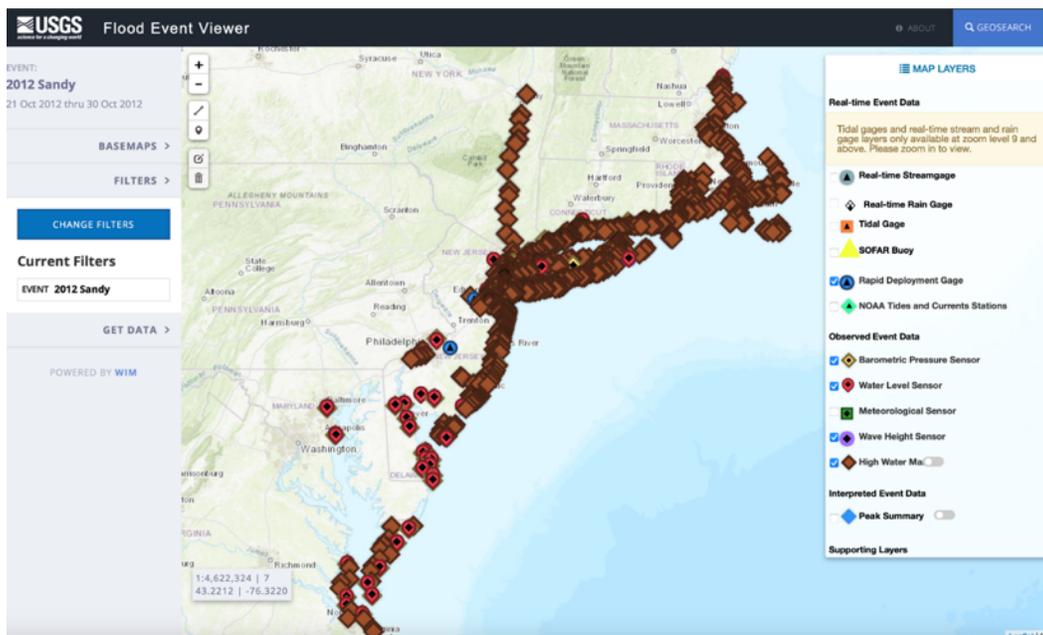


Figure 1. USGS Flood Event Viewer

- **ASCE 7 Hazard Tools:** ASCE 7 Hazard Tools is an online platform provided by ASCE to look up site-specific environmental and structural design hazards used in ASCE 7. It provides map with various parameters needed for infrastructure design. The user can retrieve design hazard values such as wind speeds, seismic ground motion parameters, flood data references, snow loads, and tsunami design zones depending on the ASCE 7 edition by address or coordinates.

- National Hurricane Center Storm Surge Risk Maps:** This map shows potential areas and potential depth of saltwater inundation above ground level for flood from storm surge during hurricanes of different categories from Category 1 through Category 5. Although it does not provide real-time conditions, but it would be a useful tool to identify the maximum reasonable storm surge that could occur for planning, evacuation, and risk assessment.

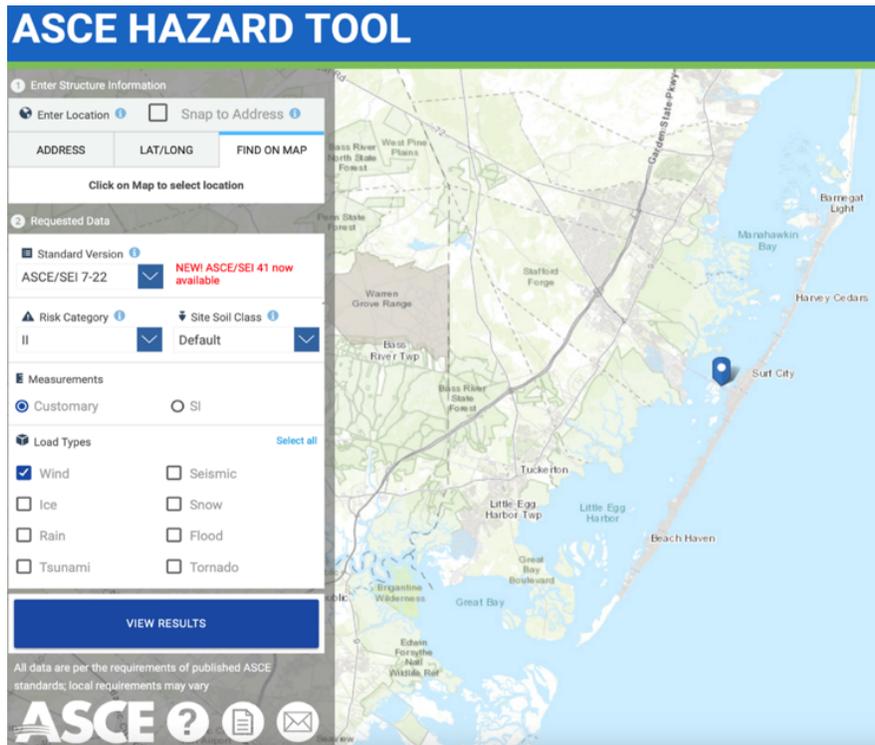


Figure 2. ASCE 7 Hazard Tools

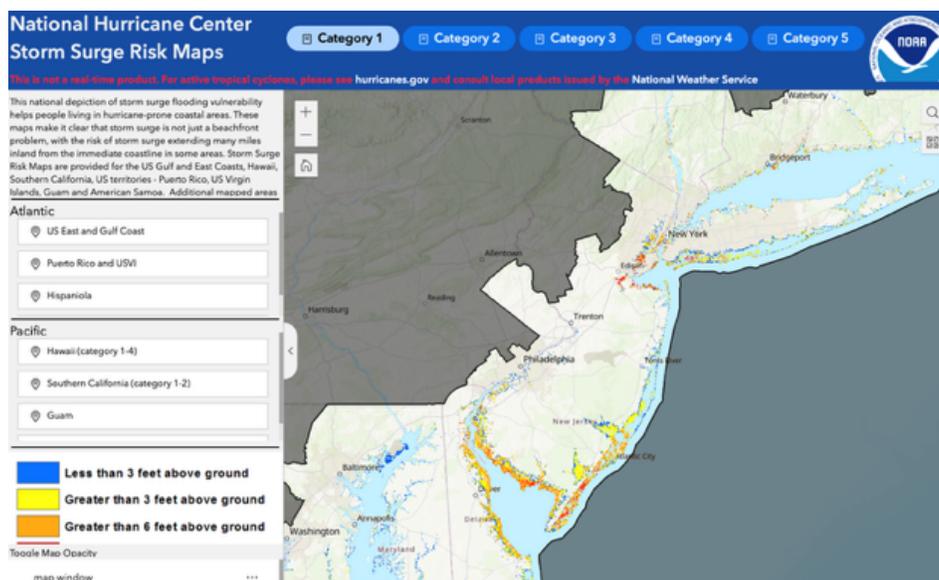


Figure 3. National Hurricane Center Storm Surge Risk Maps

## Data Sources and Mapping Tools

### National Ocean and Atmospheric Administration (NOAA) Data and Sources

NOAA provides extensive flood data that can be utilized to analyze conditions before and after the implementation of flood barriers which is physical structure or system designed to control the intrusion of floodwaters. While NOAA doesn't offer a specific tool labeled "before and after barriers," several resources can assist in such comparative analyses:

- **Coastal Flood Exposure Mapper:** This tool allows users to visualize the exposure of people, infrastructure, and natural resources to coastal flooding. By selecting different flood scenarios, such as sea level rise or storm surge, users can assess potential impacts and vulnerabilities in specific areas. This can help infer the effectiveness of flood barriers by comparing exposure levels before and after their implementation. See Figure 4.
- **Sea Level Rise Viewer:** NOAA's Sea Level Rise Viewer offers interactive maps that show potential sea level rise and coastal flooding scenarios. Users can examine how different sea level rise scenarios might affect coastal communities, which is useful for evaluating the protective benefits of flood barriers over time. See Figure 5.
- **National Water Prediction Service:** This service provides real-time and forecasted hydrologic information, including river forecasts and flood outlooks. By analyzing historical and current data, users can assess how flood barriers have influenced flood frequencies and magnitudes in specific regions. See Figure 6.

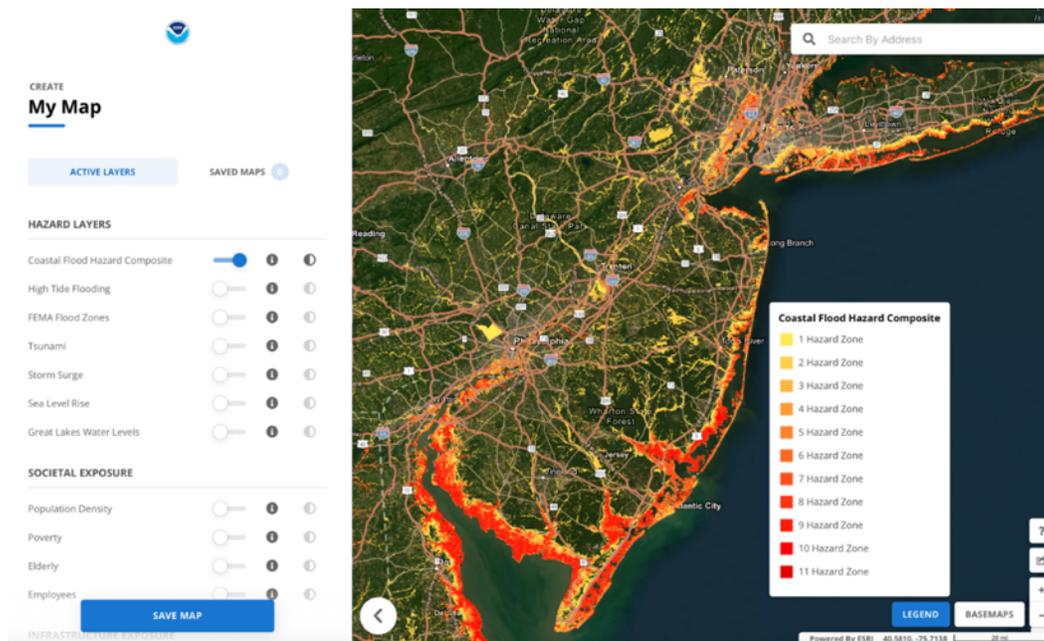


Figure 4. NOAA Coastal Flood Exposure Mapper

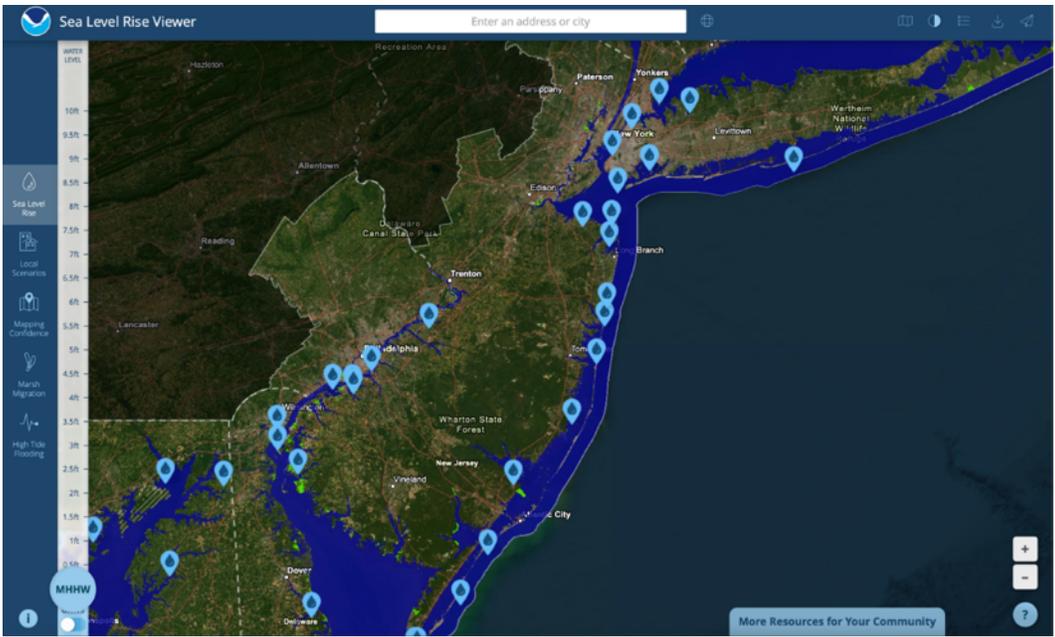


Figure 5. NOAA Sea Level Rise Viewer

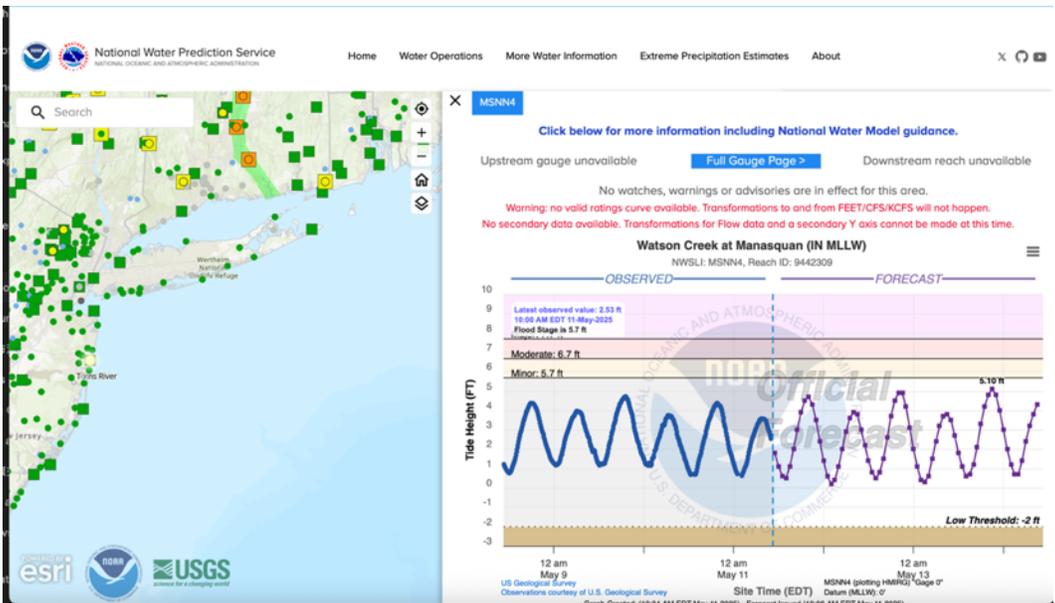


Figure 6. National Water Prediction Service

## Risk Assessment of Hazards

The risk assessment of multiple hazards should adopt a probabilistic approach because these hazards do not usually occur concurrently; when one is at its maximum, the others are typically at average or near-average levels. Therefore, the agency should first define which hazards to consider (such as overloading, fatigue, scour, flooding/storm surge, seismic events, vehicle and vessel collisions, and functional obsolescence) and link each of them to specific bridge and site characteristics available from external data sources (NBI fields, WIM, USGS, NOAA, hydraulic studies, etc.). For each bridge and each

relevant hazard, the engineer then uses simplified probabilistic models to estimate how likely it is that the bridge will reach or exceed a damage or failure state, based on factors such as traffic loading, material and structural type, foundation and waterway conditions, and regional seismic or coastal hazard levels. In parallel, they estimate the consequences if that damage or failure were to occur by combining direct costs (repair, replacement, or retrofitting) with indirect “user” costs (traffic delays and detours estimated from ADT, truck percentage, detour length, and typical speeds). The annual risk for each hazard is obtained by combining the probability of failure with its associated consequences and then converting these results into normalized risk indices. This procedure was described in the literature [4], and the simple graphical protocol is summarized below.

### Definition of Risk

$$R_i = P_{f,i} C_i$$

$$P_{f,i} = P_f(H) P_{f/H}$$

$P_{f,i}$  = Probability of failure

$C_i$  = Consequence of failure

$P_f(H)$  = occurrence probability of  $H$

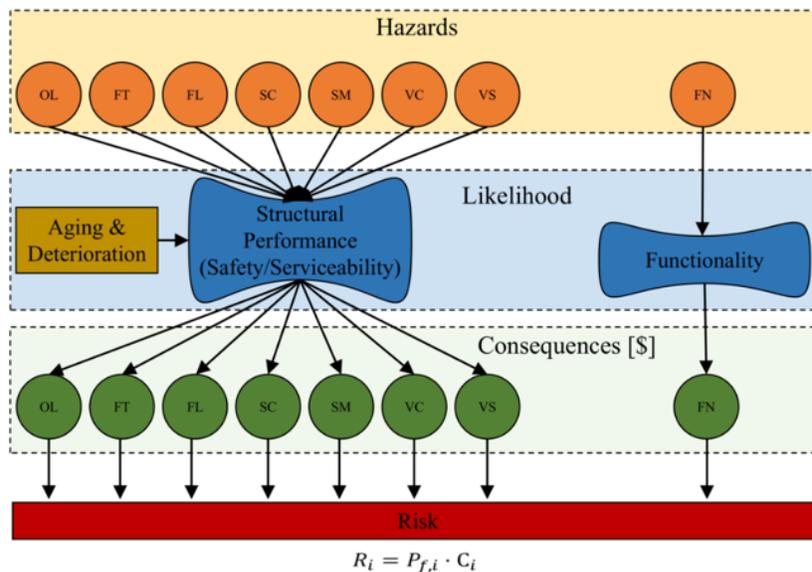


Figure 7. Risk Assessment in NJ [4]

## DESIGN PHILOSOPHY AND OBJECTIVES

Three (3) design philosophy should be considered.

- **Probability-Based Design:** Use annual exceedance probabilities to assess loads (e.g., 1% for floods, 2% for seismic events).
- **Performance-Based Design:** Define performance objectives including life safety, immediate use, and collapse prevention.
- **Life-Cycle Considerations:** Designs should facilitate inspection, maintenance, monitoring, and future retrofitting.

According to guidance provided in Section 3 of the New Jersey DOT Design Manual for Bridges & Structures, “the design of new structures and new elements of rehabilitated bridge structures in New Jersey shall be completed with the use of the *AASHTO LRFD Bridge Design Specifications*.” The Load and Resistance Factor Design (LRFD) methodology is a key aspect of these design specifications. It employs a reliability-based approach to design, ensuring that the minimum resistances or capacities of bridge components exceed the potential maximum demands or force effects due to various loads during the design life. The LRFD methodology provides a systematic and rational way to select load and resistance factors with uniform margins of safety.

### Probability-based Design Approach

Probability-based design is a methodology that incorporates uncertainty and variability into the design process. Instead of assuming fixed values for loads, material strengths, or environmental conditions, it uses statistical distributions to model them, with the intent to design safer, more efficient, and cost-effective designs. Reliability-based design and probability-based design are not the same. Reliability-based design focuses on ensuring the reliability of a system under uncertainty, while probability-based design incorporates probability theory to evaluate the likelihood of uncertain events. These two design approaches serve different purposes in engineering and are used in different contexts.

Core Principles of the Probability-based Design Approach include:

- **Uncertainty Modeling:** Recognizes that loads (such as wind, earthquakes, traffic) and resistances (like material strength) vary and are not deterministic.
- **Reliability Analysis:** Evaluates designs based on the likelihood that they will perform successfully under expected conditions based on probability of failure.
- **Risk Assessment:** Quantifies the chance of failure and its impact, supporting informed decision-making.
- **Performance-Based Criteria:** Aims for a specific reliability level based on specific performance objectives rather than just complying with prescriptive codes.

Benefits of applying a Probability-based Design Approach include:

- Optimizes material use and reduces costs
- Improves safety and performance
- Fosters innovation by enabling flexibility beyond strict codes
- Supports better lifecycle planning and maintenance strategies

The main challenges include data quality and availability, computational demands, standards integration, cross-disciplinary teamwork, and persuading stakeholders to embrace probabilistic thinking.

#### 1. Data and Uncertainty Characterization

- Limited or biased datasets make fitting statistical distributions challenging.
- Measuring correlations between loads and resistances can be difficult.
- Material properties often lack historical data needed for precise modeling.

#### 2. Computational Complexity

- Monte Carlo or advanced sampling methods demand significant processing power.
- Convergence criteria are often unclear - how many simulations are enough?
- Commercial design software may not support custom probabilistic workflows by default.

#### 3. Standards and Code Integration

- Most building codes are prescriptive rather than performance-based or reliability-based.
- The lack of unified guidelines means each project may need to start from scratch.
- Regulatory agencies might hesitate to approve designs that deviate from established safety factors.

#### 4. Interdisciplinary Collaboration

- Statisticians, engineers, and domain experts must collaborate, but they often speak different languages.
- Integrating structural analysis, risk assessment, and project management increases complexity.
- Training teams to understand probabilistic concepts requires time and resources.

#### 5. Risk Communication and Stakeholder Acceptance

- Clients and contractors tend to prefer “black-and-white” safety factors over probability-based data.
- Explaining a 1 in 10,000 failure risk can be counterintuitive for non-technical audiences.
- Building trust and convincing decision-makers to invest in upfront analysis instead of simply adding more material is challenging.

Using reliability-based load factors can help reduce over-engineering in critical infrastructure.

## Performance-Based Design Approach

The main difference between performance-based design and probability-based design lies in their focus and application. Performance-based design is a methodology that identifies and selects a performance level from several options, aiming to exceed the minimum requirements set by codes. It provides tools to meet specific performance objectives, enabling a more tailored design process that considers the unique aspects of a building or structure. Performance-based design is particularly useful for economically critical facilities where the potential for significant losses due to downtime is high.

In contrast, probability-based design is a probabilistic approach that calculates the likelihood of achieving a certain hazard level and estimates the expected damage and losses. It is mainly oriented toward calculating financial losses for the insurance industry and addressing emergency management or community recovery concerns. Additionally, it guides building owners and designers in making informed decisions about design or retrofitting.

Both methodologies are probabilistic and aim to assess the likelihood of certain hazard levels while estimating potential damage and losses. However, performance-based design focuses more on the design process and specific vulnerabilities of a building, whereas probability-based design emphasizes calculating financial impacts and addressing emergency management issues.

Performance-Based Design is an innovative design approach that prioritizes achieving specific performance objectives over adherence to prescriptive codes and standards. This method allows for greater flexibility and innovation during the design and construction process, as it emphasizes desired outcomes rather than the means to achieve them.

There are several Key Principles in using Performance Based Design.

- **User Requirements:** The first step in Performance-Based Design is identifying and formulating the relevant user requirements. These requirements are then transformed into performance requirements and quantitative performance criteria.
- **Performance Requirements:** These are specific, measurable criteria that the bridge must meet. They are derived from user requirements and used to evaluate whether the proposed design solutions meet the desired performance levels.
- **Evaluation Tools:** Reliable design and evaluation tools are used to assess whether the proposed solutions meet the stated criteria at a satisfactory level. This involves using various methods such as simulations, calculations, and testing.

Performance-Based Design enables a more customized approach to bridge design, focusing on achieving specific performance outcomes. This method is especially valuable for complex projects where traditional prescriptive codes can be too limiting. Performance-Based Design is commonly used in seismic design to ensure bridges can withstand earthquakes by meeting particular performance criteria related to structural integrity and safety. By emphasizing desired performance results, Performance-Based Design offers a flexible and innovative approach that can produce better, more efficient, and safer structures.

## Life-Cycle Considerations

Too often, designers make decisions primarily to keep initial project costs low. Although the resulting structures are built according to AASHTO codes and state DOT Design Manuals, these guidelines often overlook long-term costs or environmental hazards that the structure might encounter over its designed lifespan. Hazard-related maintenance costs can be substantial over the life of a structure. The NJDOT Design Manual for Bridges and Structures states that when considering Life Cycle Costs, “The total cost of an item’s ownership over a specified period. For NJDOT Bridge Projects, this period will be 100 years. This includes initial acquisition costs (right of way, planning, design, construction), operation, maintenance, modification, replacement, demolition, financing, taxes, disposal, and salvage value as applicable.” The manual also states that “A LCCA (Life Cycle Cost Analysis) shall be made in studying alternate design concepts to compare the benefits and costs that arise at different times in a bridge structure’s lifespan. Future benefits and costs over the proposed time span of each alternative should be considered. A long-term perspective should be taken in programming improvements and selecting among alternative design, maintenance, rehabilitation, and reconstruction strategies in designing bridge structures.”

One goal of this research is to support these directives by promoting planning for and using codes and standards that include hazard mitigation in the structure’s design. Because of natural hazards, it may be most effective to evaluate the benefits of incorporating mitigation measures separately from the life cycle cost of the structure. This approach enables owners to assess risks associated with hazards and to make decisions based on acceptable protection levels offered by different design strategies. In some cases, the importance of the structure may demand that no reduction in service is acceptable after an event that requires a higher initial investment, while in others, some reduction might be tolerated. The authors believe that losing a structure should never be considered acceptable.

NJDOT already has tools regarding determining the Criticality of its assets (NJDOT Criticality Assessment Tool) as well as specific guidance contained within its Transportation Asset Management Plan (TAMP) that should be considered as a starting point when making decisions in developing a site-specific mitigation plan. Also to be considered is AASHTO Guidance on Prioritization of Bridges (Criticality) discussed later in this report.

For most infrastructure projects, addressing natural hazard mitigation during the early conceptual development phase is vital. The designer involved in the conceptual or preliminary design should inform the owner about prevalent hazards and available methods to avoid or lessen the impacts of extreme natural events. It is essential to identify any hazards that could affect the project during the preliminary design phase. Key factors to consider include:

- Locating the facility to prevent flooding, soil erosion, exposure to high winds, and unstable soils, while reducing exposure to storm surge and high waves for harbors, docking facilities, and coastal structures.

- Designing and shaping the bridges' elements and structural systems to reduce the effects of high winds and earthquake forces, and for protection works, to prevent unwanted effects such as beach erosion, accretion, or negative impacts on coastal reefs and wetlands.
- Using construction materials that are corrosion-resistant and have appropriate durability and strength.

Throughout the process of designing and implementing an infrastructure project, distinct but interconnected phases (planning, design, construction, operation, maintenance, modification, replacement) require special attention to natural hazards, and resources should be allocated for necessary investigations. The cost-benefit analysis of designing structures for natural hazards provides several important insights:

- Incorporating hazard and vulnerability information into the design process is essential for ensuring resilience and reducing costs throughout the project's lifespan.
- Risk-based and performance-based design strategies can enhance infrastructure resilience by evaluating the benefit-cost ratio and considering risk in decision-making.
- Benefit-cost analysis (BCA) is crucial for evaluating the effectiveness of hazard mitigation measures and supports the allocation of public funds for disaster preparedness and response.
- Nature-based solutions (NbS), such as ecosystem restoration, are cost-effective options for hazard mitigation and can sometimes outperform engineering solutions.

These insights highlight the importance of careful planning and design to balance costs and benefits in structures built to resist natural hazards. When considering life-cycle aspects, a mitigation measure can be seen as an addition to the original design and construction of the project, aimed at reducing the risk of failure from a historic event. These measures add an extra cost during construction but provide a benefit by avoiding losses if an extreme event impacts the project.

Incremental costs of the additional mitigation measures include: (a) the cost of further investigations into hazards that could impact the project and the project's vulnerability to these hazards; (b) the cost of extra design work; and (c) the cost of additional construction [5]

*Sum (Hazard & Vulnerability Study + Additional Design Costs + Additional Construction Costs)  
= Incremental Costs of Hazard Mitigation*

The benefits of investing in additional mitigation measures come from avoiding losses by lowering the chances of failure and reducing the expected loss per failure. These benefits add up over the project's lifetime and are discounted relative to the extra costs at the start of the project.

$$\begin{aligned} & \text{Reduced probability of failure, year } t \\ & \times \\ & \text{Reduced expected losses per failure, year } t \\ & = \\ & \text{Avoided losses, year } t : B(t) \end{aligned}$$

$$\text{Avoided losses over project lifetime } T = B(T) = \sum_t \frac{B(t)}{(1+i)^t}$$

While estimating the components of the incremental cost of hazard mitigation is straightforward, it is much more challenging to estimate the components of avoided losses, such as failure probabilities and losses per failure. Examining these incremental solutions can be valued using traditional Life Cycle Cost Analysis (LCCA) equations. The relationship between the amount of a future expenditure and its present value (PV) is calculated using the following expression with a real discount rate (r).

$$PV = C_n * 1 / (1+r)^n$$

Where  $C_n$  = Cost of expenditure at year n, (in today's dollars)  
 $r$  = real discount rate  
 $n$  = year in the future when cost will be incurred

The LCC is then calculated as the sum of the PVs of accumulated costs ( $C_n$ ) incurred at time t, over a period of time (T) as given by the following formula:

$$PV_{LCC} = \sum_{t=0}^T C_n * 1 / (1+r)^n$$

wherein each time-step considers costs associated for that year.

In summary, natural hazard mitigation should address the prevalent hazards that a structure might face throughout its service life. Implementing additional mitigation measures during the initial design and construction can result in significant savings compared to the costs of reconstructing the facilities. It's important to recognize that the reconstruction cost is a conservative estimate of the losses caused by a failed project, as it does not account for various indirect and collateral damage related to the disruption of the damaged facility's operation. Most natural hazards' impacts can be avoided or reduced by applying appropriate design principles tailored to the hazards present. Therefore, the owner must understand the facility's vulnerabilities early in the project design process.

## DESIGN CRITERIA FOR INDIVIDUAL HAZARDS

Designing for wind, earthquake, vehicle collision, vessel collision, blast, fire, scour, storm surge, and hurricanes involves understanding and mitigating the specific impacts of each hazard. Wind loads require aerodynamic optimization and structural reinforcement, while earthquakes necessitate seismic analysis and ductile design. Vehicle and vessel collisions demand impact resistance and protective barriers, and blasts require blast-resistant materials and protective measures. Fire protection involves fire-resistant materials and fire protection systems. Similarly, designing for scour, storm surge, and hurricanes involves ensuring foundation stability under erosive forces, elevating critical components to protect against wave action, and addressing high wind loads, combined flood effects, and debris impact. Integrating these considerations into a comprehensive design strategy enhances the safety, resilience, and durability of infrastructure against various structural, hydrologic, and meteorological risks.

### Design Implications/Aspects of various hazards.

- Flood, Storm Surge, and Hurricane: AASHTO Guide Specifications for Bridge Vulnerable to Coastal Storms [6]
- Blast, Prioritization of Bridges in Inventory, Risk-based Prioritization of Bridge Components: AASHTO Bridge Security Guidelines [7]
- Vehicular Collision, Vessel Collision: AASHTO LRFD BDS [8]
- Wind: ASCE-22 [9] and AASHTO LRFD BDS [8]
- Seismic: Proposed AASHTO Guidelines for Performance-Based Seismic Bridge Design [10], AASHTO Guide Specifications for LRFD Seismic Bridge Design [11], AASHTO Guide Specifications for Seismic Isolation Design [12]
- Fire: limited resources, NCHRP 12-85 Highway Bridge Fire Hazard Assessment [13]

Table 3 – Summary of Hazards and Design Standards

Hazard	Standards	Design Notes
Seismic	Various AASHTO specifications and guidance	Various AASHTO specifications and guidance, see Section 4.1 in the AASHTO Guide Specifications for LRFD SBD
Flood	HEC-18, NJDEP Flood Rules	Design for 100-year flood; check against 500-year flood. Use scour analysis.
Storm Surge	AASHTO Coastal Guide	Elevate decks, restrain unseating, assess hydrostatic and hydrodynamic forces.
Scour	HEC-18, NJ SEM	Apply three-level analysis; incorporate river morphology and local hydraulics.
Wind	ASCE 7-22, AASHTO LRFD	Use 3-sec gust values (80 mph), Strength III/IV and Service I/IV load combinations.
Vehicle Collision	AASHTO LRFD §3.6.5	Design 600-kip static force or TL-5 barrier with 3.25 ft offset.
Vessel Collision	AASHTO LRFD §3.14	Perform vessel risk analysis, use fender systems, apply scour-collision load combinations.
Blast	AASHTO Bridge Security, NCHRP 645	Use Extreme Event II load case, consider threat-specific analysis, apply fragmentation and standoff criteria.
Fire	NCHRP 12-85, NFPA 502	Coordinate with local emergency services. Use fire-resistant materials, enable access.

## Design for Seismic

There are four AASHTO specifications guidelines available regarding the seismic design, as listed below.

- AASHTO LRFD, 9<sup>th</sup> Edition, 2020: traditional force-based R-Factor method, basic approach.
- AASHTO Guide Specifications for LRFD Seismic Bridge Design, 3rd Edition, 2023: displacement-based design procedures.
- AASHTO Guidelines for Performance-Based Seismic Design of Highway Bridges, 1st Edition, 2023: comprehensive performance-based seismic design framework with multiple performance objectives, strain-based design procedures.
- AASHTO Guide Specifications for Seismic Isolation Design: design of seismic isolation system.

Below is a summary of the goal, design philosophy, applications and limitations of the four AASHTO specifications mentioned above. Furthermore, the summary and comparison of the design philosophy is summarized in Table 5.

### **AASHTO LRFD BDM**

- **Goal and focus:**
  - life-safety objective
- **Design philosophy:**
- Force-based seismic design,
  - Horizontal force effects
  - Strength and ductility with simplified methods for estimating seismic loads
  - Earthquake ground motions: 7% probability of exceedance in 75 years, approximately 1000-year return period (7%/75).
- **Application:**
  - Conventional vs Non-Conventional: Conventional bridge, owner-approval needed for non-conventional bridges
  - Critical, essential, or other: can be apply to all
- **Limitations:**
  - Partial or complete replacement may be required, may suffer damage
  - Limited guidance for advanced seismic design,
  - non-performance-based
  - may not adequately address complex seismic demands or high-seismic hazard level.

### ***AASHTO Guide Specifications for LRFD Seismic Bridge Design [11]***

- **Goal and focus:**
  - enhanced seismic design, life safety
- **Design philosophy:**
  - Displacement-based seismic design.
  - Advanced analysis methods including equivalent static analysis, elastic dynamic analysis and nonlinear time-history method.
  - Emphasizes ductility and deformation capacity of structures.
  - Earthquake ground motions: two levels of ground motions,
- **Application:**
  - Conventional vs Non-Conventional: Conventional bridge
  - Critical, essential, or other: apply to other (noncritical, non-essential)
- **Limitations:**
  - Only one level of performance
  - More complex than force-based methods; requires detailed analysis.
  - Can be resource-intensive due to the need for advanced analysis and detailing.
  - May not be necessary for low-seismic regions.

### ***AASHTO Guidelines for Performance-Based Seismic Bridge Design (GPBSB) [10]***

- **Goal and focus:**
  - provides a comprehensive performance-based seismic design framework
- **Design philosophy:**
  - multiple performance objectives, operational categories, ground motion levels,
  - strain-based engineering design parameters
  - Incorporates detailed material specifications and structural detailing requirements
  - Earthquake ground motions: 2018 Hazard Model Multi-Period Spectra
- **Application:**
  - All seismic regions, with emphasis on higher (increased) levels of seismic performance practical
  - Critical infrastructure and complex bridge systems require a detailed performance assessment
  - Conventional vs Non-Conventional: both
  - Critical, essential, or other: can be apply to all
- **Limitations:**
  - Requires extensive analysis and detailed modeling.
  - It can be resource-intensive and requires advanced engineering expertise.
  - Not typically necessary for simpler bridges in low-seismic regions.

The basic elements considered using the performance-based design of bridges based on AASHTO GPBSB is shown in Table 4. Figure 8 shows the flowchart of basic steps in framework for Performance-based seismic design of bridges.

Table 4 – Basic elements in performance-based design of bridges (AASHTO GPBSB 2024 Table 3.0-1)

Element	No.	Description	Table No.
Bridge Operational Categories	3	Critical Recovery Ordinary	Table 13
Performance Levels and Associated Damage Descriptors and Engineering Design Parameters	3	PL1: Life Safety PL2: Operational PL3: Fully Operational	Table 14, Table 15, and Table 16
Earthquake Ground Motion Levels <sup>b</sup>	2	Lower Level (100 years) Upper Level (1000 years)	Table 17
Seismic Hazard Levels	4	I, II, III, IV	Table 18
Seismic Design Categories	5	A1, B1-2, C1-3, D1-3, and E1-2	Table 19, Table 20

<sup>a</sup> To the extent possible, methodology is compatible with AASHTO Guide Specifications for LRFD Seismic Bridge Design and the FHWA's Seismic Retrofitting Manual for Highway Structures: Part 1—Bridges (Buckle et al. 2006).

<sup>b</sup> Selection of 100 years and 1000 years for the return periods of the lower- and upper-level ground motion is discussed in Step 3 of Article 3.1 of the AASHTO guidelines.

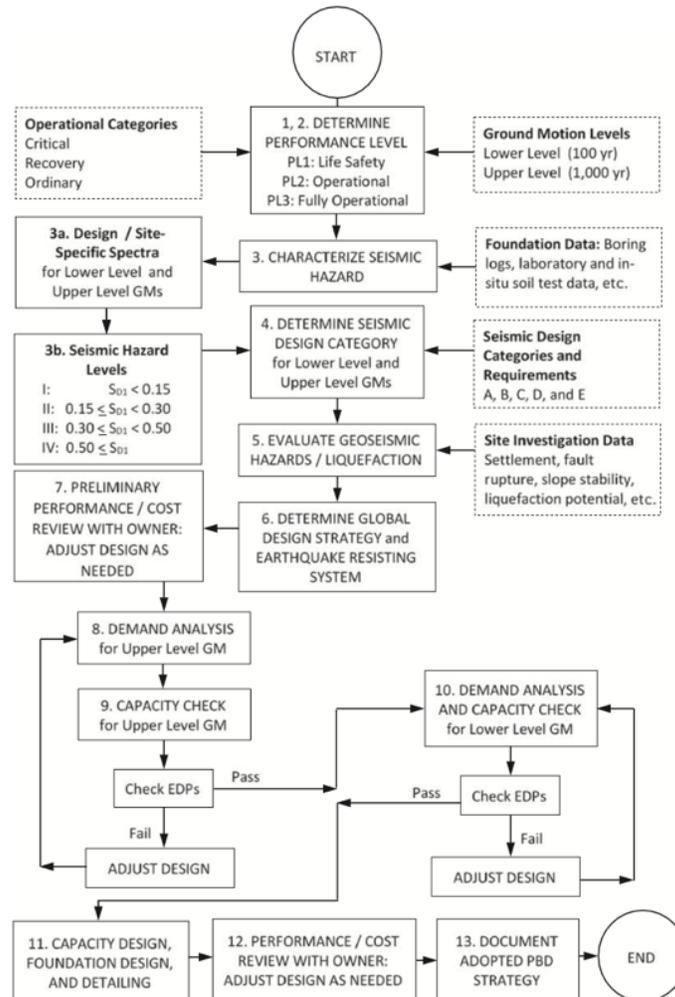


Figure 8. Flowchart of basic steps in framework for Performance-based seismic design of bridges, (GM=ground motion) (AASHTO GPBSB 2024 Figure 3.0-1)

## ***AASHTO Guide Specifications for Seismic Isolation Design***

- **Goal and focus:**
  - Minimize seismic forces transmitted to the bridge structure, and Enhance performance and safety
- **Design philosophy:**
  - Incorporates seismic isolation devices (e.g., elastomeric bearings, lead rubber bearings) to decouple the bridge superstructure from ground motions.
  - Reduces structural demands by lengthening the natural period of the bridge and providing additional damping
  - Requires detailed analysis of the isolated bridge response, including linear and nonlinear time-history analysis
  - Earthquake ground motions: focusing on isolation system response and design
- **Application:**
  - Suitable for high seismic regions.
  - Conventional vs Non-Conventional: both
  - Critical, essential, or other: can be applied to all
- **Limitations:**
  - Requires specialized knowledge and detailed analysis.
  - May involve higher initial costs due to the incorporation of isolation devices.
  - Not applicable for all bridge types or sites.

## ***NJDOT Bridge Design Manual***

Section 38 of the 2016 NJDOT BDM [14] elaborates on seismic design and retrofit, employing the AASHTO Guide Specifications for LRFD Seismic Bridge Design. It emphasizes displacement-based seismic design methods, reflecting on Extreme Event-I load combinations for seismic analysis as noted in Section 3.4 of the AASHTO LRFD Bridge Design Specifications.

## ***Displacement-Based vs Strain-Based Design Philosophy***

- **Displacement-Based Design** is suitable for a wide range of seismic design scenarios, especially when a balance between simplicity and accuracy is desired.
- **Strain-Based Design** is more appropriate where a detailed understanding of material behavior is necessary. This approach is ideal when specific performance levels must be met.

Table 5 – Summary for Seismic Design Approaches

AASHTO Specifications and Guilds		AASHTO LRFD BDS [8]	AASHTO Guide Specifications for LRFD Seismic Bridge Design [11]	AASHTO Guidelines for PBSBD [10]	AASHTO Guide Specifications for Seismic Isolation Design [12]
Performance levels		Life safety	Life safety	Life safety, operational, fully operational	Life safety
Design approach		Force-based	Displacement-based	Strain-based	Displacement-based
Risk Methodology		Uniform-Hazard Ground Motion	Risk targeted ground motion	Uniform-Hazard Ground Motion	Risk targeted ground motion
Risk level		Hazard Risk: 7% in 75 years, MRI=1000 years	Seismic Risk: 1.5% in 75 years, $\beta=2.2$	Hazard Risk: 50% in 75 years MRI=100-year, 7% in 75 years, MRI=1000-year	Seismic Risk: 1.5% in 75 years
Hazard Map		2002 USGS NSHM Uniform-Hazard Ground Motions	2018 USGS NSHM Risk-Targeted Ground Motions	2014 (2018*) USGS NSHM Uniform-Hazard Ground Motions	2018 USGS NSHM Risk-Targeted Ground Motions
Conventional vs non-conventional		Conventional	Conventional	Both	Both
Bridge Operational Categories (LRFD definition)	Critical	X	X	X	
	Essential	X	X	X	
	Others	X	X	X	X

### Design for Flood and Storm Surge

Flood/Storm Surge Guides and Requirements are summarized below, and each item is described in the following:

- NJDOT Bridge Design Manual (BDM) [14]
- NJDEP Rule<sup>1</sup>
- NJDOT Roadway Design Manual [16]
- AASHTO LRFD BDS [8]
- AASHTO Guide Specifications for Bridge Vulnerable to Coastal Storms [6]

### ***NJDOT Bridge Design Manual (BDM)***

Section 22 of the 2016 BDM elaborates on the general criteria, hydraulic criteria for drainage on bridges. From the NJDOT BDM, the clearance is measured from Mean High-Water (MHW) Elevation.

<sup>1</sup> [https://dep.nj.gov/wp-content/uploads/njreal/real\\_adoption\\_courtesy.pdf](https://dep.nj.gov/wp-content/uploads/njreal/real_adoption_courtesy.pdf)

Table 6 – Minimum Vertical Clearances for Bridges & Structures (NJDOT BDM, 2016)

Roadway Functional Classification Facility Type	Vehicular and Railroad Over Crossings	Pedestrian and Bikeway Over Crossings	Overhead Sign Structures	Tunnels	Notes
Inter-Coastal Waterway	55'-0"	--	--	--	5
Navigable Waterways	Varies	--	--	--	6
Other Waterways	Varies	--	--	--	7
Existing Bridges and Structures	--	--	--	--	8

***NJDEP Rules***

In August 2024, NJDEP introduced the REAL rule proposal aimed at enhancing New Jersey’s resilience to climate change. While it doesn’t directly modify bridge clearance standards, it introduces concepts that could indirectly affect infrastructure design:

- Inundation Risk Zone (IRZ): Areas projected to be permanently inundated by tidal waters by 2100, defined by adding 5 feet to the current Mean High Water (MHW) elevation.
- Climate Adjusted Flood Elevation (CAFE): A new standard adding 5 feet to FEMA’s 100-year flood elevation, Base Flood Elevation (BFE), in tidal flood hazard areas, setting higher benchmarks for floodplain management and infrastructure design.

These proposals emphasize the need for infrastructure projects, including bridges, to account for future sea-level rise and increased flood risks. The final adoption of these rules is anticipated in early 2026.

***NJDOT Roadway Design Manual [15]***

The following requirements are specified in the NJDOT Roadway Design Manual [15].

- Flood Hazard Area (Stream Encroachment):
  - Any manmade alteration, construction, development, or other activity within a floodplain. (The name “NJDEP Stream Encroachment Permit” is changed to the “NJDEP Flood Hazard Area Permit”.)
- Floodplain:
  - The area described by the perimeter of the Design Flood. An area designated by a governmental agency as a floodplain.
- Regulatory Flood:
  - For delineated streams (i.e., those for which a State Adopted Flood Study exists), it is the Flood Hazard Area Design Flood, which is the 100-year peak discharge increased by 25 percent. State Adopted Flood Studies can be obtained from the NJDEP Bureau of Floodplain Management. For non-delineated streams, it is the 100- year peak discharge, based on fully developed conditions within the watershed.

### ***AASHTO LRFD Bridge Design Specifications (BDS) [8]***

The AASHTO LRFD BDS mandate that bridges over navigable waters must provide adequate vertical and horizontal clearances to accommodate marine traffic. While AASHTO sets the framework, it defers to the USCG for specific clearance requirements. These requirements are established through the bridge permitting process and are based on factors such as the type of vessels using the waterway and future navigational considerations. AASHTO LRFD more towards the risk side, e.g., vessel collision. No specific rules for flood/storm surge.

### ***AASHTO Guide Specifications for Bridge Vulnerable to Coastal Storms [6]***

The AASHTO Guide specifies when practical, the vertical clearance of highway bridges should be sufficient to provide at least 1 ft of clearance over the 100-year design wave crest elevation, which includes the design storm water elevation.

### **Design for Bridge Scour**

NJDOT BDM [14] Section 39 offers insight into scour, referencing Subsection 2.6 of the AASHTO LRFD BDS and the AASHTO Model Drainage Manual [16] for hydrologic and hydraulic designs. Furthermore, some key items are summarized below.

- Scour Design Flood Guidance: HEC-18 recommends considering higher scour design flood (discharge) from 100-year flow to 200-year flow for risk reduction depending on hydraulic conditions and bridge importance.
- New Bridges: Design is based on the 100-year flood for scour, consistent with the NJDOT BDM [14] Section 39, while higher scour design flood of 200-year may be considered based on site-specific risk and criticality.

### **Design for Wind Load**

AASHTO LRFD BDS 9<sup>th</sup> Edition (2021) [17] has extensive design specifications regarding the wind load. A total of four limit states is involved for wind load from the AASHTO LRFD [17]. They are described below.

- Strength III – Load combination relating to the bridge exposed to the design wind speed at the location of the bridges.
  - Background: wind load provisions in earlier editions of specifications were based on fastest-mile wind speed measurements. The current wind load provisions are based on 3-second wind gust speed with 7 percent probability of exceedance in 50 years (MRI of 700 years, annual exceedance probability of  $1/700 = 0.001428$ )
- Strength V – Load combination relating to normal vehicular use of the bridge with wind of 80 mph velocity.
  - Background: when applied with the load factor specified in AASHTO LRFD Table 3.4.1-1, (i.e. 1.0), the 80 mph 3-second gust wind speed is equivalent to the 100 mph fastest-mile wind used in earlier specifications applied with a load factor of 0.4. The latter was meant to be equivalent to a 55 mph fastest-mile wind applied with a load factor of 1.4.
- Service I – Load Combination relating to the normal operational use of the bridge with a 70-mph wind and all loads taken at their normal values.
  - Background: When applied with the load factor specified in Table 3.4.1-1

(i.e., 1.0), the 70 mph 3-second gust wind speed is equivalent to the 100 mph fastest-mile wind used in earlier specifications applied with a load factor of 0.3. The latter was meant to be equivalent to a 55 mph fastest-mile wind applied with a load factor of 1.0.

- Service IV – Load combination relating only to tension in prestressed concrete columns with the objective of crack control.
  - Wind load for Service IV load combination in earlier specifications was based on fastest-mile wind of 100 mph applied with a load factor of 0.7. This load represents an 84 mph fastest-mile wind applied with a load factor of 1.0.

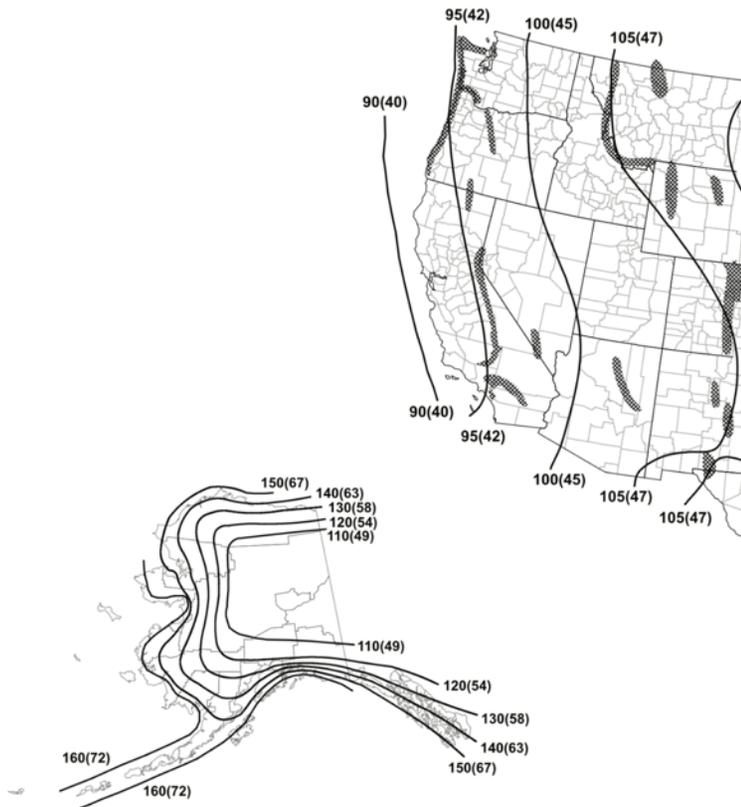
Based on ASCE 7-22 [9], the design wind speed is defined as the 3-second gust wind speed at 33 ft (10 m) above ground in Exposure C. Table 7 shows the specified Design 3-Second Gust Wind Speed for the four limit states mentioned above from AASHTO LRFD 9<sup>th</sup> [17]. However, the AASHTO LRFD 9<sup>th</sup> [7] references ASCE 7-10 [18] for the 3-Second Gust Wind Map. Figure 9 shows the updated 3-Second Gust Wind Map from ASCE 7-22 [9] for Risk Category II (Annual Exceedance Probability = 0.00143, Mean Recurrence Interval (MRI) = 700 years) used in AAASHTO LRFD BDS 10<sup>th</sup> [8]. The risk levels defined in ASCE 7-22 are listed below.

- Risk Category I, corresponding to a 15% probability of exceedance in 50 years
- Risk Category II, corresponding to a 7% probability of exceedance in 50 years
- Risk Category III, corresponding to a 3% probability of exceedance in 50 years.
- Risk Category IV, corresponding to a 1.6% probability of exceedance in 50 years.

Table 7 – AASHTO LRFD (2021) Design 3-Second Gust Wind Speed [17]

**Table 3.8.1.1.2-1—Design 3-Second Gust Wind Speed for Different Load Combinations,  $V$**

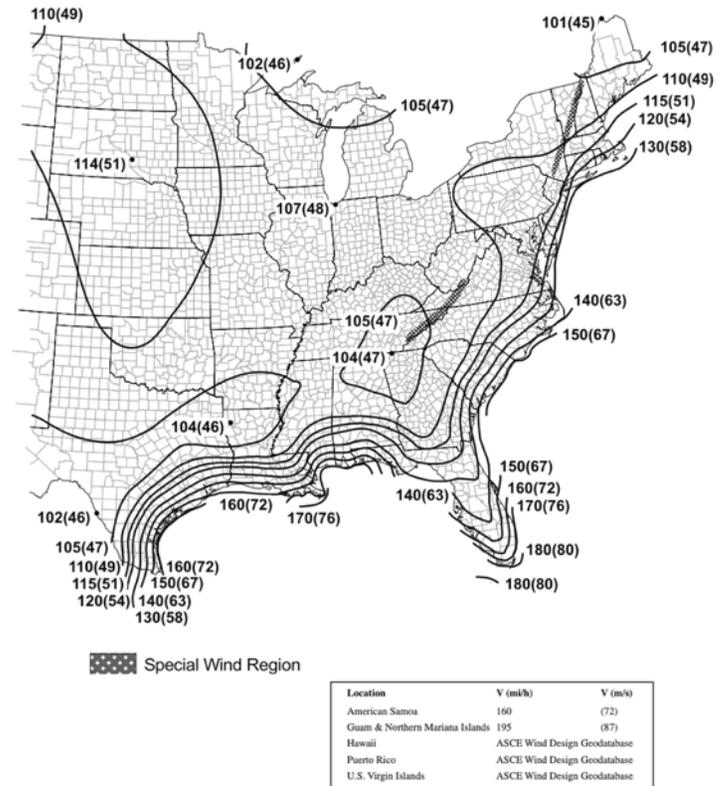
<b>Load Combination</b>	<b>3-Second Gust Wind Speed (mph), <math>V</math></b>
Strength III	Wind speed taken from <span style="border: 1px solid red; padding: 2px;">Figure 3.8.1.1.2-1</span>
Strength V	80
Service I	70
Service IV	0.75 of the speed used for the Strength III limit state



**Notes:**

1. Values are 3 s gust wind speeds in mi/h (m/s) at 33 ft (10 m) above ground for Exposure Category C.
2. Linear interpolation is permitted between contours. Point values are provided to aid with interpolation.
3. Islands, coastal areas, and land boundaries outside the last contour shall use the last wind speed contour.
4. Location-specific basic wind speeds shall be permitted to be determined using the ASCE Wind Design Geodatabase.

**Figure 26.5-1B. Basic wind speeds for Risk Category II buildings and other structures.**



Special Wind Region

Location	V (mi/h)	V (m/s)
American Samoa	160	(72)
Guam & Northern Mariana Islands	195	(87)
Hawaii	ASCE Wind Design Geodatabase	
Puerto Rico	ASCE Wind Design Geodatabase	
U.S. Virgin Islands	ASCE Wind Design Geodatabase	

5. Wind speeds for Hawaii, US Virgin Islands, and Puerto Rico shall be determined from the ASCE Wind Design Geodatabase.
6. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions. Site-specific values for selected special wind regions shall be permitted to be determined using the ASCE Wind Design Geodatabase.
7. Wind speeds correspond to approximately a 15% probability of exceedance in 50 years (Annual Exceedance Probability = 0.00143, MRI = 700 years).
8. The ASCE Wind Design Geodatabase can be accessed at the ASCE 7 Hazard Tool (<https://asce7hazardtool.online>) or approved equivalent.

**Figure 26.5-1B (Continued). Basic wind speeds for Risk Category II buildings and other structures.**

**Figure 9. ASCE 7-22 Basic wind speeds for Risk Category II (a 7% probability of exceedance in 50 years, Annual Exceedance Probability = 0.00143, MRI = 700 years) buildings and other structures [9]**

## Design for Vehicle Collision

AASHTO LRFD BDS 10<sup>th</sup> Edition [8] Section 3.6.5 has updates regarding the vehicle collision over the 9<sup>th</sup> Edition. The changes have been summarized below. These revisions should be incorporated into the current practices of design for vehicle collision.

- Clarified Engineering Responsibility
  - 10th Edition Addition: Emphasizes that assessments must involve input from highway safety and structural engineers.
  - Implication: Reinforces multidisciplinary review, especially for collision risk and mitigation design.
- Updated Load Basis Explanation
  - Clarified: The 600-kip static load is now explicitly tied to crash tests and finite element models of 80.0-kip trucks.
  - Implication: Adds rigor and transparency to the load derivation — practitioners must now recognize the dual-peak nature of truck impact (at 2 ft and 5 ft heights).
- Expanded Discussion on Column Failure Modes
  - 10th Edition Adds: Shear, flexural, and detailing vulnerabilities are discussed in more depth.
  - Implication: Designers are now explicitly advised to verify both shear and flexural capacity, when assessing vulnerability.
- Performance-Based Design Reference
  - New in 10th: Cites work by Agrawal et al. for using pulse-based analysis to model collision effects.
  - Implication: Suggests moving toward more nuanced, performance-based vehicle collision modeling.
- Removed Requirement for Train Collision Force
  - 10th Edition Removes: Legacy language about train collision force.
  - Implication: Train collision design now deferred entirely to AREMA or railroad guidelines, decoupling bridge design from rail considerations.
- Barrier Placement Guidance
  - Clarified: Placement of barriers closer than 3.25 ft is acceptable when geometry demands.
  - Implication: Introduces design flexibility for retrofits and constrained bridge footprints.

Furthermore, AASHTO Bridge Security Guidelines, 2nd Edition [7] states that vehicular collision is treated as an Extreme Event II load in LRFD load combinations with reduced or discarded live load because full traffic is unlikely during a collision event. It provides guidance on how to apply collision loads to critical members (piers, abutments, girders) within these extreme-event combinations, and an appropriate load factors for collision ( $\gamma_{CB}$ ) as specified in AASHTO LRFD.

## Design for Vessel Collision

For hazards such as vessel collision, methodologies from Subsection 3.14 of the AASHTO LRFD Bridge Design Specifications are employed. AASHTO Bridge Security Guidelines, 2nd Edition [7] provides more details on load combinations, and load factors for vessel collision.

## **Design for Blast Load**

The design for blast load in LRFD is addressed in the Extreme Event II limit state. Furthermore, the AASHTO Bridge Security Guidelines provided detailed design specifications for blast load design. The following should be considered, where it has been determined whether a bridge or a bridge component should be designed for intentional or unintentional blast force:

- Size of explosive charge
- Shape of explosive charge,
- Type of explosive,
- Stand-off distance,
- Location of the charge,
- Possible modes of delivery and associated capacities (e.g., maximum charge weight will depend upon vehicle type and can include cars, trucks, ships, etc.), and
- Fragmentation associated with vehicle-delivered explosives.

NCHRP Report 645 Blast-Resistant Highway Bridges Design and Detailing Guidelines [19]: this report developed design and detailing guidelines for improving the structural performance and resistance to explosive effects for new and existing bridges.

## **Design for Fire**

NJDOT BDM [14] section 41.2 (vulnerability assessment) has limited information about considering protection measures from fire hazard. NCHRP 12-85 Highway Bridge Fire Hazard Assessment [13] provides guide specifications for fire damage evaluation in steel bridges.

## MULTI-HAZARD INTERACTION AND LOAD COMBINATIONS

Multi-hazard design shall apply AASHTO LRFD Table 3.4.1-1 for Extreme Event I and II, consider correlated/cascading events (e.g., flood + scour, seismic + fire), and include long-term hazard evolution due to climate change. Design should address the followings:

- Concurrent hazards (e.g., wind and flood)
- Sequential hazards (e.g., earthquake followed by fire)
- Compounding effects (e.g., scour weakening before vessel collision)

### Extreme Events and Load Combinations

Table 8 – AASHTO LRFD (2024) Load Combinations

Table 3.4.1-1—Load Combinations and Load Factors

Load Combination Limit State	DC DD DW EH EV ES EL PS CR SH	LL IM CE BR PL LS	WA	WS	WL	FR	TU	TG	SE	Use One of These at a Time				
										EQ	BL	IC	CT	CV
Strength I (unless noted)	$\gamma_P$	1.75	1.00	—	—	1.00	0.50/1.20	$\gamma_{TG}$	$\gamma_{SE}$	—	—	—	—	—
Strength II	$\gamma_P$	1.35	1.00	—	—	1.00	0.50/1.20	$\gamma_{TG}$	$\gamma_{SE}$	—	—	—	—	—
Strength III	$\gamma_P$	—	1.00	1.00	—	1.00	0.50/1.20	$\gamma_{TG}$	$\gamma_{SE}$	—	—	—	—	—
Strength IV	$\gamma_P$	—	1.00	—	—	1.00	0.50/1.20	—	—	—	—	—	—	—
Strength V	$\gamma_P$	1.35	1.00	1.00	1.00	1.00	0.50/1.20	$\gamma_{TG}$	$\gamma_{SE}$	—	—	—	—	—
Extreme Event I	1.00	$\gamma_{EQ}$	1.00	—	—	1.00	—	—	—	1.00	—	—	—	—
Extreme Event II	1.00	0.50	1.00	—	—	1.00	—	—	—	—	1.00	1.00	1.00	1.00
Service I	1.00	1.00	1.00	1.00	1.00	1.00	1.00/1.20	$\gamma_{TG}$	$\gamma_{SE}$	—	—	—	—	—
Service II	1.00	1.30	1.00	—	—	1.00	1.00/1.20	—	—	—	—	—	—	—
Service III	1.00	$\gamma_{LL}$	1.00	—	—	1.00	1.00/1.20	$\gamma_{TG}$	$\gamma_{SE}$	—	—	—	—	—
Service IV	1.00	—	1.00	1.00	—	1.00	1.00/1.20	—	1.00	—	—	—	—	—
Fatigue I— LL, IM & CE only	—	1.75	—	—	—	—	—	—	—	—	—	—	—	—
Fatigue II— LL, IM & CE only	—	0.80	—	—	—	—	—	—	—	—	—	—	—	—

Table 9 – Recommendations on Load Combinations

Load Type	Permanent	Transient									Extreme (Transient)				
		LL IM CE BR PL LS	WA	WS	WL	FR	TU	TG	SE	Use One of These at a Time					
Load Combination Limit State	DC DD DW EH EV ES EL PS CR SH									EQ	BL	IC	CT	CV	
Seismic - (High Level) Critical or Recovery	1.00	$\gamma_{EQ}^*$	1.00	-	-	1.00	-	-	-	1.00	-	-	-	-	
Seismic - Other (Lower Level)	1.00	-	1.00	-	-	1.00	-	-	-	1.00	-	-	-	-	
Blast, Vessel Collision, Vehicle Collision, Ice Load	1.00	$\gamma^*$	1.00	-	-	1.00	-	-	-	-	1.00	1.00	1.00	1.00	
Coastal Bridge - Critical or Recovery (High Level)	1.00	$\gamma_{CB}^*$	1.75	1.00	1.00	-	-	-	-	-	-	-	-	-	
Coastal Bridge - Other (Lower Level)	1.00	-	1.00	1.00	-	-	-	-	-	-	-	-	-	-	

**Coastal Bridge Design Guidance in Multi-Hazard Load Combinations**

A hurricane is a powerful tropical cyclone with strong winds, heavy rainfall, and storm surges, capable of causing widespread damage and flooding. The following design considerations should be taken for design of coastal bridges.

- Wind Loads:
  - Design structures to withstand high wind speeds associated with hurricanes.
  - Perform structural analysis to ensure that bridges and other structures can withstand the wind speeds expected during a hurricane.
- Flood and Surge:
  - Water load: static pressure, buoyancy, stream pressure, wave load, change in foundations due to limit state for scour (not a force effect, but might significantly alter the consequences of force effects on structures)
  - Consider the combined effects of heavy rainfall, storm surge, and wind: ensuring that all potential impacts are considered. Ensure that critical components are protected against both wind and water forces.
  - Design the bridge to handle elevated water levels and wave action from storm surge.

- Debris Impact:
  - Account for the impact of wind-borne debris on structures. Incorporate features that protect against debris impacts.
  - Design structures to resist impacts from debris carried by high winds or floodwaters, such as robust guardrails and reinforced piers.
  - Use materials and construction techniques that provide resilience against debris impact.

The design event should be assumed to be a 1 in 100-year event. 100-year return period wind velocity combined with the 100-year return period wave height (and period), the 100-year return period water level, and the 100-year return period current speed (AASHTO 2023). This applied to both Critical or Recovery bridges and other bridges. Load factors for water load (WA) of 1.75 will be used to differentiate the probability, while WA load factor AASHTO LRFD BDS Interim Revision [20] is 1.0.

For Critical or Recovery bridges (High Level), live load,  $\gamma_{CB} = 1.0$ , is recommended in load combination to accommodate the use for traffic. For Other bridges (Lower Level), no live load is recommended.

Several design strategies can be utilized to design coastal bridges:

- Avoiding Wave Loads
- Accommodating Full Loads
- Accommodating Partial Loads with Superstructure Repairable Damage
- Submergence

#### Force Mitigation

Where it is not possible to provide the vertical clearance recommended in Article 4.2, the following may be considered to reduce the wave forces acting on the superstructure:

- Setting the vertical elevation as high as practical
- Using open or sacrificial parapets and adjusting the parameter  $r$  in Articles 6.1.2.2.3, 6.1.2.2.4, 6.1.2.3.1 and 6.1.2.3.4
- Venting the cells that could potentially entrap air, resulting in increased buoyancy forces and adjusting the parameter TAF (trapped air factor) in Article 6.1.2.2.1 to account for the venting
- Using large holes in concrete diaphragms or framed cross-frames and end diaphragms on concrete superstructures to promote venting and the exchange of trapped air between spans, and adjusting the parameter TAF in Article 6.1.2.2.1
- Using continuous superstructures to increase the reactive force of individual spans
- Using solid or voided slab bridges to reduce buoyancy forces

#### Force Accommodation

Where wave and surge forces cannot be fully avoided or reduced to acceptable levels through elevation and force mitigation measures, the bridge shall be proportioned and detailed to accommodate the factored wave demands without loss of support or disproportionate damage. Force accommodation focuses on providing sufficient strength, stability, ductility, and robustness in the superstructure, substructure, bearings, and connections so that primary load paths remain intact even when local damage occurs.

### Limit States and Performance Objectives for Bridges, or Spans of Bridges

This is for the bridges that cannot be raised above the wave zone. Bridge designated as “critical/essential” by the owner should be designed at the strength limit state using Eq. 5.2-1 to achieve a performance level of “service immediate” or “repairable damage,” depending on how quickly they must be passable after the hurricane.

"Typical bridges," considered secondary to rescue and recovery, may be designed at the extreme event limit state for the performance level of major repair or replacement needed, primarily due to superstructure dislodgement. Where bridges are designed for the strength limit state, the following load combination shall be considered, in addition to the minimum load specified in Article 5.3, for bridges vulnerable to wave and surge forces associated with coastal storm:

$$\gamma_p DC + \gamma_p DD + \gamma_p DW + \gamma_p EL + \gamma_{wave} WA$$

where:

DC = dead load of structural components and nonstructural attachments

DD = down drag

DW= dead load of wearing surfaces and utilities

EL = accumulated locked-in force effects resulting from the construction process, including the secondary forces from post-tensioning

WA = wave forces  $F_v$ ,  $F_s$ ,  $F_H$  and  $M_T$  as specified in Articles 6.1.2 and 6.1.3

$\gamma_p$  = minimum load factors for dead loads as specified in Article 3.4.1 of the AASHTO LRFD Bridge Design Specifications (AASHTO, 2007)

$\gamma_{wave}$  = load factors on wave forces, 1.75 for strength limit state, 1.0 for extreme limit state

### **Blast, Vessel Collision, Vehicle Collision, Ice Load Design Guidance in Multi-Hazard Load Combinations**

For both Critical or Recovery bridges, and other bridges, live load,  $\gamma$ , is recommended in load combination to accommodate the use for traffic.

- The live load factors can be further divided for cases: (1) open to emergency vehicles, (2) open to all traffic, once inspected.
- AASHTO LRFD BDS Interim Revision [20] recommended  $\gamma = 0.5$

### **Seismic Design Guidance in Multi-Hazard Load Combinations**

For Critical or Recovery bridges (High Level), live load ( $\gamma EQ$ ) is recommended in load combination to accommodate the use for traffic. The live load factors can be further divided for cases: (1) open to emergency vehicles,  $\gamma EQ = 0.75$ , (2) open to all traffic, once inspected,  $\gamma EQ = 1.0$ . For Other bridges (Lower Level), live load is not included in the EQ load combination. Guide Specifications for Seismic Isolation Design can be applied for both conventional and non-conventional bridges

Table 10 – Applicable AASHTO Specifications and Risk Levels for Seismic Design

Bridge Types	Bridge Criticality	AASHTO Specifications	Risk level
Conventional	Critical or Essential	AASHTO Guide	Seismic Risk: 1.5% in 75 years
	Other	Specifications for LRFD Seismic Bridge Design	Seismic Risk: 1.5% in 75 years
Non-conventional	Critical or Essential	AASHTO Guidelines for	Hazard Risk: 50% in 75 years
	Other	PBSBD	Hazard Risk: 7% in 75 years

## **STRUCTURAL SYSTEM DESIGN AND DETAILING**

In a multi-hazard environment, overall structural system configuration and detailing are as important as the selection of individual design loads. Bridge systems should be proportioned and detailed so that damage remains ductile and localized, alternate load paths are available, and disproportionate or progressive collapse is avoided even when one or more components are damaged by an extreme event.

### **Superstructure**

Design the superstructure to provide ductility, redundancy, and robustness

- Provide multiple, well-connected girder lines or other redundant load-carrying elements wherever feasible so that the loss or impairment of a single element does not lead to collapse.
- Use continuous spans where possible to promote redistribution of forces, reduce unseating risk at supports, and improve performance under seismic, collision, and flood-induced demands.
- Design girders, diaphragms, and cross-frames details to encourage ductile behavior and to develop predictable, non-brittle failure modes under extreme events.
- Where fracture-critical elements cannot be avoided, provide system-level redundancy (e.g., additional girders, continuity, and robust cross-frame systems) and ensure access for inspection and future retrofit.
- Coordinate the number of deck joints and expansion devices minimized, protected, and located where maintenance and replacement can be undertaken without compromising overall system performance.

### **Substructure and Foundations**

Substructure and foundation systems shall be configured to support multi-hazard demands and limit detrimental secondary effects.

- Employ deep foundations in scour-prone or liquefaction zones, or provide adequately embedded spread footings where geotechnical conditions permit, in coordination with geotechnical investigations and scour analyses.
- Consider interaction between soil and structure under lateral loading, including kinematic demands from seismic ground motions, lateral spreading, and debris or collision forces from flowing water and ice.
- Consider secondary effects such as P-delta under lateral loading when evaluating pier and column stability under seismic, collision, wind, and flood demand.
- Orient pile groups, shafts, and pier stems, where practical, to optimize resistance to predominant flow and impact directions, while maintaining constructability and long-term durability.
- Detail abutments, wingwalls, and retaining elements to avoid brittle failures and to account for earth pressure changes associated with flooding, scour, and long-term settlement.

## **Connections and Bearings**

Connections and bearings are critical to multi-hazard performance and should be detailed to maintain support, accommodate movement, and control forces.

- Detail for uplift resistance, impact, and thermal movement by providing positive anchorage, adequate seat widths, keeper plates, dowels, and restraints that limit relative displacements and prevent unseating.
- Where feasible, use integral or semi-integral abutments to eliminate bearings and reduce maintenance, while still accommodating thermal, shrinkage, and creep movements within acceptable limits.
- Ensure that bearings and connections can accommodate the combined deformations from thermal effects, seismic displacements, settlement, and differential movements induced by scour or foundation rotation.
- Use sacrificial elements to manage blast or collision where appropriate (e.g., shear keys, stops, or selected bearings designed to yield or fail in a controlled manner), protecting primary load-carrying members from catastrophic damage.
- Provide adequate access for inspection, maintenance, and replacement of bearings and critical connections to support long-term resilience and recovery following hazard events.

## **Energy Dissipation and Resilience**

Energy-dissipation and displacement-control devices can significantly improve performance under multiple hazards

- Include restrainers, shear keys, dampers, and fuse mechanisms to limit relative displacements, control impact forces, and provide defined locations for damage under seismic, collision, and wave or surge loading.
- Where isolation bearings or damping devices are used, integrate their behavior into global analysis and verify that other components (e.g., substructure, foundations) remain within acceptable demand and deformation limits.
- Design fuse and sacrificial elements so that they are clearly identifiable, accessible, and replaceable after an event, with defined inspection and replacement criteria documented in the bridge records.
- Evaluate the system response considering potential sequential or compounding hazards (e.g., post-earthquake flooding or scour) to ensure that damage to energy-dissipation devices does not compromise the ability of the system to withstand subsequent events.

## RISK-BASED PRIORITIZATION OF BRIDGES (CRITICALITY)

### Risk Classification

Bridges should be classified by criticality and exposure, with higher performance requirements for emergency and evacuation routes, lifeline infrastructure, and urban corridor crossings. A structured risk classification helps NJDOT allocate resources toward the bridges whose loss would have the greatest safety, mobility, and economic consequences, and provides a basis for defining performance objectives and design requirements.

### Step 1: Determine Criticality Factor

$CF = S^2 + ExD$  (Eq 1.2-1, AASHTO Bridge Security Guidelines)

- S = Symbolic Importance (Importance, location of the bridges)
  - Symbolic importance reflects how “visible” or strategically important the bridge is within the transportation network and community. Bridges serving major interstate routes, key river crossings, or locations adjacent to critical facilities (e.g., hospitals, ports, power plants) may be assigned higher symbolic importance. This factor also captures structures that, if damaged, would have a significant social or political impact beyond simple traffic delay.
- E = Economic Importance (Traffic size)
  - Economic importance is primarily related to traffic volume, vehicle mix (e.g., trucks, transit), and the role of the bridge in freight, commuting, and regional commerce. Bridges that carry high AADT, high truck percentages, or provide unique access to industrial areas, logistics hubs, or ports should receive higher E values. This factor recognizes that the loss of certain bridges can result in substantial economic disruption, even if there are alternate routes.
- D = Detour Impact (Alternativeness)
  - Detour impact reflects the availability, length, and capacity of alternate routes if the bridge is closed. Bridges with long detours, low-capacity alternate routes, or limited redundancy in the network will have higher D values. This factor is particularly important for rural or constrained urban corridors where a single structure carries most of the traffic across a river, rail corridor, or other barrier.

Once bridges are prioritized using the Criticality Factor, individual components within bridges should be prioritized. Bridges with high CF values become candidates for enhanced multi-hazard design, monitoring, and retrofit, recognizing that not all structures can be upgraded at the same time.

### Step 2: Evaluate Risk-based Prioritization of Bridge Components

$$R = \sum [I_j \sum (O_{ij} V_{ij})]$$

- $I_j$  = Component Importance (load path, redundancy)
  - Component importance reflects the role of a given element (e.g., girder, floorbeam, connection, bearing, foundation) in maintaining global stability and serviceability. Components that are fracture critical, non-redundant, or difficult to inspect and repair may receive higher  $I_j$  values. This term captures how the loss or impairment of a single component could affect overall bridge performance.
- $O_{ij}$  = Threat Occurrence (probability)
  - Threat occurrence represents the likelihood that a given hazard (e.g., flood, scour, collision, blast, fire) will affect that component during the bridge's service life. This factor can be informed by hazard maps, historical data, site conditions, and expert judgment. Higher  $O_{ij}$  values are assigned where exposure is frequent or intense, such as piers in deep, fast-flowing channels or columns adjacent to high-speed roadways.
- $V_{ti}$  = Component Vulnerability
  - Component vulnerability describes how susceptible the component is to damage if the hazard occurs, considering detailing, material properties, age, condition, and existing protective measures. For example, an unprotected, corroded steel girder near a roadway might have higher vulnerability to fire or collision than a well-protected, redundant system.

The approach from the AASHTO Bridge Security Guidelines is complicated, and it may be impractical to implement in its full quantitative form for all NJDOT bridges. For many applications, the same framework can be applied qualitatively or semi-quantitatively (e.g., using rating scales and decision matrices) to rank components within high-criticality bridges and to identify where multi-hazard retrofits, monitoring, or additional analysis will provide the greatest risk reduction.

## **CURRENT PRACTICES**

### **Inspection, Maintenance, and Retrofit Guidance**

The bridge designer plays a crucial role in inspection, maintenance, retrofit, and the recovery process from a bridge failure. During the design of the structure, designers, operators, maintainers, and owners should perform a fault-tree analysis to identify potential events that could lead to a bridge failure. This analysis helps prevent the need for forensic engineering after a failure by ensuring that the design addresses weaknesses that could cause malfunction or failure.

The work of the bridge designer is essential in preventing failures and enhancing the resilience of bridge design. They must consider all extreme accidents and structural degradation effects throughout the service life of a bridge. This includes addressing issues related to failures due to natural and manmade hazards the bridge may encounter during its service life and consider and prepare for possible responses that may be appropriate. By focusing on robustness, redundancy, reparability, and the agency's response, bridge designers can reduce the downtime of a facility post-event. This approach ensures that bridges are designed to be more resilient and capable of withstanding various extreme actions and long-term deterioration.

Responses to bridge emergencies, regardless of type and size, can be divided into four phases: Preparedness, Response, Recovery, and Post-Event. There are two levels of the Preparedness phase – overall agency preparedness and event preparedness – but most themes and subcategories are duplicated across these levels, so they are not broken out and discussed separately. It is important to note that these four phases create a cycle where the post-event actions inform or even serve as Preparedness activities for the next event.

### **Response Guidelines**

Standard procedures for emergency response that are implementable, quickly accessible, and easy to follow are extremely helpful during an emergency event. Procedures should be scalable to the type and size of emergency events and should include communication protocols. Caltrans has a First Responder Bridge Assessment Guide. This guide was developed for the use of Caltrans maintenance crews to report accurate bridge damage information to the Structure Maintenance and Investigation (SM&I) Bridge Emergency Response Center (BERC) in Sacramento to make decisions to close a bridge. The guide summarizes SM&I's emergency operation, damage response thresholds, and spells out the type of information to be reported by first responders, which include California Highway Patrol and other state departments responding to the emergency. Caltrans procedures include a hierarchy of emergencies, from Level 1 (widespread) to Level 3 (localized).

Minnesota DOT has established procedures that include checklists broken down for responses to different types of emergencies. Appendix J of the MnDOT Bridge Inspection Manual has an overall flow chart for response to bridge and tunnel emergencies. MnDOT's checklist for bridge hit (high load) response is further broken down into structure type, and they also have a checklist for post-flood even response. All these documents

are accessible on MnDOT’s website.

Clear, concise guidelines improve response times by ensuring that response staff is not searching for or interpreting procedures. Pocket guides and checklists are good examples of concise guidelines. Missouri DOT has a laminated “cheat sheet” (see Figure 10) that is carried by all bridge inspection staff. Washington DOT has an index-card size pocket guide titled “Preliminary Damage Assessment Guide” that is required to be carried by field staff.

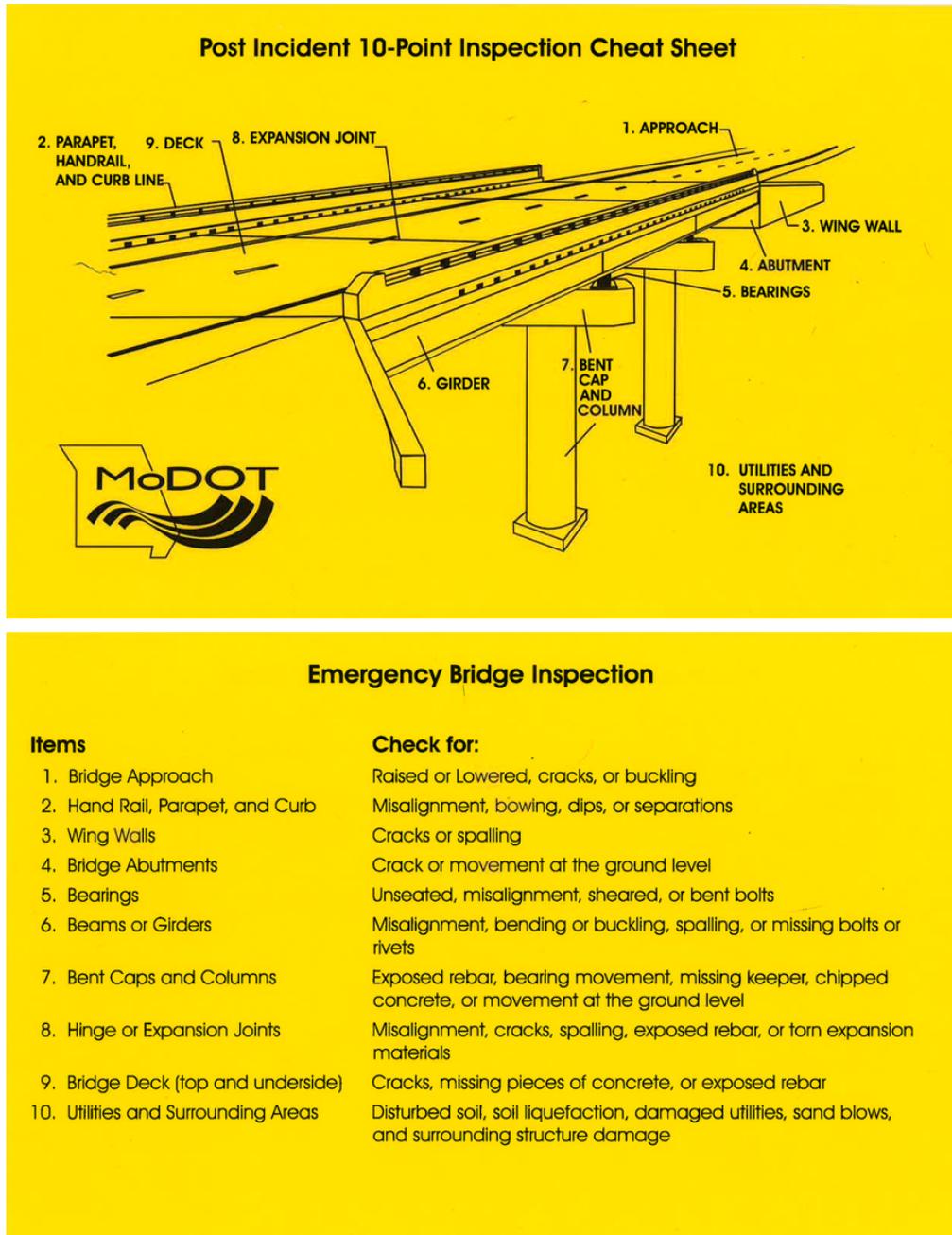


Figure 10. ASCE MoDOT Bridge Assessment Cheat Sheet

## **Training**

A key component in the Preparedness Phase is ensuring staff are well-trained for all types of emergencies. The best training programs include tabletop exercises and mock events to enhance the agency's readiness for an event. The Great Shakeout is an annual earthquake preparedness event that includes millions of participants from around the world. Both Utah DOT and Washington DOT, among others, use this event as a training opportunity for their personnel. Minnesota DOT conducts flood drills on a routine basis and provides training for staff for high angle rescues.

## **Standards**

The use of standards allows for expedited recovery. By using pre-established details and specifications, recovery efforts can proceed without waiting for specific designs or specialized fabrication of structural elements in many emergency responses. Texas DOT uses standard prestressed concrete girders, and KYTC has standard beam tables which allow for quick designs in a rapid response situation.

## **Resources**

Having critical resources available and well-positioned reduces lead time during an emergency response. NYSDOT has a program to stockpile long-lead items. They have several temporary bridges stored throughout the state and ready to be rapidly deployed when needed. Precast box culverts of standard sizes, such as 24'x10' and 16'x8', are stockpiled in various maintenance yards and excess state properties to aid in responding to culvert and smaller bridge closures.

Florida DOT has a program to deploy base camps in advance of imminent hurricanes. These base camps provide shelter to responders without taking critical hotel rooms needed for evacuees. One key is to ensure they are properly positioned to be close enough for rapid deployment without being directly in the impact zone of the hurricane.

## **Contracts**

Emergency contracting methods and rapid procurement procedures are excellent tools to ensure the agency can bring in additional resources quickly. Both Georgia DOT and MnDOT, among many other states, have emergency contracting procedures that allow the DOT to quickly contract out work when additional support is needed.

## **Software Tools**

Many states DOT's use technology, such as dashboards and mobile applications, to speed up communication as well as data collection and transfer. Caltrans uses ShakeCast for help with determining potential impact areas from earthquakes. Vermont Agency of Transportation uses ESRI tools to track response events.

## **Emergency Funding**

States vary in their approach to funding emergencies, with many just adjusting budgets whenever an emergency occurs. However, an efficient approach found by the scan team appears to be having a dedicated emergency funding source available to help with timely action. For example, Minnesota has a special state emergency fund that serves this need.

### ***Detour/Evacuation Routes***

Planning associated with detours helps prevent gridlock in an emergency. Using innovative traffic management solutions, such as contraflow or emergency shoulder running on evacuation routes helps move traffic more efficiently. Florida DOT has a program to allow for emergency shoulder use in evacuations on preplanned routes. Texas DOT sets up contraflows on preplanned interstate routes in similar scenarios.

### ***Innovation***

Emerging technologies enhance safety and efficiency. There are various tools coming into the marketplace that allow for better, often unmanned, access, which is safer for personnel and allows for quicker response times. Texas DOT uses a robotic canine to enter spaces humans cannot or may not be able to access. Drone use has expanded exponentially over the past few years and allows for innovative response.

### **Response Phase**

The Response Phase includes the immediate actions taken after an emergency event occurs. During this phase, communication is the most critical aspect to having a successful response to the event. Assessing the size, scope, and impact of the event is the focus of the agency during this phase. A summary can be found in Table 11, with additional elaboration in the subchapters that follow.

Table 11 – Response Phase Summary

<b>Subcategory</b>	<b>Key Findings and Notable Practices</b>
Communication and Coordination	<ul style="list-style-type: none"><li>• Redundant communication systems essential.</li><li>• Notable Practice: Kentucky &amp; Texas deploy satellite systems.</li></ul>
Event Initiation and Triage	<ul style="list-style-type: none"><li>• Triage based on severity optimizes resources.</li><li>• Notable Practice: Caltrans ShakeCast prioritization.</li></ul>
Structure Evaluation	<ul style="list-style-type: none"><li>• Initial damage assessments must be rapid and standardized.</li><li>• Notable Practice: Utah Emergency; Washington PDA guides.</li></ul>
Closures and Detours	<ul style="list-style-type: none"><li>• Immediate communication of closures improves safety.</li><li>• Case Study: Georgia DOT I-16 Bridge Strike.</li></ul>
Reporting and Data Collection	<ul style="list-style-type: none"><li>• Automated dashboards streamline reporting.</li><li>• Notable Practice: Florida DOT integrates FEMA reporting.</li></ul>

### ***Communication and Coordination***

Redundant communication systems in an emergency are essential. KYTC’s emergency response has a significant focus on redundant communication by using Starlink, Sat phones, CB radios, and Cellular on Wheels (COWs) devices. Utah DOT uses software apps that also work offline. Including both low tech and high-tech options for documentation helps accomplish this redundancy as well.

### ***Event Initiation and Triage***

Triage the event based on the level or hierarchy of emergencies allows the agency to scale the response to the event and more efficiently use resources. Caltrans, among others, uses ShakeCast to get an understanding of the size and scale of a seismic event, allowing them to rapidly focus resources where needed. Having an emergency hierarchy or prioritization process in place will help inform the triage effort at the beginning of the response.

### **Structure Evaluation**

It is important that initial damage assessments be rapid and standardized. For large scale events, simplistic system for identifying which bridges have been assessed and their initial condition is a powerful addition to the initial damage assessment process. Utah DOT, CalTrans, and Washington DOT all use stickers to tag bridges that have been assessed and identify the condition of the bridge, whether the bridge is safe to open, needs to remain closed, or requires further evaluation before the bridge can be reopened. Washington DOT has a pocket guide mentioned earlier that bridge evaluators carry to guide the evaluation process.

### **Closures and Detours**

Implementing and communicating closures and detours enhance public safety and increase the efficiency of the response time. Many state DOTs communicate with navigation apps. NJDOT does a tremendous job of communication closures through media outlets, press releases and VMS.

### **Reporting and Data Collection**

Automated dashboards are an effective way to streamline the reporting and data collection effort. Several states, including Florida and Kentucky, use dashboards that support automated reporting. Minnesota and Vermont, among others, have automated systems that create specialized reports that provide data needed by FEMA or FHWA as well as useful information to help the public and agency decision-makers. Florida and Georgia DOTs have debris tracking systems to help collect real-time and accurate data needed as documentation for future reimbursement efforts.

### **Recovery Phase**

Once the event has been triaged, the response team moves into the Recovery Phase. During this phase, efforts transition from initial and immediate assessment to focusing on repairs to be able to reopen bridges. A summary can be found in Table 12, with additional elaboration in the subchapters that follow.

Table 12 – Recovery Phase Summary

<b>Subcategory</b>	<b>Key Findings and Notable Practices</b>
Resource Reallocation	<ul style="list-style-type: none"><li>• Shifting personnel accelerates recovery.</li><li>• Notable Practice: Washington SIP protocols.</li></ul>
Deploying Additional Resources	<ul style="list-style-type: none"><li>• Mobilizing temporary structures quickly is critical.</li><li>• Case Study: NYSDOT Superbox Program.</li></ul>
Emergency Contracting	<ul style="list-style-type: none"><li>• Flexible contracting reduces delays.</li><li>• Notable Practice: Georgia DOT expedited contracts for I-85 fire.</li></ul>
Reporting and Reimbursement	<ul style="list-style-type: none"><li>• Accurate documentation ensures funding eligibility.</li><li>• Notable Practice: Minnesota automated reporting.</li></ul>

### **Resource Reallocation**

The ability to shift resources from “response” activities to “recovery” activities accelerates the recovery time. Washington DOT has protocols for reallocating key maintenance personnel to recovery efforts during the emergency response. These protocols include the ability to reallocate forces from other parts of the state to the impacted area.

### **Deploying Additional Resources**

During the Recovery Phase, it is important to be able to quickly deploy additional resources, such as equipment and materials, to the personnel performing recovery efforts. NYSDOT has a material stockpiling program mentioned earlier that allows response staff access to structures, such as temporary bridges and precast concrete box culverts, so that lead times for these items are minimized or eliminated.

### **Emergency Contracting**

As mentioned in the Preparedness Phase, the ability to quickly procure additional support, whether personnel, equipment, materials, etc., helps the agency have a successful emergency response. Using these emergency contracting methods during the Recovery Phase helps expedite the reopening of bridges. Georgia DOT used expedited contracting during the recent response to the I-85 bridge fire.

### **Reporting and Reimbursement**

Developing accurate documentation throughout the Recovery Phase helps ensure funding eligibility when reimbursement requests are submitted. Vermont and Minnesota have developed reporting systems that use the collected field data to produce FEMA or FHWA specific reports to streamline the reimbursement approval process. It should be noted that there is often time limits associated with emergency procurement that need to be adhered to ensure compliance with reimbursement eligibility rules.

### **Post-Event Phase**

Once the event has been resolved, the response team moves into the Post-Event Phase. During this phase, the team focuses on documentation for the event and getting the applicable reimbursements. As noted in the beginning, this phase also informs the Preparedness Phase for the next bridge emergency. A summary can be found in Table 13, with additional elaboration in the subchapters that follow.

Table 13 – Post-Event Phase Summary

<b>Subcategory</b>	<b>Key Findings and Notable Practices</b>
After Action Review	<ul style="list-style-type: none"><li>• Formal reviews identify gaps and drive improvement.</li><li>• Notable Practice: Georgia after-action reports; FL statewide debriefs.</li></ul>
Resource Recovery	<ul style="list-style-type: none"><li>• Inventory check-in/out and restocking protocols maintain readiness.</li><li>• Notable Practice: NYSDOT restocking procedures.</li></ul>
Risk Mitigation	<ul style="list-style-type: none"><li>• Incorporating resilience measures reduces future risk.</li><li>• Notable Practice: Washington seismic retrofits.</li></ul>

### ***After Action Review***

Once the emergency has been mitigated, an in-depth formal review may occur to identify gaps and drive improvement in processes and guidelines for future events. Georgia DOT develops formal after-action reports and distributes them to all participants in the event. Florida DOT holds statewide debriefs after hurricane responses.

### ***Resource Recovery***

After the emergency is resolved, having the team follow inventory check-in/out and restocking protocols helps maintain readiness for future events. As part of their stockpile program, NYSDOT has restocking procedures that ensure the stockpiled materials, including temporary bridges and precast concrete box culverts, remain available.

### ***Risk Mitigation***

Incorporating resilience measures in the bridge inventory after an emergency event helps reduce risks for future emergencies. One example of this effort is with Washington DOT and their program to perform seismic retrofits after a seismic event has occurred.

### ***Post-Hazard Inspection***

Establish protocols per FHWA Emergency Response Guide or modeled after other state guidelines as outlined above, and deploy rapid inspection technologies (e.g., drones, sensors). These protocols should define clear roles, responsibilities, and communication channels so that inspections can be initiated and completed quickly after an event. They should also include criteria for when bridges can be reopened, require load posting, or must remain closed pending further evaluation. Documentation from post-hazard inspections should be archived in the asset management system to inform future design, retrofit, and emergency planning decisions.

### ***Monitoring Systems***

Install scour probes, strain gauges, accelerometers on critical bridges. Monitoring data should be regularly reviewed and compared against predefined thresholds to identify unusual behavior or emerging distress. When threshold values are exceeded, the system should trigger alerts that prompt targeted field inspections, temporary traffic restrictions, or other short-term risk-reduction measures. Long-term trends from monitoring can also be used to refine design assumptions, validate analytical models, and prioritize future rehabilitation or replacement projects.

### ***Retrofit Techniques***

Seismic retrofitting (column jacketing, base isolation) and scour retrofitting (riprap, micropiles) strategies should be selected based on site-specific hazards, bridge importance, constructability constraints, and life-cycle cost considerations. Priority should be given to bridges that are critical to emergency response, freight movement, and regional connectivity, recognizing that incremental retrofits can be phased over time. Retrofit designs and construction records should be documented so that future evaluations and modifications can appropriately account for the improved capacity and remaining vulnerabilities of the retrofitted bridge.

## **IMPLEMENTATION GUIDELINES**

### **Integration into NJDOT Bridge Design Manual (BDM)**

Update the NJDOT Bridge Design Manual with multi-hazard sections. These sections should summarize the risk classification process, hazard characterization, climate and future-condition considerations, structural system design and detailing guidance, and post-event inspection and retrofit strategies. Cross-references to relevant AASHTO LRFD provisions, NJDOT policies, and example design problems should be incorporated so that designers can readily apply the multi-hazard framework within the existing BDM structure. Clear triggers should be defined for when multi-hazard provisions are required or recommended (e.g., for new critical bridges, major rehabilitations, or projects located in high-risk coastal or flood-prone areas).

### **Coordination**

Work with FEMA (flood maps), NJDEP (flood rules), USCG (vessel clearance). Early coordination with these agencies is essential to ensure that hazard data, regulatory requirements, and navigational needs are properly reflected in project scoping and design criteria. Designers should use the latest effective FEMA flood insurance rate maps and related products, confirm applicable NJDEP flood hazard and coastal regulations, and coordinate with USCG to confirm required vertical and horizontal clearances and any navigation-related constraints. Regular communication during planning and design can help avoid conflicting requirements, reduce permitting delays, and support the selection of multi-hazard adaptation measures that are both technically sound and regulatory compliant.

### **Permitting**

Address environmental impact for adaptation features. Adaptation strategies such as elevating approach roadways, adding floodwalls or scour countermeasures, or modifying channel geometry can have environmental and community impacts that must be evaluated under applicable federal, state, and local permitting processes. Designers should identify these potential impacts early, document avoidance and minimization efforts, and coordinate with NJDEP and other permitting agencies to develop acceptable mitigation measures where needed. Submit resilience checklists with bridge design submissions. These checklists should document the hazards considered, performance objectives, climate and future-condition assumptions, and multi-hazard design and detailing decisions. Incorporating such checklists into the design submission process promotes consistency, improves transparency, and provides a record that can be used for future evaluations, retrofits, and updates to NJDOT policy.

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## APPENDIX A: STATE DOTs' RESOURCES

This section provided a detailed review of practices from various state DOTs regarding the various hazards, such as wind, earthquake, scour, flood, storm surge, vehicle collision, vessel collision, blast, and fire. This detailed table provides an overview of each state's approach to handling different hazards in bridge design, reflecting their adherence to standards, advanced practices, or any unique considerations.

### **NYSDOT (New York)**

New York has a concise manual. The wind load is under standard specifications. The wind states changes made between different guideline versions. Notable earthquake retrofitting specifications by the NYSDOT manual, and certain bridges are classified as more susceptible to seismic damage than others. The scour analysis is very in depth; it accounts for temporary structures along with waterways that are associated with vessels. There is standard vessel and vehicle bridge specifications along with maintenance of rails used for impact resistance. Little to no mention of blast or fire design specifications. The fire design accounts for different materials such as wood members.

- Wind
  - Considered as lateral forces that the designer should keep in mind
  - Considered in pier design as an intermediate support for a bridge superstructure, between the abutments, extending from below the ground surface to the bottom of the superstructure.
- Earthquake
  - Base isolation bearings are a type of bearing designed to minimize the transfer of lateral forces between the substructures and the superstructure during an earthquake event. In addition to transferring the vertical loads, movement, and rotation, base isolation bearings supply a degree of separation or decoupling between the superstructure and the substructures from horizontal ground motions.
  - The intent of the retrofitting guideline is to follow the SRMHS incorporating the latest NYSDOT LRFD Bridge Design Specifications design response spectrum and minimum design requirements.
  - Certain bridge types (e.g., multiple simple spans), or details (e.g., high rocker bearings) which are more vulnerable to earthquake damage shall be evaluated for seismic retrofit work based on the probable severity of damage and its impact on serviceability of the bridge.
- Scour
  - Any temporary structure that is in service for less than two (2) years shall be designed to withstand scour resulting from the projected Q50 design flow.
  - The minimum length of pile below the bottom of footing shall be the greater of 10'-0" or the scour depth below the footing plus 10'-0".
  - The computed maximum depth of scour shall be used to determine overall structure stability. Deep foundations should be socketed into rock if scour can affect their stability.
  - A bridge crossing a waterway where there is a potential for scour and where the substructures are not supported on a deep foundation or rock shall be

considered for replacement. If replacement is not a feasible alternative the rehabilitation shall include scour mitigation.

- Flood
  - When a bridge project crosses an established or proposed flood control project, the responsible agency (e.g., U.S. Army Corps of Engineers) will establish the desired vertical clearance over the Floodway Project Design Elevation. The Hydraulics Unit of the Office of Structures will assist in obtaining the criteria
  - An investigation of the vertical flood elevation and corresponding horizontal floodplain subject to flooding from the current Q500 flows shall be completed to determine if the project is in the Q500 floodplain. If the project is in the Q500 floodplain, alternative locations outside of the floodplain shall be investigated.
- Storm Surge
  - No less than a 2-year storm event shall be used when designing temporary streambank protection.
  - The design is to be based on rainfall intensity of the most severe storm with at least a five minute duration likely to occur in a ten-year period.
- Vehicle Collision
  - Actions such as repair of railing collision damage and localized maintenance repair of curbs, sidewalks and snow fencing do not require an evaluation of bridge railing replacement/upgrade. In a more general sense, if the anchorage system is exposed or will be exposed by the intended work, strong consideration should be given to replacing/upgrading the bridge railing.
- Vessel Collision
  - Bridges in navigable waterways shall be designed for vessel collision according to NYSDOT LRFD Bridge Design Specifications, Article 3.14
- Blast
- Fire
  - Large wood members also offer a surprising resilience to damage by fire. Today's treated lumber provides a material that is highly resistant to decay, rot and attack by insects.

### **CTDOT (Connecticut)**

Concise Manual with unique specifications tied to specific extreme events. The CTDOT can waive bridges off from standard seismic design. The scour analysis is very detailed with heavy analysis related to design due to water and depth. Culvert scour analysis due to inspection is important. Specialized floorway mentioned in hydraulic designs. The scour design flood, scour check flood, and the changes in foundation conditions resulting from scour shall be determined in accordance with the CTDOT Drainage Manual. Classifications of Extreme Events for severity of floodplain and storm analysis is made clear between bridge designs within the manual. Detailed specifications for vessel collision since it's classified as Extreme Event II along with vehicle collision. Blast load is also classified as Extreme Event II. No detailed specifications for Blast and Fire load.

- Wind
  - Intermediate Diaphragms: Intermediate cross frames shall be designed to satisfy the lateral wind load stresses and slenderness ratio,  $KL/r$ , requirements

outlined in the LRFD. When computing the AASHTO allowable compressive stress, a value of 0.75 shall be used for the effective length factor,  $K$ .

- Lateral bracing for I-Shaped Members: Bracing members, if required, shall be designed to satisfy lateral wind load stresses and slenderness ratio,  $KL/r$ , requirements. The allowable fatigue stress ranges shall not be exceeded at the connections.
- The design shall be based on 120 mile per hour wind load, with the appropriate adjustment for height based on the elevation of the structure above surrounding ground or water.
- Earthquake
  - Earthquake analysis for horizontal restraint and for beam seat length in accordance with BDM 3.8.1. Rehabilitation sub-scopes may afford an opportunity to address earthquake force effects. Such opportunities may include installing earthquake horizontal restraint or increasing beam seat length.
  - When a superstructure can be replaced with an identical superstructure, no bridge load rating analysis is required. An earthquake analysis shall be performed to identify the need for horizontal restraint of the superstructure.
  - For steel substructures, an earthquake analysis is required to determine if horizontal restraint and beam seat length are adequate. If significant deterioration is present, failure mechanisms may form that make the substructures unstable when lateral earthquake force is applied. In such cases the substructures shall be checked for earthquake lateral force effects.
  - All existing conventional bridges in Seismic Performance Zone 1 and undergoing major rehabilitation, such as bridge widening, superstructure replacement, deck replacement, bearing replacement, shall be analyzed and designed for earthquake load effects, unless specifically waived by CTDOT.
  - All non-conventional bridges, new and existing bridges being rehabilitated, shall be designed for earthquake load effects as directed by the CTDOT. Non-conventional bridges include bridges with cable-stayed, cable-suspended superstructures, bridges with truss towers or hollow piers for substructures and arch bridges.
- Scour
  - The potential for scour at bridges over waterways must be evaluated and submitted to the CTDOT for review and approval.
  - Substructures for bridges over waterways shall be designed to safely support the structure subjected to the design scour. Substructures, subjected to scour shall be designed with pile foundations, foundations on rock, foundations located below the maximum estimated scour depth, or any other means approved by the CTDOT, provided adequate scour protection is maintained.
  - Repairs to box culverts and pipes: Therefore, a scour analysis shall also be performed to determine if roughness elements or scour countermeasures are required to be installed.
    - Scour analysis is not required for box culverts, but if the velocity of the flow is increased due to restriction of flow by repairs, erosion of the

natural channel downstream of the outlet is possible and shall be investigated.

- Structure Type Studies: The studies shall be developed after careful appraisal of the site conditions, foundation conditions, hydraulic and drainage conditions, design discharge and scour potential, coordination with DEEP fisheries, rights of way, utilities, and highway limitations present and future.
- Flood
  - A Hydraulic Study is required if the structure requires work within the floodplain of a watercourse or stream with a watershed area exceeding one square mile.
  - If a floodway is established, every effort should be made to avoid encroachment into it. Note, certain activities, such as the construction of bridge piers within the floodway may be acceptable provided there is no increase in the “with floodway” water surface profile for the base flood or the 10-year flood.
  - Flood events associated with low tail water, occurrence of ice or debris dams, overtopping conditions, waterway confluences, changes in the angle of approach flow due to movement of the channel or any other flood events that can adversely affect the scour depth shall be considered when determining the governing the flood event for the scour design flood and the scour check flood.
- Storm Surge
  - For new bridges and new walls retaining highways, changes in foundation conditions resulting from a scour design flood and scour check flood shall be determined without the benefits provided by scour countermeasures
  - The structure should also be connected to a storm drainage system or a standard outlet. Where the bottom of the drainage structure is not the top of the abutment footing, a 2-foot deep sump should be detailed to catch sediment.
- Vehicle Collision
  - Classified as Extreme Event II
  - Analysis for Vehicle collision force (LRFD Section 13)
  - Extreme events include scour check flood, vessel and vehicle collision, seismic loading, and other site-specific situations that the Engineer determines should be included. Appendix A10 gives
- Vessel Collision
  - Classified as Extreme Event II
  - Evaluation of the following vessel collision events shall be combined with foundation conditions due to scour.
    - Case A - A drifting empty barge breaking loose from its moorings and striking the bridge.
    - Case B - A ship or barge tow striking the bridge while transiting the navigation channel under typical waterway conditions.
- Blast
  - Classified as Extreme Event II
- Fire
- Hurricanes:
  - Extreme Event I State Limit: contribution from long-term degradation, contraction scour, and local scour, respectively addresses the following

- A conservative assumption that a 975-year seismic event can occur near the end of an anticipated 75-year service life of a bridge when the full magnitude of long-term degradation is attained. The full magnitude of contract
- The full magnitude of contraction scour would occur under the first 100-year flood event and retain the calculated value thereafter.
- 0% local scour assumes the holes refill shortly after the scour design flood event and is not considered probable in conjunction with 100% long-term degradation, 100% contraction scour, and a design seismic event.
- Other Extreme Events 1-3
  - Extreme Event II: Load combination relating to ice load, blast load, and collision by vessels and vehicles.
  - Extreme Event III: Load combination for design considering the effects of check flood scour condition.
- Sources:
  - <https://portal.ct.gov/-/media/DOT/documents/dbridgedesign/Publications/CTDOT-Bridge-Design-Manual-0923.pdf>

### **PennDOT (Pennsylvania)**

Concise manual that uses drawings and titled sections. Standard wind load design with LRFD for horizontal pressure. Seismic design is only under consideration for sites where soil is at risk. Mentions seismic modeling software WinSEISAB. Guide has in depth section for scour and flooding. Scour is designed for different years along with incorporating a geotechnical section for the hydraulic report. Footing design must withstand hundreds of years. Standard vehicle collision design with retaining walls. There is a defined waterway for specific vessel collision, and certain sections of notable rivers are defined as points of interest for design. Standard blast and fire design along with inspections.

- Wind
  - Revised the design method from ASD to LRFD unless noted otherwise; revised the application of the horizontal wind pressure to include interior beams in accordance with the AASHTO Guide
  - The wind load includes a gust factor of 1.3 and a drag factor of 1.2 and is based on a maximum 50-year Mean Wind Velocity at 30'-0" above the ground surface of 80 mph
  - Provide wind breaks to protect working areas from direct wind
  - The applied horizontal load, acting at mid-depth at the end of the beam, shall be taken as the horizontal wind load. But not less than 2% of the total applied vertical load
  - Wind pressure is 30 psf acting horizontally and upward
  - Lateral bracing, when used, is provided to resist wind loads, but it is generally not needed since the girders can be designed to carry wind loads between the diaphragms.
  - Wind uplift on the superstructure and transverse wind loads on the superstructure and on live load shall be considered in the design. The magnitude and point of application of these forces shall be calculated according to A3.8 and D3.8.
- Earthquake

- Seismic design criteria: structures are designed for a seismic acceleration coefficient = 0.15
- For joints and bearings: Highlight any special details needed for earthquake requirements, such as uplift details, temporary attachments, or other requirements.
- Pennsylvania remains classified as Seismic Zone 1 in the 2014 Edition. For Seismic Zone 1, the basic seismic rehabilitation requirements are to provide:
  - Stable bearing types
  - Adequate connection between the superstructure to substructure
  - Proper reinforcement detailing of pier columns
- Pennsylvania is classified as Seismic Zone 1.
  - Detailed seismic analysis is not required for single span bridges or bridges in Seismic Zone 1, unless the site soils are classified as either Site Class E or F
  - A seismic analysis may be performed for multi-span bridges in Seismic Zone 1, for non-Site Class E or F soils, if designers feel such an analysis will more accurately reflect the connection forces and produce a more economical design.
  - WinSEISAB should be used for seismic analysis. If WinSEISAB is not suitable for a structure, other structural analysis programs capable of seismic modeling
- Scour
  - Scour protection shall be provided in accordance with a scour analysis. Use a Q25 flood to determine scour depth.
  - Include a special provision in the PS&E requiring the Contractor to close the bridge during high water. In the special provision, define high water as a specific water surface elevation.
  - This water surface elevation will normally be based on a Q10 flood, but can be based on a larger flood, not to exceed Q20, if the designer feels the superstructure can safely tolerate the forces imposed by high water. Specify that the bridge may be reopened after inspection and
  - Scour Countermeasures: Scour countermeasures including underpinning, riprap placement, streambed paving, etc. properly designed for predicted scour.
  - Scour investigations shall be completed for all drainage structures and retaining walls (cast-in-place, precast modular and mechanically stabilized earth (MSE)) along streams. This investigation shall be included with the foundation submission and H&H Report. The investigation shall contain scour calculations per PP7.2.2. The investigation shall also include site inspections, including inspection of nearby structures as necessary
- Flood
  - For definition and requirements for highway vertical clearance, see D2.3.3.2. For drainage structures, the minimum vertical clearance is the maximum unobstructed design flood flow depth under a bridge.

- Bridge railing: If the temporary bridge could cause hydraulics problems during flooding conditions, the use of an open metal railing (e.g. the PA Type 10M) is encouraged to minimize restrictions to water flow during high water events.
- 100-year and other floods as required and specified in Design Manual
- Superflood: Footings shall be checked for a super flood (Q500), which is defined as a 500-year flood event. Scour calculations shall be performed for this event to determine if the Q500 scour depth is below the bottom of the footing elevation. Stability of deep foundations, including unsupported length of piles, must be analyzed with the maximum scour depth at the Service I limit state
- Vehicle Collision
  - Horizontal loads on the overhang resulting from vehicle collision with barriers shall be in accordance with the provisions of Section A13 and its Appendix.
  - The deck overhang slab provided in BD-601M has been designed for the vertical design loads (D3.6.1.3.1) or a strength greater than the applied forces transmitted to the overhang when the barrier is subjected to the maximum collision force it can resist (Section A13) whichever is greater
  - For transverse vehicular collision loading transferred to the substructure for u-wings and retaining walls, use a load of
- Vessel Collision
  - The vessel collision provisions provided in A3.14 and D3.14 shall only be used in the substructure design of bridges which cross a navigable waterway. The Department defines a navigable waterway as those waterways which
    - presently support commercial barge and/or ship traffic
    - have supported commercial barge and/or ship traffic within the past 20 years
    - there is some reason to believe that the waterway will support commercial barge and/or ship traffic in the future
    - The vessel collision provisions will most likely be applicable for bridges over the following waterways:
      - lower portions of Delaware River
      - lower portions of Schuylkill River
      - lower portions of Allegheny River
      - lower portions of Monongahela River
      - Ohio River
  - Using the measured dynamic force to evaluate the additional load due to a vehicle collision as was done in the NCHRP Report 663 may result in an overly conservative value
- Blast
- Fire
  - Provide access doors in the wall if required by local fire departments, for inspection, or if directed by the District Bridge Engineer, in accordance with the Standard Drawings.
  - Infrared or motion cameras have been typically used for prevention of vandalism or fire, but could be modified to log a license plate should a bridge hit occur.

- Wiring should be run through conduit. The conduit should meet fire and electronic code as well as protect the wiring from animals, insects and people who could break the conduit causing damage to the wires.
- Hurricanes:
  - AASHTO: Design loads and loading combinations of dead load, lateral earth pressure, live load surcharge, wind load, seismic load, ice load, and traffic impact load shall be in accordance with this Guide Specifications and as modified herein.
  - a site-specific analysis of historical wind data in nonhurricane areas and a site-specific numerical simulation of potential hurricane wind speeds may be used to determine design wind criteria, or representative wind tunnel tests using approved procedures may be utilized to determine wind loads and to evaluate aeroelastic stability.
- Sources:
  - <https://www.penndot.pa.gov/ProjectAndPrograms/Bridges/Pages/Plans,-Standards-and-Specifications.aspx>
  - <https://www.dot.state.pa.us/public/PubsForms/Publications/PUB%20219m.pdf>
  - <https://www.dot.state.pa.us/public/PubsForms/Publications/PUB%2015M.pdf>

## **MDOT (Maryland)**

The manual is sectioned off by design, plan development, and inspection. A revision history which includes information on how to design specific components of the bridge. The section 3 inspection manual includes a detailed guide on flood response. The promotion of safe and efficient emergency action is something to note. There is little to no mention of wind and earth loads which is unconventional. The scour and flood analysis section is very detailed and is applied to all components of the bridge, such as footings, walls, and foundations. A 100-year flood and storm is the standard for design. The guidelines mention how the bridge is designed for collision load (railings) along with specific guidelines that bridges must adhere to. There is no unique mention of vessel collision, fire, and blast load.

- Wind
  - All secondary fabricated structural steel members, such as wind bracing and diaphragms, in the bridge superstructure shall have a minimum thickness of 3/8".
- Earthquake
- Scour
  - For all hydraulic culverts the bottom of the toe wall, wing walls and headwall or slope protection cut-off wall shall be placed 3'-0" minimum below the invert elevation of the culvert. Each site must be evaluated for scour potential and the footings or cut-off walls adjusted accordingly.
  - Regardless of type of support, where applicable, all bridges over water shall be evaluated for scour potential. After the preliminary screening, scour critical bridges shall receive a complete scour analysis per the OOS Manual for Hydrologic and Hydraulic Design.
  - After the preliminary screening, scour critical bridges shall receive a complete scour analysis and address the following:

- Lowering the footings, spur dikes, stone blankets and revised pier alignment.
- Where pile foundations are used, piles must be driven deep enough to assure structure stability relative to potential scour depth.
- Spread footings will only be used in rock or with subfoundation concrete where it is not feasible to use piles or lower the footing enough to protect against anticipated scour.
- Flood
  - Using Hydraulic Design Criteria for Structures in FEMA Flood Plain
  - All new and/or rehabilitated hydraulic structures on the State Highway system and on County Roads in Counties having the 100 year Federal Flood Insurance shall be designed so as not to cause any increase in the Water Surface Elevation of the "100 year Flood" for the waterway and its flood plain affected by the proposed construction.
  - Mechanically Stabilized Earth (MSE) retaining walls that are to be placed adjacent to streams, floodplains, SWM ponds, or other water features shall be placed so that no stream flows up to the 100 yr flood elevation or standing water comes in contact with the face of the wall.
- Storm Surge
  - The design storm for the above indicated location shall be a "100 year Storm" for existing conditions as opposed to ultimate development as per existing zoning
  - Vehicle Collision
  - Bridge Rail Height – Bridge rail is intended to provide stability to an impacting vehicle during a collision to reduce vehicle overturn and rollover. The key contributor to the stability provided by the bridge rail is the bridge rail's height.
  - Consider the impact to traveled way width if bridge structure safety were to be achieved by redirecting or absorbing collision load with a traffic barrier.
- Vessel Collision
- Blast
- Fire
- Special Note for Hurricanes:
  - Flood Response Program and Inspection: When a Flood Warning is issued by the National Weather Service for a particular county or drainage system, the Flood Response Program shall be initiated for these locations.
- The primary goal of all flood inspections is to determine that increased flow rates have not affected the stability of the structure. This includes looking for signs of structural movement, roadway settlement, scour countermeasure displacement, undermining, increased foundation exposure or other related issues of concern.
- Flood Warning is issued. Inspection Teams are not to go out into the active storm. Once the majority of the storm system has passed, Inspection Team Leaders are to contact the District Shops to inquire whether there have been any reports of overtopped roadways or other bridge related issues.
- For any bridges which were reported to have been overtopped or have any other flood related issues, site visits shall be made as soon as possible after the storm event has passed.

- Approximately 12 to 24 hours after the storm event has effectively passed, flood inspections shall begin for all bridges on the respective Flood Response Crew Bridge Lists. Dive firms will be contacted regarding the inspection of bridges on the Flood Response Dive Bridge Lists.
- If the inspector cannot safely enter the stream to take soundings and probe the foundation elements, the inspection team must return to perform the in-stream flood inspection as soon as the waters suitably subside. If a diver will be required to perform the in-stream inspection, notify the Structures Inspection Senior Project Team Leader or Division Chief as soon as possible.
- Sources:
  - <https://roads.maryland.gov/mdotsha/pages/Index.aspx?PagelId=150>
  - <https://roads.maryland.gov/mdotsha/pages/index.aspx?pagelId=777>
  - <https://roads.maryland.gov/OBD/MDOT%20SHA%20OOS%20Bridge%20Railling%20Manual.pdf>

### **DeIDOT (Delaware)**

Sectioned off bridge design specifications with design and inspection manual. Standard wind specifications under AASHTO. No earthquake or seismic design mentioned. Earthquakes result in a damage inspection. Scour considering in design is under hydraulic with in depth scour monitor system. Detailed stormwater analysis which includes sediment and pollution control.

Sources. Inspections include classifications of vessel collisions such as underwater compared to boat safety. Mentions timber design within the bridge under inspections for decay. No special blast specifications for design. Manual specifies catastrophic events where hurricanes are noted to ensure proper bridge analysis.

- Wind
  - Evaluate steel members for erection loads including self-weight, wind loading in accordance with the LRFD Guide Specification for Wind Load on Bridges in Construction, and construction live loading.
  - Paint operations may be stopped by the engineer due to wind. Stop painting operations if the wind velocity exceeds 20 mph, unless specific and approved precautions are taken to prevent the escape of paint droplets and overspray
  - Secure the polyethylene sheet material to prevent displacement by wind. Immediately repair sheets torn or damaged during the curing period. All curing operations must be performed without damaging the surface.
  - Inspections: check for debris affecting the movement of the structure, damage due to debris, and misalignment of roadway elements. The direction of wind or aerodynamic characteristics of the structure may cause the bridge to experience uplift, unintended stress reversals, or vibrations.
- Earthquake
  - Considered Excusable, under Non-Compensable Delays.
  - Damage that occurs due to vehicular or marine traffic striking the bridge, or damage resulting from major storm or earthquake event may warrant a cursory, or damage inspection.
  - Although rare, Delaware has experienced small seismic occurrences in the past. The lateral ground forces of an earthquake could affect bridges in a way

that most structures in Delaware were not designed to withstand. Rocker bearings should be upright and in an appropriate state of expansion for the ambient temperature.

- Scour
  - Inspections: A Scour Monitoring Inspection is required to document the inspection or monitoring of a scour critical bridge during storm/weather events if the trigger(s) specified in the Scour POA occur.
  - Along with the inspection report, a copy of the Incident Report and the Scour Critical Bridge Storm Response Form shall be included with the inspection report.
- Flood
  - Construct cofferdams in accordance with the approved working drawings to protect new concrete against flooding damage during the concrete curing period. Provide a cofferdam to obtain, as nearly as possible, a water-free work area large enough to allow for a sump and for form inspection
  - Stockpile excavated material outside the 100-year floodplain and temporarily stabilize.
- Storm Surge
  - Install erosion and sediment control measures that comply with stormwater regulations for staging areas. Restore areas used for staging operations to their original conditions.
  - When preparing and using off-site disposal areas, comply with all stormwater and environmental rules, regulations, or applicable permits issued by DNREC, USACOE, and all other applicable government agencies. Obtain permits, if necessary.
  - An inspector of sediment and stormwater controls certified by the Department of Natural Resources and Environmental Control (DNREC) and as appointed by the engineer.
- Vehicle Collision
  - Investigate areas of collision damage for tearing, crushing, spalling, cracking, loss of reinforcing bond, or broken members or connections. Check connections and anchorages to determine if the rail and its components are securely fastened to the bridge. Use a hammer to verify bolted connections are secure
- Vessel Collision
  - Navigation Data Clearances for vessels on the waterway
  - Larger, motorized boats or barges may be considered for inspections over water and are often used for conducting underwater inspections or when restricting traffic is undesirable. These options typically require additional inspection team members or operators dedicated to safely maneuvering the vessel.
  - Marine impact can occur from boats, vessels, or debris striking or becoming lodged under or against the bridge structure. Often marine impact inspections will also require a special underwater inspection to check the condition of substructure units and foundations below the waterline.
- Blast

- Fire
  - Fire codes may require special storage facilities for some components of the system.
  - Painting: Take precautionary measures to ensure protection of workers and work areas from fire hazards and health hazards resulting from handling, mixing, and applying materials.
  - Ensure conformance with applicable fire codes that may require special storage facilities for some components of the overlay system.
  - Timber: Clean and inspect areas of decay and insect or fire damage to determine the extent of the defect.
- Special Note for Hurricanes:
  - Inspections: When weather such as forecasted high wind, heavy rain, or hurricanes may result in potential on-call inspection assignments, the BIE and/or BME will receive updates
  - Packets will identify bridge locations, include a copy of the most recent waterway sketch, and provide forms and sketch sheets to document water levels, response findings, and maintenance needs.
  - The Department defines "items not under the control of the contractor" as earthquakes, tidal waves, tornadoes, or hurricanes; catastrophic conditions such as hazardous waste materials spills or explosions; or, acts of public enemy or of governmental authorities.
- Source
  - <https://deldot.gov/Business/drc/index.shtml?dc=bridge#horizontalTab2>
  - [https://deldot.gov/Publications/manuals/standard\\_specifications/pdfs/2024/DelDOT%202020%20Standard%20Specification\\_January%202024.pdf?cache=1711997507406](https://deldot.gov/Publications/manuals/standard_specifications/pdfs/2024/DelDOT%202020%20Standard%20Specification_January%202024.pdf?cache=1711997507406)
  - [https://deldot.gov/Publications/manuals/bridge\\_inspection/pdfs/bridge\\_inspection\\_manual.pdf?cache=1711994802876](https://deldot.gov/Publications/manuals/bridge_inspection/pdfs/bridge_inspection_manual.pdf?cache=1711994802876)
  - [https://bridgedesignmanual.deldot.gov/index.php/Main\\_Page](https://bridgedesignmanual.deldot.gov/index.php/Main_Page)

### **NCDOT (North Carolina)**

The design manual is dispersed out between design, inspection, and repair. The design manual was updated in 2023 whereas the other manuals were updated in 2018. The wind loads and seismic design were standard according to AASHTO. The scour analysis is done with a geotechnical engineer who provides elevations for stream crossing structures. A rock embankment design has design specifications. The flood design is 100-years with other storm surge designs. Detailed vehicle collision guidelines that mention clearance along with impact resistant exits. Assessment of vessel collisions must be followed to surve protection. There is minimal information about fire and blast loads.

- Wind
  - Loading conditions and erection stages that can contribute to girder/frame instability include, but are not limited to, exposure to high wind loads, temporary erection stages consisting of two or three parallel girders, or girders cantilevered over a bent during erection
  - Pile panel sound barrier walls shall be in accordance with Standards SBW1 and SBW2 and the Special Provisions. The wall components shall be designed for the wind pressure as determined by the Exposure Category map

- Earthquake
  - Design all structures in accordance with the seismic requirements of the AASHTO LRFD Bridge Design Specifications.
- Scour
  - Stream crossing structures shall include design to protect against bridge scour in accordance with HEC 18 (Evaluating Scour At Bridges), dated November, 1995 or subsequent updates.
  - The Foundation Recommendations consider the scour potential of the site. Subsurface and hydraulic investigations will be made to determine the probable depth of scour or floatation of material. Foundation and structural analysis will determine the required lateral support of the pile. The bottom of a spread footing or pile tip elevations for pile footings should be determined such that scour will not endanger the structure
  - The Geotechnical Engineering Unit will provide scour critical elevations for all stream crossing structures.
  - Generally, the Hydraulics Unit will recommend a rock embankment when the proposed approach fill is to be constructed within the limits of a lake or stream. A rock embankment is used to reduce the siltation of lakes and streams and provides a stable embankment resistant to scour.
  - If scour is prevalent and if recommended by the Hydraulics Unit on the Culvert Survey and Hydraulics Design Report, detail rip rap in front of the culvert wing, approximately 3 feet (900 mm) above the wing footing.
- Flood
  - In location maps: Navigation clearances above the appropriate datum and the 100-year flood level
  - Show the following information, attained from the Culvert Survey and Hydraulic Design Report, near the location sketch for all culvert types: Design Discharge, Frequency of Design Flood, Design High Water Elevation, Drainage Area, Base Discharge (Q100), Base High Water Elevation
  - show the Overtopping Flood Data for all Federal Aid projects when the data is provided
- Storm Surge
  - Metal rails: bridge replacements where the conveyance of storm water requires the use of an open rail.
  - Vehicle Collision
  - Wherever possible, provide adequate clearance to avert design for vehicular collision and rail car collision with structures.
  - Specification: Abutments and piers located less than 30 ft. (9.14 m) from the edge of roadway shall be protected with a 2'-8" (813 mm) tall concrete barrier and approach guardrail in lieu of being designed for the equivalent static force of 400 kips. Abutments and Piers located less than 25'-0" (7.62 m) from the centerline of a railroad track must be protected by a crashwall.
  - Where the possibility of collision from highway, railroad or vessel traffic exists, an assessment should be made to determine the degree of impact resistance and/or protection to be provided.
  - Vessel Collision

- Where the possibility of collision from highway, railroad or vessel traffic exists, an assessment should be made to determine the degree of impact resistance and/or protection to be provided.
- Blast
- Fire
- Hurricanes:
  - The dead load, ice load, and wind loads have been considered in the panel and pile design.
- Sources
  - <https://connect.ncdot.gov/resources/Structures/Pages/Design-Manual.aspx>
  - <https://www.ncdot.gov/initiatives-policies/Transportation/bridges/Documents/bridgepolicy2000.pdf>

### **Caltrans (California)**

California is a large state with around 25,000 bridges maintained by Caltrans. The manual is very in depth with 20 chapters that covers many areas of design. References and case studies are updated within the manual. Mentioned use of concrete and steel design within the manual. The manual constantly refers to the AASHTO manual for load design. California experiences thousands of earthquakes every year which has resulted in them making their specialized Caltrans Seismic Design Criteria (SDC) for seismic loads. The hydraulic factors which covers flooding and scour are standard from the AASHTO manual using the 100-year flood used for scour analysis. For vehicle collisions, standard guidelines with barrier rails are applied. Special note for vessel collision, under waterways there are special fender systems for protection. Blast and fire must be referred to standard AASHTO manual.

- Extreme event forces:
  - ice loads (IC)
  - vehicular collision forces (CT)
  - vessel collision forces (CV)
  - blast loading (BL)
  - earthquake loads (EQ)
- Wind
  - Wind load is based on a base wind velocity that is increased for bridges taller than 33 ft from ground to top of area exposed to wind which is usually the barrier but may be a sound wall on top of the bridge.
  - First find the design wind velocities from AASHTO Table 3.8.1.1.2-1
  - Wind pressure and drag coefficients:
    - $C_d = 1.3$  (for box-girder bridge superstructures)
    - $C_d = 1.6$  (for bridge substructures)
  - Table 3.4-8 Wind Load at Various Angles of Attack
  - Wind on Live Load, WL: This load is applied to vehicles traveling on the bridge during periods of a moderately high wind of 80 mph.
  - Uniform Temperature (TU) can be quite significant, especially for bridges with long frames and/or short columns. Wind load on structure (WS) and wind on live load (WL) are significant on structures with tall single column bents over 30 feet.
- Earthquake

- Earthquake load (EQ) is specified by Caltrans Seismic Design Criteria (SDC) (Caltrans, 2019b) or Caltrans Seismic Design Specifications for Steel Bridges (Caltrans, 2016) and generally controls the majority of column designs in California.
- In California, a high percentage of bridges are close enough to a major fault to be controlled by EQ forces.
- It is recommended that EQ forces be considered early in the design process in order to properly size members.
- Scour
  - The hydraulic design of the bridge should aim to accommodate waterway conveyance with the least amount of impact to velocities and water surface levels.
  - 100-year flood used for scour analysis.
  - AASHTO LRFD-BDS requires scour at bridge foundations to be investigated for two conditions: (1) design flood and (2) check flood.
  - The geologic material underlying a waterway may be either: (1) granular or fine material, (2) cohesive or non-cohesive, (3) erodible or non-erodible rock.
  - Scour prediction methods assume that scour may reach predicted depths given sufficient time, regardless of the type of foundation material and its properties.
  - The potential effects of channel degradation or aggradation, contraction scour and local scour must be investigated in the different scour condition limit state load combinations
- Flood
  - 50-year or 100-year flood used for adequate waterway conveyance OR as specified by any flood control agency
  - Minimum of 200-year flood or a maximum of 500-year flood used for check flood.
  - Design Flood - The peak discharge (when appropriate, the volume, stage, or wave crest elevation) of the flood associated with the probability of exceedance selected for the design of a highway encroachment.
- Storm Surge
- Vehicle Collision
  - Vehicle collision refers to collisions that occur with the barrier rail or at unprotected columns
  - Referring to AASHTO Section 13, the design loads for CT forces on barrier rails are as shown in AASHTO Table A13.2-1. Test Level Four (TL-4) will apply most of the time.
- Vessel Collision
  - California bridges over navigable waterways are protected by a fender system. If the bridge piers are not protected by a fender system, they must be designed to withstand the CV force
- Blast
  - The importance of the bridge is used as the basis for determining whether a bridge should be designed for blast forces. More information on blast loading

design can be found in the AASHTO Bridge Security Guidelines, 2nd Edition (AASHTO, 2022)

- Fire
  - Hurricanes are not common (last one to make landfall was in 1939)
- Sources
  - <https://dot.ca.gov/programs/engineering-services/manuals/bridge-design-practice>
  - <https://dot.ca.gov/-/media/dot-media/programs/engineering/documents/memotodesigner/f0006651-mtd-16-1-final.pdf>

### **FDOT (Florida)**

Florida is near the gulf coast which results in many coastal storms within the area. Many components of the bridge such as traffic lights must be designed to withstand wind loads. Additionally, the wind load used in the manual is higher than average at 150mph. The manual does not mention earthquakes which are uncommon within the area. The manual has in-depth storm surge guidelines related to stormwater management and erosion. The design for scour analysis is tested in many cases to ensure all levels of analysis. The vehicle and vessel collision conditions are standard with adequate load designs. The design guidelines are also closely regulated by the fire authority.

- Wind
  - Develop the required bracing designs in accordance with the AASHTO LRFD Bridge Design Specifications (LRFD) and Chapter 11 of the SDG using wind loads specified in the SDG. For information not included in the SDG or LRFD, refer to the AASHTO Guide
  - For a single point attachment, use only a catenary wire to support the imposed dead and wind load from the attached signs and traffic signals.
  - The sign assembly must be designed and constructed to withstand 150 mph wind loads meeting the requirements of the Department's Structures Manual
- Earthquake
- Scour
  - When the channel lining design is not provided in the Contract Documents or must be 428 FY 2024-25 redesigned, submit a hydraulic analysis and scour evaluation, signed and sealed, by the Contractor's Engineer of Record.
  - A riprap rubble ditch lining with a minimum thickness of 18 inches will be permitted if the flow velocity corresponding to the Design Flood Scour Event does not exceed five feet per second.
  - With concurrence of the Engineer, the Dynamic Testing Engineer (DTE) may modify the scour resistance shown in the Plans if the dynamic load test is used to determine the actual soil resistance through the scour zone
- Flood
  - A riprap rubble ditch lining with a minimum thickness of 18 inches will be permitted if the flow velocity corresponding to the Design Flood Scour Event does not exceed five feet per second.
- Storm Surge

- The Contractor shall comply with all environmental permits, including measures identified in the National Pollutant Discharge Elimination System (NPDES) Stormwater Pollution Prevention Plan and Sediment and Erosion Control Plan for the work.
- Conduct the operations and maintain the work in such conditions to provide adequate drainage at all times. Do not obstruct existing functioning storm sewers, gutters, ditches, and other run-off facilities.
- Ensure the Erosion and Sediment Control Plan include procedures to control off-site tracking of soil by vehicles and construction equipment and a procedure for cleanup and reporting of non-storm water discharges
- Inspect all erosion and sediment control devices at least once every seven calendar days and within 24 hours of the end of a storm event that is 0.50 inches or greater.
- Vehicle Collision
- Vessel Collision
  - Design criteria: Provide adequate stiffness to distribute vessel impact loading to meet the minimum required energy absorption capacity (EAC) of the system
- Blast
- Fire
  - Do not begin work around fire hydrants until the local fire authority has approved provisions for continued service.
- Hurricanes:
  - Submit a written containment system design plan in accordance with this section and the contract documents at the pre-construction conference or as directed by the Engineer which clearly describes the proposed containment system
  - Submit a contingency plan addressing natural weather events such as 811 FY 2024-25 tropical storms and hurricanes.
- Sources
  - [https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/programmanagement/implemented/specbooks/fy-2024-25/fy2024-25ebookfinalcomp-revised1-24-24.pdf?sfvrsn=15b17f9c\\_1](https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/programmanagement/implemented/specbooks/fy-2024-25/fy2024-25ebookfinalcomp-revised1-24-24.pdf?sfvrsn=15b17f9c_1)

### **LaDOTD (Louisiana)**

Louisiana has a huge update within the bridge manual due to Hurricane Katrina. New bridges were designed with the manual required specifications that adhered to new storm surge requirements. The wind load AASHTO specifications utilized 70-100 mph for design. There are few earthquakes and most of them are of low magnitude, so seismic specifications are standard. The hydraulic specifications are in depth within the manual. Mentions scour protection, spur dikes, and abutment protection. The manual uses the standard AASHTO guide for vehicle and vessel collision. The vessels that travel within the bridges must be under strict U.S. coast guard guidelines. Little to no mention or blast or fire protection.

- Wind
  - Wind forces are to be applied in accordance with the AASHTO Specifications.
  - Truss design velocity 70-100 mph

- Earthquake
  - In order to design to resist the effect of earthquake motions, the designer is referred to by AASHTO Standard Specifications for Highway Bridges, Section 3.21 to Division 1-A.
  - The provisions in this section apply to bridges of conventional steel and concrete girder and box girder construction with spans not exceeding 500 ft. Suspension bridges, cable-stayed bridges, arch type and movable bridges are not covered.
- Scour
  - Hydraulic studies: determination of special requirements (scour protection, spur dikes, abutment protection); predicted scour depths; and documentation of design.
  - The predicted scour elevation should always be shown on the general bridge plans and in the hydraulic data table.
  - Serviceability is related to factors like stream scour, maintenance of movable bridges, and deck deterioration
  - Pile unsupported length (ft.)
  - The unsupported length is measured down below the channel bottom or ground line accounting for estimated scour, if appropriate (5 ft. minimum), plus a distance to the assumed point of pile fixity. In general, pile fixity can be assumed at 5 ft. below scour line or ground line.
  - For piles with a diameter less than 24", a 20 ft. minimum pile penetration should be provided for stream crossings below the estimated scour elevation.
  - Static load test capacity: The soil resistance will depend on the as-driven conditions such as overburden of the scour zone, scour zone soil resistance if it has not been cased or excavated
- Flood
  - Hydraulic studies: determination of flood plain discharge for the design event; determination of normal water surface elevations and the stage-discharge relationship; design selection based upon computed backwater;
  - The Hydraulic Report will include: a general discussion of the watershed and the scope of and the reasons for the proposed improvement; documentation of any coordination with other agencies or governments; brief discussion of any local or regional ordinances influencing design; general site data used in hydraulic design; general discussion of design analysis; final design recommendations; a general "Flood Hazard Summary".
  - Recommended finish grade elevation for a 25-year design flood is 127.23 ft/N.A.V.D- 88
  - If debris is a consideration, the finish grade should be set to provide 2 ft. of freeboard between the bottom chord and the design year flood (if debris is not then the finish grade should be set to provide 1 ft). The bottom chord should clear the 100 year flood elevation by 1 ft.
- Storm Surge
  - The length and finish grade of the detour bridge shall be determined using a flood frequency equal to the detour service life multiplied by the drainage design factor (DDF).

- The Environmental Protection Agency (EPA) is required to develop an approach to regulating storm water discharges under this Act.
- Section 405 of the Water Quality Act of 1987 (WQA) added Section 402(p) of the Clean Water Act (CWA) which requires the Environmental Protection Agency (EPA) to develop an approach to regulating storm water discharges under the National Pollution Discharge Elimination System (NPDES). The NPDES General Permit requires that discharges from construction sites will be managed to prevent pollutants from entering waters of the United States.
- Vehicle Collision
  - Under AASHTO it should be referred to for more information
  - The directional slip bases should be placed such that their operational characteristics will be the most probable direction of high-speed collision where practical.
- Vessel Collision
  - The U.S. Coast Guard maintains strict guidelines to insure the least possible interference with navigation.
  - For newly constructed bridges crossing navigable waterways, it is required that a permit sketch be submitted to the Coast Guard for their review and approval of the navigation permit. This is also generally true for reconstruction projects and extensive maintenance projects, where navigation might be affected, or any changes to the original permit is made.
  - Bridges crossing navigable waterways where vessel collision by merchant ships or barges may be anticipated shall be designed to prevent collapse of the superstructure.
  - Consideration should be given to the size and type of the vessel, available water depth, vessel speed, and structure response. It should be noted that the specifications do not apply to special purpose vessels, wood, or fiberglass constructed vessel, ships smaller than 1,000 DWT, naval vessels, or to recreational vessels. Vessel impact requirements for these types of vessels shall be determined by the Bridge Design Engineer.
- Blast
- Fire
- Hurricanes:
  - Roadside ground-mounted signs: These signs must be designed for vehicle impact and wind loading
  - Hurricane Katrina resulting in a \$30.9 million repair to bridges which used steel panels
  - DOTD determined that the bridges were extensively damaged and too vulnerable to storm surges in the future. Within a year of Katrina, DOTD secured \$803 million in federal funds for the construction of a new Twin Span Bridge
  - The new Twin Span Bridge is designed to withstand powerful storm surges and unexpected events, and it is equipped with a complex monitoring system that includes sensors to detect when the structure has been hit by a barge or a storm surge, enabling DOTD to take immediate action to ensure safe travel

for drivers and monitor the bridge structure over its life. It has a strict maintenance guidelines.

- Sources:
  - [http://wwwsp.dotd.la.gov/Inside\\_LaDOTD/Divisions/Engineering/Bridge\\_Design/Archived%20Manuals/Archived%20Manuals%20and%20Guidelines/Bridge%20Design%20English%20Manual.pdf](http://wwwsp.dotd.la.gov/Inside_LaDOTD/Divisions/Engineering/Bridge_Design/Archived%20Manuals/Archived%20Manuals%20and%20Guidelines/Bridge%20Design%20English%20Manual.pdf)
  - <https://www.fhwa.dot.gov/candc/factsheets/interstate10louisiana.pdf>

### **Alaska DOT&PF (Alaska)**

Alaska is the one of states which are most seismically active, but the number of bridges managed by DOT is around 1,000. The standard seismic design is linked to the AASHTO guide. The wind loads are divided into different strength loads across multiple time spans. Additionally, it has special cases of snow and ice loads. Standard specification for vehicle and vessel collision. Uses an in-depth guide for fire relative to the material of the bridge. Engineers must communicate the damage taken by the bridge.

- Wind
  - Strength III Load Combination: This load combination represents the most severe wind during the bridge's 75-year design life. During this event, assume that no significant live load crosses the bridge
  - Assume wind on live load (WL) acts horizontally at a distance of 6 feet above the roadway.
- Earthquake
  - Use the AASHTO Guide Specifications for LRFD Seismic Bridge Design to design bridges in Alaska. Other chapters in this Manual present DOT&PF's seismic detailing practices.
- Scour
  - The hydraulics engineer will prepare a Hydraulics Report in accordance with the Alaska Highway Drainage Manual and provide preliminary hydraulic recommendations in coordination with the Bridge Section's structure-type selection.
  - Forms: contraction, local, and long-term scour
  - The bridge foundation must not fail or be damaged for the scour design event of the 100-year and 500-year flood. Check lesser flood events if there are indications that less frequent events may produce significantly deeper scour than the 100-year flood.
  - For abutments: Scour risks can usually be addressed by providing an adequate waterway opening and scour countermeasures. Orientation is usually the same as for adjacent piers.
- Flood
  - Design Flood Frequency. The hydraulics engineer determines the minimum design flood frequency, which is based on the roadway classification, scour design criteria, flood plain regulations, and ranges from the 50-year event to the 500-year event.
- Storm Surge
  - The hydraulics engineer is responsible for deck drainage analysis to determine the need for deck drains or other stormwater controls.

- AASHTO Culvert and Storm Drain System (accepted but not yet published guide)
- Vehicle Collision
- Vessel Collision
- Reference: Guide Specifications and Commentary for Vessel Collision Design of Highway Bridges, 2nd Edition
- Vessel collision is a site-specific consideration that the bridge engineer will consider on a case-by-case basis in active boating channels.
- Blast
- Fire:
  - If the concrete is damaged by heat and/or fire, then take cores as directed by the engineer to determine the extent of the concrete damage. Use abrasive blast methods to clean all construction joints to the extent that clean aggregate is exposed.
  - Condition sub-structure:
    - Satisfactory: Fire damage limited to surface scorching of timber with no measurable section loss.
    - Fair: Fire damage limited to surface charring of timber with minor, measurable section loss.
    - Poor: Fire damage with significant section loss of timber that may reduce the load-carrying capacity of the member.
    - Serious: Major fire damage to timber that will substantially reduce the load-carrying capacity of the member.
- Hurricanes:
  - Common examples of events that may require a damage inspection include earthquakes, floods, vehicular impacts, fire damage, and marine vessel impacts. The Bridge Management Engineer determines the need and frequency for damage inspections.
  - Conditions for timber and concrete deck
- Sources
  - <https://dot.alaska.gov/stwddes/desbridge/bridgemanual.shtml>

## **WSDOT (Washington)**

WSDOT has extensively in-depth bridge design manual. The manual includes information about differences in design-build contracts along with information on every piece of utility and component necessary for the bridge build. The wind design mentions wind shear as a component to consider for design at each support location. The maximum wind speed for design is lower than average at 50 mph and lowest at 30 mph. Washington state also experiences many earthquakes, so the seismic design is unique. The standard design conforms to the LRFD-SGS and classifies bridges according to how susceptible they are to seismic damage. The scour depends on the total scour at the scour design flood. The design for floods works with the State Hydraulics Office. Preliminary design for flood plains will be considered for walls. The Geotechnical Design Manual is also used to consider the design for retaining walls. Vehicle collision design for abutments and piers is standard according to the AASHTO Guide. A crash test is accordingly assigned for rigid barrier testing. Guide has little to no blast or fire consideration. Inspections are required for damages.

- Wind:
- Horizontal Analysis: Historically a wind pressure of 50psf was used on trusses.
  - Compute the LRFD-BDS design wind pressure for the bridge elements based on the existing site conditions.
  - Apply the wind pressure to the bridge elements and calculate total horizontal wind shear at each support location.
  - Utilize the total design wind shear at each support as the allowable upper bound horizontal wind loading.
- The calculated maximum shears will be based on the latest AASHTO wind speeds and could be higher than the original design. As a good check, the designer should review the existing stress sheets as they often will have design wind shear for the bearings.
- For simple design structures: As a rule of thumb, 30 to 35 mph has been successfully used as maximum wind speeds on several projects (A more desirable maximum wind speed is in the range of 45 to 50 mph.)
- Basic wind speed of 115 mph shall be used in computing design wind pressure using equation 3.8.1-1 of AASHTO Section 3.8.1. This is based on the high-risk category with a mean recurrence interval of 1700 years per AASHTO
- A 3 second gust wind speed shall be used in the AASHTO wind pressure equation.
- Earthquake
  - Seismic design of new bridges and bridge widenings shall conform to LRFD-SGS
  - Special major bridges fitting the classifications of either “Critical” or “Recovery” will be so designated by either the WSDOT Bridge and Structures Engineer or the WSDOT Bridge Design Engineer. (For service)
    - Critical bridges are expected to provide immediate access to emergency and similar life-safety facilities after an earthquake. The Critical designation is typically reserved for high-cost projects where WSDOT intends to protect the investment or for projects that would be especially costly to repair if they were damaged during an earthquake.
    - Recovery bridges serve as vital links for rebuilding damaged areas and provide access to the public shortly after an earthquake.
    - The Design Spectrum for Safety Evaluation Earthquake (SEE) shall be taken as a spectrum based on a 7% probability of exceedance in 75 years
- Scour
  - The potential for scour need not be considered when choosing a design corrosion rate as it relates to zones of exposure.
  - It is assumed that any significant scour would be repaired and the applicable zone of a structural element would not be changed.
  - Unless otherwise specified, the top of footing locations for bridges shall be based on total scour at the scour check flood, and design shall be based on the total scour at the scour design flood or scour check flood, depending on the controlling load case. If there is lateral migration, then the determination of total scour during both the scour design flood and the scour check flood shall account for the migrated state

- Flood
  - The State Hydraulics Office should be consulted for walls that are subject to floodwater or are in a flood plain. The State Bridge and Structures Architect should review the architectural features and visual impact of the walls during the Preliminary Design stage. The designer is also directed to the retaining walls chapter in the Design Manual M 22-01 and Geotechnical Design Manual chapter pertaining to retaining walls, which provide valuable information on the design of retaining walls.
- Storm Surge
  - Detention vaults are used for stormwater storage and are to be watertight. These Structures can be open at the top like a swimming pool or completely enclosed and buried below ground. Detention vaults shall be designed in accordance with the LRFDBDS and the following: Seismic design effects shall satisfy the requirements of ACI 350.3-06, Seismic Design of Liquid-Containing Concrete Structures
- Vehicle Collision
  - Abutments and piers located within the clear zone as defined by the AASHTO Roadside Design Guide shall be investigated for collision. Collision shall be addressed by either providing structural resistance or by redirecting or absorbing the collision load. The provisions of LRFD-BDS 2.3.2.2.1
  - Where the design choice is to redirect or absorb the collision load, protection shall consist of one of the following:
    - For new or retrofit construction, a minimum 42.0-in. high crash tested rigid TL-5 barrier, as specified in LRFD-BDS Section 13, located such that the top edge of the traffic face of the barrier is 3.25 ft or more from the face of the pier component being protected
    - For retrofit construction, a minimum 42.0-in. high crash tested rigid TL-5 barrier may be placed closer than 3.25 ft from the top edge of the traffic face of the barrier to the nearest traffic face of the pier component being protected when there is no other practical option. Such rigid barriers shall be structurally and geometrically capable of surviving the crash test as specified in LRFD-BDS Section 13.
- For walls with traffic barriers constructed integral with the wall stem, the vehicular collision load shall be included in the design. To ensure that any failure due to the collision remains in the barrier section, the top of the wall stem shall have sufficient resistance to force the yield line failure pattern to remain within the barrier. The top of the wall stem shall be designed in accordance with the requirement of the LRFD-BDS Article A13.4.
- Vessel Collision
  - Collision protection or design for collision loads for piers with one or two columns shall be provided.
- Blast
- Fire
  - The Bridge Preservation Office has requested that maintenance clean up transient camps when it becomes difficult or impossible to do an adequate

inspection of the bridges. Campfires set by the homeless have also caused damage to bridges.

- Hurricanes
  - BPO is responsible for the bridge load rating and scour programs. It provides damage assessments and emergency response services when bridges are damaged because of vehicle or ship collision or natural phenomenon such as: floods, wind, or earthquakes.
- Sources
  - <https://wsdot.wa.gov/engineering-standards/design-topics>
  - <https://www.wsdot.wa.gov/publications/manuals/fulltext/M23-50/BDM.pdf>

## **ODOT (Ohio)**

Ohio has the 2nd the greatest number of bridges in their state at over 25,000 bridges. The guidelines mention pedestrian safety, and for wind loads railings for pedestrians are kept in mind. The LRFD and AASHTO bridge specifications are used for all standard designs. The seismic capacity must resist a seismic performance zone with BDM seismic geotechnical requirements. Material design is used for scour resistance. Bank material must utilize scour-resistant rocks along with proper elevation aligned with strength and service limit state checks. Additionally, all other hydraulic specifications, such as flood and storm surges, must be in accordance with the service limit states. The flood design uses a 100-year flood plain as the baseline, while a 10-year storm event is used for drainage design. Standard specifications for vehicle and vessel collision. A fendering system is used for piers on navigable waterways. Material specification for fire safety is detailed which considered temperature, moisture, thawing, salt, and pH.

- Wind
  - Include wind-induced loads on noise barriers mounted on top of retaining walls in the design.
  - Pedestrian: For decorative railing that includes lettering and/or other appurtenances, determine the appropriate wind pressure per LRFD 3.8 and apply the loading to the wind contact area for each appurtenance including the area for the posts and rails.
- Earthquake
  - Steel pier caps: While normally adequate, verify that bearing seat widths of 3-ft are adequate. Large bearings, skew angles, intermediate expansion devices, AASHTO earthquake seat requirements, etc. may require additional width.
  - All bridges in the State of Ohio are located within Seismic Performance Zone 1. Refer to BDM Section 305.1.5 for Seismic Geotechnical requirements.
  - Bridges designed according to the Strength and Service Limit States of the AASHTO LRFD Bridge Design Specifications are assumed to have sufficient capacity to resist Seismic Performance Zone 1 design loads applied at the Extreme Limit State.
- Scour
  - The changes in foundation conditions resulting from scour do not apply to the overall (global) stability

- B. Except as noted in BDM Section 305.2.1.2.b.(A), locate the bottom of footings directly on scour resistant rock. If footings require lateral restraint, provide drilled and grouted steel anchors.
- Spread footing elevation: Include the maximum estimated scour depth at the check flood, considering any streambed or bank material displaced by scour from the check flood.
- See BDM Section 306.1.1 for pile-supported footing elevation requirements. If the design flood scour reaches top of rock, do not use driven piles
- Where scour is predicted, neglect the pile resistance provided by soil in the scour zone. Use the depth of scour resulting from the design flood, per LRFD 2.6.4.4.2, with Strength and Service Limit State checks. Use the depth of scour resulting from the check flood with Extreme Event II Limit State checks.
- Flood
  - All foundation requirements shall be satisfied for the changes in conditions resulting from the design flood at the strength and service limit states and the check flood at the extreme event limit states. Determine the design flood frequency and the check flood frequency for scour in accordance with L&D Vol. 2
  - Flood Insurance Studies use the 100-year flood as the baseline. Carry WSE in a FEMA Zone out to two decimal places
  - The following requirements apply to spread footings located outside of the plan view limits of the 100-yr flood plain:
    - For footings founded on rock, key the bottom of footings at least 3-in into rock.
    - Embed the tops of footings founded on soil at least 1-ft from the nearest soil surface.
    - Embed the bottoms of footings founded on soil at least 4-ft from the nearest soil surface.
    - Embed the bottoms of footings founded on embankment fill at least 5-ft from the nearest soil surface. See BDM Figure 305-2.
    - In no case shall the bottom of the footings in existing soil or on embankment fills be above the frost line. Refer to BDM Figure 305-3 to determine the frost depth at the project site in inches.
- Storm Surge
  - Identification of the NWE, OHWM and design storm event water elevations provides information as to how the channel responds to varying occurrences of surface water runoff and can be critical in planning and bidding in stream work.
  - For retaining walls other than culvert headwalls and wingwalls, ensure that surface drainage for the entire contributing drainage area does not overtop the coping or face of retaining walls for the 10-year storm event. Redirect surface drainage away from the wall or provide supplemental drainage consisting of a ditch above the wall with sufficient capacity to capture the drainage without overtopping.

- When it is necessary to place a storm sewer within the limits of the select granular backfill of an MSE wall, provide reinforced concrete pipe according to C&MS 706.02.
- Vehicle Collision
  - Substructure Protection for Vehicle Collision - refer to BDM Figure 1003-1.
  - Designers should investigate the cost and feasibility of connecting all single column substructure units into adjacent units. Even though single column substructure units that support one primary redundant superstructure member may be assumed as redundant, connecting the single column into an adjacent substructure unit will provide additional resistance to loss in the event of a vehicle collision regardless of the pier protection required.
- Vessel Collision
  - Piers on navigable waterways: Unless protected from collision by an adequate fendering system, design piers in the navigation channel of waterways, to resist collision forces based on AASHTO Guide Specification for Vessel Collision Design of Highway Bridges
- Blast
- Fire
  - Material design: Test data documenting material durability to environmental variables including: UV, temperature, moisture, freeze-thaw, fire, salt, petroleum, pH, etc.
  - An emergency vehicle, as defined in the Fixing America's Surface Transportation Act (FAST Act), is designed to use under emergency conditions to transport personnel and equipment to support the suppression of fires and mitigation of other hazardous situations
- Hurricanes
  - All structures shall have some mechanism to transfer horizontally applied superstructure loads (e.g. vehicular braking force, centrifugal force, vehicular collision force, friction load, water load, wind load, and wind load on live load) to the substructure to ensure structural stability. Inspection: Each bridge record shall include a chronological record of the date and the type of all inspections performed on the bridge. When available, scour, seismic, wind and fatigue evaluation studies; fracture critical information; deck evaluations; field load testing, and corrosion studies should be part of the bridge record.

### **IDOT (Illinois)**

Extremely detailed manual due to having over 25,000 bridges within the state. It incorporates drawing specifications within the manual. Detailed sections for wind loads, which incorporate graphs and drawings. Earthquake design is tailored to locations where earthquakes are more common. The Department's primary objective when designing bridges to resist earthquake loadings is to prevent loss of span and plan failures at certain locations. Flood design is all considered with 100- or 200-year specifications. Detailed hydraulic and Geotech reports are used for flood and storm surge design. The vehicle and vessel collision design are under standard specifications. There are little to no fire and blast specifications.

- Wind

- The wider flanges have higher moments of inertia in the lateral direction and help resist wind loads and deflections during construction.
- Article 3.8 in the AASHTO LRFD Bridge Design Specifications contains the provisions for wind loadings on bridges.
- The longitudinal and transverse load transmission properties of elastomeric bearing types employed in Illinois should be considered when determining tributary areas for wind loadings on superstructures and forces in substructures.
  - AASHTO LRFD Bridge Design Specifications Articles 3.8.1.2, 3.8.1.3 and 3.8.2 apply to pier design for most bridges built in Illinois. Wind on super and substructures is covered in Article 3.8.1.2
  - Note that overturning wind forces are not applied simultaneously with wind on live load in the AASHTO LRFD Bridge Design Specifications. Article 3.8.1.1 should only be used when bridges or parts of bridges are more than 30 ft. above ground or water level.
- The nominal design wind load for bridge/structure mounted noise walls shall be 35 psf. For ground mounted noise walls, the nominal design wind load shall be 25 psf.
- Earthquake
  - Pier types: Multiple round column frame piers are preferred for the resistance of earthquake loadings.
  - When required, the following data shall be given on the TSL for AASHTO LRFD Bridge Design Specification jobs when the planned level of seismic resistance to be provided is for the 1000 yr. or 2500 yr. design return period earthquake: Seismic Performance Zone (SPZ), Design Spectral Acceleration at 1.0 sec. (SD1), Design Spectral Acceleration at 0.2 sec. (SDS), and the Soil Site Class.
  - The lateral earthquake design force for SPZ 1 to 4 (LRFD) is 20% of the dead load reaction as described previously in Section 3.7.3 according to Departmental policy. Usually, this load is less than 10% of the total service vertical design load.
  - The basic IDOT philosophy for seismic bridge design is to allow certain levels of damage or element failures to occur at planned locations in a structure during an earthquake which will not cause a loss of span
  - New bridges on the State System and, as appropriate, new bridges on the Local System shall be designed according to the AASHTO LRFD Bridge Design Specifications for the 1000 yr. design return period earthquake (or a 7% probability of exceedance in 75 yrs.).
- Scour
  - This multidisciplinary concern requires the engineers responsible for hydraulic evaluations, geotechnical/foundation analyses, and structure TSL planning to work together to determine the appropriate design scour depths, strategically locate the substructures and design the foundations to withstand the design flood.

- The scour depths shall continue to be adjusted for soil or rock type per “Scour Estimation at Bridges” below, and the Strength and Service limit state design scour depths shall continue to be determined using the Q100 flood.
- The Hydraulic Report provides the initial theoretical scour calculations for the 100 year event
  - Analyses may be completed at an early stage in the project using a specific set of assumed parameters including pier width, shape, foundation configuration, soils information, opening area, bridge skew, and others.
  - The hydraulics engineer should be contacted to determine if the calculated scour depths need to be recalculated.
  - The Structure Geotechnical Report should include the total Q100 and Q200 scour depths and provide any reductions in the final design scour amount when cohesive soils or rock exist.
- TSL engineer should consider alternatives to ensure the foundation is structurally stable for design scour without the use of riprap, gabions, or some other type of revetment intended to reduce or mitigate estimated scour.
- The design scour elevations be provided on all new bridge plans over waterways to assist the bridge maintenance engineers during their inspections.
- Flood
  - A review of any existing hydraulic capacity analysis results and records of flooding should be made, if available. Changes since initial construction in the channel location or hydraulic opening through the structure should be noted.
  - When designing for the Extreme Event II limit state, the check flood scour depth for routine bridges in Illinois shall be determined using the Q200 flood, rather than the Q500 flood referred to in previous editions of the AASHTO LRFD Bridge Design Specifications.
- Storm Surge
  - Under the supervision of the Unit Chief, the Hydraulics Unit is responsible for the review and approval of the Hydraulic Report (HR) for bridge projects and the Pump Station Hydraulic Report (PSHR) for storm water pumping stations.
  - The Drainage Manual is the primary reference for H&H studies that include, in addition to structure Hydraulic Reports; Location Drainage Studies for roadway improvements, storm drain and detention analysis, and bridge scour evaluation\countermeasure design and drainage connection permits.
- Vehicle Collision
  - Abutments and MSE walls are not required to be designed for vehicle collisions; however, a concrete barrier is recommended to be cast or placed against the abutment or MSE wall when they are located at grade with the shoulder to help mitigate potential vehicle impact damage.
  - Section 3.9.3.7 contains policies and procedures for the design of new grade separation piers subject to vehicle collisions. The vehicle collision requirements of LRFD Article 3.6.5 must be applied to new grade separation piers classified as critical or essential unless the piers are protected as specified therein.

- Vessel Collision
  - AASHTO LRFD Bridge Design Specifications Article 3.14 contains provisions for vessel collision forces. Typically, piers for bridges over navigable waterways should be designed for vessel collision forces. A partial list of navigable waterways in Illinois is given in Section 2.3.9.3. I
- Blast
- Fire
- Hurricanes:
  - The AASHTO LRFD Bridge Design Specifications should also be referenced for more complete information on such loadings as vehicular live, braking, centrifugal, temperature gradient, friction, creep, wind, etc.
  - Earthquake loading, with or without liquefaction, is considered in Extreme Event I limit state
  - The Department's primary objective when designing bridges to resist earthquake loadings (and other extreme event loading cases) is loss of span shall be prevented.
  - The most common cause of bridge failure is foundation and structural instability resulting from excessive removal of stream bed soils (scour) during major flood flow events.
- Sources:
  - <https://public.powerdms.com/IDOT/documents/2504297/Bridge%20Manual>

### **GDOT (Georgia)**

Short bridge manual with focus on design and drawings within the sections. Standard wind load specifications with mention of 140 max design wind speed for diaphragms. Earthquakes refer to AASHTO and LRFD design manual with different specifications related to the geographical location of the bridge. Scour analysis is vital within a report, and it will be present in the as-built drawings when foundations are installed. Different components such as the columns, wall embedment, culverts, and foundations all consider scour. However, scour information is not to be included in the final bridge design. For standard flood conscious a surveyor will collect data such as elevation and location of houses. Manual mentions for certain locations with abnormal flood conditions, it will be approximated from USGS maps. Deep foundation design will utilize a 500-year storm event. Vehicle collision design is in depth with multiple systems to counteract forces. No mention of fire or blast loads.

- Wind
  - Considered as lateral loads acting through the superstructure
  - Diaphragm and Cross Frames: In lieu of using LRFD Fig. 3.8.1.1.2-1, steel diaphragms shall be designed for a minimum load equal to the force generated by a three second gust wind speed of 140mph applied to one half of the vertical surface area of the exposed beam being braced.
- Earthquake
  - Use the design earthquake and subsurface soil condition at the bridge site to determine the seismic performance zone and design/detailing requirements for the bridge.
  - Use the 2007 AASHTO Seismic maps presented in the 2009 AASHTO Seismic Guide Specifications and included in LRFD 3.10.2.1 to determine the

following three acceleration coefficients for the geographical location of the bridge:

- Horizontal peak ground acceleration coefficient, PGA
- Horizontal response spectral acceleration coefficient at period of 0.2 second, SS
- Horizontal response spectral acceleration coefficient at period of 1.0 second, S1
- Variables will all be used to determine the design response spectrum and seismic performance zone for the bridge.
- Scour
  - The documentation of As-Built Foundation Information (As-Built), especially for hydraulic structures susceptible to scour, is a critical record keeping activity. A note should be included on the As-Built sheet of all bridge plans directing the Engineer to submit the complete record to the Bridge Office email address once foundations are installed
  - Designers should be aware that the use of Mechanically Stabilized Embankment (MSE) walls at the hydraulic opening, either as abutment walls or supporting endrolls, is discouraged due to the added structural risks associated with scour and inundation for such structures. Either wall type must be evaluated for scour in accordance with HEC 18 “Evaluating Scour at Bridges”
  - Design bridge foundations in accordance with LRFD 2.6.4.4 and LRFD 3.7.5 with the following additions and exceptions:
    - For spread footings, see BDM 4.2.4.1 for embedment criteria beyond the LRFD Specifications.
    - For pile footings, see BDM 4.2.5.4 for guidance on the location of footings, in lieu of LRFD 2.6.4.4.
    - When piles are used for pile bents or pile footings, they should penetrate a minimum of 10 feet below the 500-year scour line
  - Scour information shall not be included in the final bridge plans
- Flood
  - Two floodplain cross sections are required, one at 100 feet on each side of the roadway. Each cross section should extend to a point 2 feet above the high water mark that has been established for the stream at the bridge site. The floodplain elevations should be taken at all breakpoints in the terrain within the Bridge Survey alignment and 500 foot intervals outside the alignment.
  - The surveyor shall record the floor elevations and locations of any houses, buildings or other structures that have been flooded, or have floor elevations within 2 feet of the flood of record. For structures that have been flooded, the surveyor shall provide the flood information, including the number of times the structure has been flooded, the date(s), and the high water elevations.
  - For projects with abnormal flood conditions (creeks that flow into one of the state’s major rivers), a floodplain cross section is required of the major river below the confluence with the creek. Since this would be an extremely costly section to have surveyed, the cross section may be approximated from USGS maps.

- Storm Surge
  - For Standard Specification projects, deep foundations shall be designed for a Safety Factor = 1.0 for the 500 year storm event.
  - Detour bridges: The design storm used for the detour bridge shall be the 10 year storm. For off-system roads with a design year ADT of 400 vpd or less, the design storm used shall be the 2 year storm.
- Vehicle Collision
  - All columns that have less than 30'-0" horizontal clearance from the edge of roadway shall be designed for the vehicular collision force in accordance with LRFD 3.6.5. Protection by barrier or embankment will not waive this requirement.
  - Do not consider the transfer of the vehicular collision force to the components fully buried underground.
  - The shear force created by the vehicular collision load shall be analyzed with the assumption of a single shear plane.
  - Vehicular collision forces shall be accounted for in the design of noise barrier systems as outlined in Section 15.8.4 of the AASHTO LRFD Bridge Design Specifications.
  - A vehicular collision load of 80 kips distributed over 5 feet shall be applied perpendicularly to the alignment of the sound wall.
  - Vessel Collision
- Blast
- Fire
- Sources:
  - [https://www.dot.ga.gov/PartnerSmart/DesignManuals/BridgeandStructure/GDOT\\_Bridge\\_and\\_Structures\\_Policy\\_Manual.pdf](https://www.dot.ga.gov/PartnerSmart/DesignManuals/BridgeandStructure/GDOT_Bridge_and_Structures_Policy_Manual.pdf)

### **MoDOT (Missouri)**

Utilizes design index with independent pages for loads. Includes wind loads, pressure, and exposure for design. Manual uses standard AASHTO and LRFD design for earthquake design. Less scour design concern than other manuals. There is detailed information about floodplains within the area according to the locations where bridges are built. Note that a permit must be obtained for a structure to build in special flood hazard area. The drainage needs to be designed for a 100-year storm. Vehicle collision is very in-depth with specific design requirements and exceptions along with regard to train collision. Little to no mention of vessel collision, blast load, and fire load. Blast documentation is kept away from the public.

- Wind
  - Wind load shall be assumed uniformly distributed on the area exposed to the wind. For typical bridges, the same wind pressure will be used for all components of the superstructure or substructure, and the wind load is to be applied as a uniformly distributed load on the entire exposed area of the structure.
  - The design 3-second gust wind speed,  $V$ , will be used to determine the design wind load on a bridge.
    - Strength III -> 115 mph
    - Strength V -> 80 mph

- Strength I -> 70 mph
  - For other than typical bridges, different wind exposure categories must be identified to determine the most critical wind direction. To determine the most critical wind direction, sectors extending up to 45 degrees to either side of the wind direction must be observed.
- Earthquake
  - All new bridge/wall designs, including nonseismic (or static) designs, shall be required to meet Seismic Design Category A in accordance with AASHTO Guide Specifications for LRFD Seismic Bridge Design.
- Scour
  - Equal wing lengths are preferable at stream crossings to mitigate scour, improve erosion control and improve/mitigate parallel water flow along wing and side embankment.
  - If it is a stream crossing, the bottom of footing elevation should be based on the scour calculations. The borings should then be studied to see if a minimum of 10 ft. of piling can be placed below the footings. If this is doubtful because of the presence of shale or rock, spread footings or drilled shafts should be used.
  - The type and thickness of Rock Blanket is to be determined by the district based on the flow velocity from the Scour design flood frequency.
- Flood
  - Floodplain development permits are required for work in special flood hazard areas from the State Emergency Management Agency (SEMA).
  - For finding skew angle: On bridges over streams, pick the angle that will allow floodwater to pass through the bridge opening with the least amount of interference from intermediate bent columns.
- Storm Surge
  - Drainage needs to be designed for 100-year storm.
- Vehicle Collision
  - Train: If the face of the columns of an intermediate bent is within 25 ft. of the centerline of the railroad track, a collision wall is required. If the face of the columns of an intermediate bent is within 12 ft. of the centerline, the top of the collision wall shall be set at 12 ft. above top of rail otherwise the top of the collision wall shall be set at 6 ft. above top of rail.
  - Abutments and piers located within the clear zone shall be designed for an equivalent static force of 600 kip, which is assumed to act in a direction parallel to or 15 degree skewed from the direction of traffic, in a horizontal plane, and at a distance between 2 and 5 feet above ground.
  - The collision load shall be applied as a point load for columns, and as a distributed load, no greater than 5 feet wide by 2 feet tall, for walls. For design speeds not greater than 45 mph the design vehicular collision force may be reduced to 400 kip.
  - Design for vehicular collision force is not required if abutment or pier is protected by:
    - An embankment.
    - A Type D barrier located at least 2'-7" clear from the pier or abutment

- A minimum 42-inch MASH TL5 barrier where the top edge of front face is located at least 3'-3" from the pier or abutment
  - A collision wall meeting the standards provided in EPG 751.31.1.7 Collision Walls
  - MGS guardrail and Type C barrier in accordance with Standard Plans 606.51 and 617.10.
  - Guardrail and Type A or B barrier for roadways with design speeds not greater than 45 mph and in accordance with Standard Plans 606.01 and 617.10.
- Vessel Collision
- Blast
  - Consideration should be given to the blast loading provisions given in AASHTO LRFD Bridge Design Specifications and AASHTO Bridge Security Guidelines for major bridges only and with the approval of the State Bridge Engineer.
  - All documentation associated with consideration of and requirements for blast loading protection and/or structural design including structural design computations should be detached or separated from other publicly available documents and marked "Not for Public Consumption."
- Fire
- Special Note for Hurricanes:
  - Extreme Event I: Combination including earthquake.
  - Extreme Event II: Combination relating to ice loads, collision by vehicles or vessels, and certain hydraulic events with reduced live load other than that which is part of the vehicular collision load, CT. Since the joint probability of these events is very low, events are to be investigated one at a time.
- Sources
  - [https://epg.modot.org/index.php/Category:751\\_LRFD\\_Bridge\\_Design\\_Guidelines](https://epg.modot.org/index.php/Category:751_LRFD_Bridge_Design_Guidelines)
  - [https://epg.modot.org/index.php/751.2\\_Loads](https://epg.modot.org/index.php/751.2_Loads)
  - [https://epg.modot.org/index.php/751.1\\_Preliminary\\_Design](https://epg.modot.org/index.php/751.1_Preliminary_Design)

## **IOWA DOT (Iowa)**

The manual is divided up into design for decks, concrete beams, steel beams, concrete slabs, bearings, abutments. Wind loads have a wide range of design speeds (70 - 110 mph) under different strength classifications. Since Iowa is under Seismic Zone 1, certain bridge specifications like decking does not need seismic design. Projects will be conducted under standard seismic analysis. The guide has in-depth hydraulic design which includes multiple classifications of floodplains along with design area. Scour specifications must be tested for multiple hundreds of years up to a max year design. Vehicle collision undergoes standard procedure, but it can be ignored if certain guidelines for noise walls are met. Typical Iowa bridges do not require vessel collision specifications, but for piers in navigable waterways the design must be consulted with the supervising Unit Leader. The manual does not mention design for fire and blast loads.

- Wind

- Wind load for 100 mph wind at elevations not exceeding 30 feet above ground level: 0.050 ksf. At higher elevations the load shall be adjusted upward

**Table 6.6.2.8.1 Design wind pressure criteria**

Factors Affecting Design Wind Pressure, $P_z$	Limit States with Wind Loads		
	Strength III	Strength V	Service I
Design 3-second gust wind speed, $V^{(1)}$	115 mph	80 mph	70 mph
Pressure exposure and elevation coefficient, $K_z$	$K_z(C)^{(2)}$	1.00	1.00
Gust effect factor, $G$	1.00	1.00	1.00
Drag coefficient, $C_D$ , on I-girder and slab superstructures	1.30	1.30	1.30

Table notes:

- For typical bridges with spans not exceeding 155 feet the designer may use a simplified wind load of 100% of  $P_z$  in the transverse direction applied simultaneously with 25% of  $P_z$  in the longitudinal direction rather than using multiple skewed wind load cases.
- For typical bridges, the designer may simplify wind loading by applying the design wind pressure  $P_z$  on the substructure simultaneously in the longitudinal and transverse directions rather than using multiple skewed wind load cases.
- Earthquake
  - Based on the acceleration coefficient  $SD1$ , all of Iowa with Site Class A through E shall be classified as Seismic Zone 1. Thus, for typical bridges no seismic loading (EQ) or analysis involving the deck is required.
  - For unusual projects such as bridge sites determined to be Site Class F and for Missouri River and Mississippi River bridges the designer shall determine the seismic zone and perform seismic analysis as required by the AASHTO LRFD Specifications.
  - Typical continuous PPCB bridges with integral abutments, standard fixed pier connections, and/or standard steel reinforced elastomeric bearings do not require design for seismic connection forces. However, the designer should review bridges with deck expansion joints, bronze plate bearings, fixed shoe bearings, rocker bearings, and special bearings for the need to design for seismic connection forces
- Scour
  - Iowa DOT recommends using the Q200 or lesser discharge for scour analysis, depending on which results in the most severe scour conditions. Usually the overtopping flood results in the worst scour
  - $Q_{500}$  or  $Q_{\text{Overtopping}}$  - to determine check (maximum) scour
  - Scour analyses shall be made by hydraulic/geotechnical/structural engineers. Details on conducting a scour analysis are included in the FHWA Technical Advisory
  - Check scour is based on the occurrence of a 500-year or lesser flood used to ensure pile capacity and stability will not fail at the extreme scour event.
  - Design scour is based on the occurrence of a 200-year or lesser flood used to evaluate pile capacity and stability.
- Flood

- Flood insurance: analysis of a community's flood prone areas which determines the 100-year flood elevation and floodway for certain streams.
- Q50 is a flood that has a 2% statistical probability (chance) of being equaled or exceeded in any year.
- Q100 is a flood that has a 1% statistical probability (chance) of being equaled or exceeded in any year.
- As a general rule, the design discharge for rural structures on Iowa's primary highway system is the 50-year flood. For bridge locations where the upstream flood damage potential is high or where the site is located in a detailed Flood Insurance Study (FIS) area, the 100-year flood should be the design discharge.
- USGS SIR 2013-5086 has defined three different flood regions for the state and utilizes a multivariable equation for each region. For basins that cross region boundaries (multi-region basins), StreamStats will provide a SIR 2013-5086 RRE AEPD estimate for each region falling in the basin, and a weighted AEPD estimate per SIR 2013-5086 based on the ratio of the area of each contributory flood region to the total basin area.
- When a bridge is located within a detailed Flood Insurance Study (FIS) area, or the upstream flood plain has a high damage potential (such as a residence or business located in the upstream flood plain), the designer should perform a HEC-2 or HEC-RAS analysis to determine the impacts on flood elevations.
- Storm Surge
  - For drainage basins between 2 and 20 square miles, WRIR 87-4132 may be used for the design discharge. A thorough review of the basin characteristics and history of flooding along with engineering judgement is needed when determining design discharges for small basins.
  - For urban basins larger than 160 acres, and for some complex basins that are less in size, the design storm runoff may be analyzed by other methods such as TR-55 for watersheds up to 2000 acres. For areas larger than 2000 acres TR-20 may be used or other methodologies such as HEC-HMS or other programs.
  - When development/urbanization is located within the drainage basin, other hydrologic methodologies should be considered to account for the higher runoff potential due to additional impervious areas and the decreased travel time. In general, urban hydrology for a basin should be considered when 25% or more of the watershed has been developed.
  - Rainfall intensity for a 10 yr. frequency, 5-minute duration storm, varies throughout the state of Iowa. We are using an 8 in/hr rainfall intensity for bridge deck drains throughout the state of Iowa. This variable can be changed in the spreadsheet if determined to be necessary by the engineer.
- Vehicle Collision
  - Iowa DOT policy is to exempt design for vehicle collision force when the annual frequency of bridge collapse (AFBC) is less than the AASHTO thresholds. The AFBC calculations and resulting design accommodations shall be determined in bridge final design.

- Verify horizontal alignment adequacy with respect to Vehicle Collision Force guidelines listed in AASHTO LRFD Section 15.8.4: Design of Sound Barriers. Cases where vehicle collision forces need not be considered are summarized:
  - Noise walls located beyond the acceptable clear zone.
- Noise wall/barrier rail systems within the clear zone that have been successfully crash tested.
- Noise walls behind a crashworthy traffic railing with a setback of more than 4.0 feet. The setback is measured from the traffic face of the traffic barrier rail.
- Noise walls or portions thereof at locations where the collapse of the wall has minimal safety consequences, as determined by the Owner.
- Vessel Collision
  - Mean highwater (MHW) is a term used in the AASHTO Guide Specification for Vessel Collision Design of Highway Bridges and is defined by the Coast Guard as the average of the height of the diurnal (each day) high waters at a particular location measured over a period of 19 years.
  - The vessel collision load, CV, need not be applied to piers in typical Iowa streams. For piers in navigable waterways the designer shall consult with the supervising Unit Leader.
- Blast
- Fire
- Special Note for Hurricanes:
  - Extreme highwater is the highest water level recorded for a particular location. Information can be obtained from USGS or Corps flood reports, when available.
  - Emergency repair or replacement projects will typically be the result of extreme events such as flood damage, fire, roadway vehicle impact, and waterway vessel collision. Less common events could also include terrorist activities and unanticipated structural failures due to regular or accelerated wear under typical operating conditions.
- Sources
  - <https://iowadot.gov/bridge/policy/LRFDBridgeDesignManual.pdf>

### **Maine DOT (Maine)**

The manual was created in 2003, but the most recent version was updated in 2018. The standard AASHTO specifications are used for the design. The wind analysis is conducted at 100 mph without live load. The earthquake analysis is done using the Mononobe-Okabe Method. Good resource for northeastern earthquake specifications. Flood analysis is accounted for by historical floods dating back to 1929. Piers and abutments are designed to resist all collision types. If there is a possibility of collision exists from vehicular, railroad, etc. there must be appropriate risk analysis. No mention of specific fire and blast loads, so there are standard specifications. Notes for hurricane category in specific seasons

- Wind
  - Abutment and Geotechnical Analysis
    - Strength III: Load combination relating to the bridge exposed to high wind velocity (100 mph) without live loads.

- Strength V: Load combination relating to the bridge exposed to wind velocity of 55 mph with live loads.
  - D. Wind Loads Longitudinal components of wind on superstructure and wind on live load should be distributed to the abutments when structure fixity is at the abutments.
- Earthquake
  - Where applicable, the effects of wall inertia and amplification of active earth pressure by earthquake should be considered. The Mononobe-Okabe method should be used to determine equivalent static pressures for seismic loads on walls and abutments as described in Section 3.7.3 Substructure. If the soils are saturated, liquefaction should be evaluated and addressed per Section 3.7.4.2 Liquefaction and Seismic Settlement.
  - Soil conditions must be known to determine the seismic site coefficient for the bridge. In the AASHTO Standard Specifications Division I-A there are four soil profiles defined and a site coefficient is assigned to each profile.
  - Additionally, potential hazards and seismic design requirements related to slope stability, liquefaction, fill settlement, and any increase in lateral earth pressures as a result of earthquake motion need to be identified.
  - Certain bridge types (e.g. multiple simple spans), or details (e.g. high rocker bearings) that are more vulnerable to earthquake damage should be avoided based on the probable severity of damage and the impact on the serviceability of the structure.
  - Bridges that are required to be open to all traffic once inspected after the design earthquake and usable by emergency vehicles and for security, defense, economic or secondary life safety purposes immediately after the design earthquake.
- Scour
  - The PDR is the main source of hydrologic, hydraulic, and scour information for a bridge project. If there are any changes made to the project after the PDR has been completed that impacts hydrology, hydraulics, and/or scour, it should be documented and included in the PDR as an addendum.
  - Q500 - discharge used in evaluating scour
  - Tidal bridges are designed for unsteady flow conditions during the complete rise and fall cycle of the tide. Hydraulic design for tidal bridges establishes the minimum finished grade and minimum depth requirements for the foundation through scour analysis. For special cases, other features may require hydraulic design
  - Although some hydrologic, hydraulic, and scour analysis is necessary for all bridge drainage structures, the extent of such studies should be commensurate with the complexity of the situation, and with the importance of the structure and of the surrounding property.
  - A scour analysis will be performed for all bridge-type structures using the methods in the latest version of HEC-18.
- Flood

- Stream flow and flood related data are sometimes available from other agencies in the State. The major sources are: U.S. Geological Survey, Natural Resources Conservation Service, Maine State Planning Office, Utilities
- Many of MaineDOT's existing plans, existing flood studies, historical flood information, and U.S.G.S. topographic maps are based on the National Geodetic Vertical Datum (NGVD) of 1929.
- Q100 or flood of record - check discharge
- All bridge-type structures should also be capable of passing the Q100, or the flood of record, whichever is greater, without any serious harm to the structure, roadway, or adjacent property. When possible, there should be 1 foot of freeboard at Q100.
- Scour should also be computed for the super flood, defined as Q500 or the overtopping flood if it is between Q100 and Q500.
- Storm Surge
  - Bridges in Maine are designed for both riverine and tidal stream crossings. Riverine bridges are designed for steady flow at the peak discharge for the design storm. Hydraulic design for riverine bridges establishes:
    - Minimum finished grades
    - Bridge location
    - Bridge length
    - Span lengths
    - Orientation
  - Bridges in tidal area - Bridges on tidal rivers/streams should be designed to protect the bridge structure itself. Most of the surrounding land and the approach roadways may be inundated by relatively frequent tidal storm surges.
- Vehicle Collision
  - Unless the department determines that site conditions indicate otherwise, abutments within a distance of 30 feet to the edge of a roadway or within 50 feet to the centerline of railway track shall be investigated for collision. Collision loads and crashworthy barrier design criteria for abutments are identical to those provided for Piers
  - Pier analysis: Where the possibility of collision exists from vehicular, railroad, or water traffic, an appropriate risk analysis should be made to determine the degree of impact resistance to be provided and/or the appropriate protection system.
  - Collision walls:
    - An embankment
    - A structurally independent crashworthy ground mounted 54 inch high barrier, located
    - A 42 inch high barrier located at more than 10 feet from the pier
- Vessel Collision
  - All bridge components in navigable waterway crossings where vessel collision is anticipated shall be designed for a specified degree of vessel impact damage in accordance with LRFD 3.14, or adequately protected by dolphins, fender systems or other sacrificial devices.
- Blast

- Fire
- Special Note for Hurricanes:
  - Downstream boundary condition - Typical tide cycle based on mean tide range with storm surge due to a Category 1 hurricane. A Category 1 hurricane equates to about a 50 year storm surge. The peak of the storm surge should be checked for the following four different times:
  - Peak of storm surge at mid rising tide
  - Peak of storm surge at high tide
  - Peak of storm surge at mid falling tide
  - Peak of storm surge at low tide
- Sources:
  - <https://www.maine.gov/mdot/bdg/docs/Complete2003BDGwithUpdatesto2014.pdf>
  - <https://www.maine.gov/mdot/bdg/docs/BDGupdateJune2018.pdf>

### **WYDOT (Wyoming)**

The manual states that the loads and load factors from the AASHTO LRFD Bridge Design Specification will be used unless noted. The chapters are sectioned off by general design information, slabs, superstructure, substructures, and box culvert design. The website gives design examples along with descriptions of bridges within Wyoming. There is little to no mention of wind loads. Something unique would be the manual mentioning intermediate substructure design, and for scour design, it is 500 years for extreme events and 100 years for strength limit state. WYDOT Hydraulics Program uses a conservative approach for determining the design and checking flood scour flood frequencies. The manual has in-depth information about vehicle collision which covers design exceptions and things to consider that reduce impact. No mention of vessel collision likely due to little waterway travel. There are no separate fire and blast specifications either.

- Wind
  - The windloads and analysis shall be based on the AASHTO Guide Specification for LRFD Seismic Bridge Design.
  - Wind loading on abutments is negligible and shall be ignored.
- Earthquake
  - The seismic loads and analysis shall be based on the AASHTO Guide Specification for LRFD Seismic Bridge Design.
  - The importance of a structure will depend on many factors which include seismic classification
  - Sill type abutments: Full lateral earth pressure shall be applied to sill type abutments even if reinforced backfill is utilized. Passive earth pressure that would help resist the earth pressure shall be ignored. Superstructure loading that would help resist earth pressure shall be ignored in this case.
  - The dead loads applied to box culverts shall meet the following based on the culvert type.
    - For non-rigid culverts (No moment transfer between walls and slabs):
      - Vertical earth pressure: 120 pcf
      - Lateral earth pressure: 72 pcf
    - For rigid culverts (Moment transfer between slabs and walls):

- Vertical earth pressure: 120 pcf
    - Load case 1 - Lateral earth pressure: 72 pcf
    - Load case 2 - Lateral earth pressure: 36 pcf
  - Wingwall: Where reinforced backfill is used, the design of the wingwalls shall be based on an active earth pressure.
- Scour
  - The use of bents in streams where heavy scour and large quantities of debris are possible is discouraged.
  - The following shall be used to design foundations at intermediate substructure locations for scour: The Extreme Event Limit state shall be used for the check scour (typically 500 year event) the Strength Limit State shall be used for the design scour (typically 100 year event). The design flood scour elevation (typically 100 year event) shall be shown on the General Plan and Elevation sheet.
  - Spread footing: The bottom of footing depths shall be determined with respect to the character of the foundation materials and the possibility of scour. Spread footings shall be founded at a depth determined by scour analysis and below frost.
    - If possible, the top of spread footings on piles or drilled shafts shall be placed below scour elevation. If this is not practical, the Hydraulics Program shall be notified to determine the effects that the footing has on pier scour
  - The pile can be fully braced if it is not subject to scour and can be assured that the soil will adequately provide lateral support.
- Flood
  - Under hydraulic design
  - Abutment: The riprap countermeasures designed by the Hydraulics Section should be assumed to be adequate for providing slope protection for all flood events.
  - If crossing a waterway, determine the magnitude of design scour due to the design flood from the Hydraulic Scour Report
- Storm Surge
- Vehicle Collision
  - The 600 kip load as specified in Article 3.6.5 shall be applied to all structures not meeting the requirements of Article 3.6.5.1 and the functional classification of the roadway being crossed is not a local rural or urban roadway.
  - In lieu of designing for the collision force, the following strategies may be used in accordance with Article 3.6.5:
    - Reinforced concrete pier components that have 3 foot thick minimum dimension and 30 square feet cross sectional area.
    - Pier protection is provided in accordance with the following: 42" high MASH crash tested rigid TL-5 barrier located such that the top of the barrier is 3.25 feet or more from the face of the pier component being protected.
  - The magnitude of the load may be reduced based on the following criteria:
    - Posted Speed Limit

- Number of Highway Access Points adjacent to Bridge
  - Lane Width
  - Horizontal Curve Radius
  - Lanes in One Direction
  - Grade Approaching the Pier System
  - Engineering judgment based on site specific data
- Article C3.6.5.1 shall be used to determine the probability of collapse in justifying any reduction in collision force. Any reduction of the collision force must be approved by the Bridge Program Staff.
- Columns placed behind retaining walls do not need to be designed with the collision force.
- The minimum transverse reinforcement in drilled shafts shall be a No. 5 spiral with a 6" pitch, unless additional reinforcement is required by design (i.e., for seismic or vehicle collision load).
- Vessel Collision
- Blast
- Fire
- Sources:
  - [https://www.dot.state.wy.us/home/engineering\\_technical\\_programs/bridge/bridge\\_design\\_manual.html](https://www.dot.state.wy.us/home/engineering_technical_programs/bridge/bridge_design_manual.html)
  - [https://www.dot.state.wy.us/files/live/sites/wydot/files/shared/Bridge/Bridge%20Design%20Manual/Final%20-%20Section%201-3%20-%20Loads%20and%20Load%20Factors\\_revised%20jrb%20April%202022.pdf](https://www.dot.state.wy.us/files/live/sites/wydot/files/shared/Bridge/Bridge%20Design%20Manual/Final%20-%20Section%201-3%20-%20Loads%20and%20Load%20Factors_revised%20jrb%20April%202022.pdf)

Table 14 – Summary of State DOT’s Practices 1 (Wind, Scour, and Fire)

State	Wind	Earthquake	Fire
NJ	Design wind speed of 80 mph, $C_d = 1.20$ for horizontal wind pressure on VMS/DMS and $C_d = 1.70$ for vertical wind load	AASHTO Guide Specifications for LRFD Seismic Bridge Design; Eastern Region (Richter scale 4.0 & 5.0)	Limited information, consult local fire and emergency officials for specific needs
NY	Standard specifications, wind loads considered in pier design.	Retrofitting includes base isolation bearings, follow SRMHS and NYSDOT LRFD Bridge Design Specifications	Design includes different materials such as wood members
CT	Intermediate diaphragms and lateral bracing designed for 120 mph wind load	Seismic analysis for horizontal restraint, beam seat length; CTDOT may waive seismic design for certain bridges	No detailed specifications
PA	LRFD 80 mph wind load, horizontal wind pressure includes gust factor of 1.3, drag factor of 1.2.	Seismic acceleration coefficient of 0.15, classified as Seismic Zone 1	Access doors in walls if required by fire departments
MI	Minimum thickness of 3/8" for structural steel members for wind bracing and diaphragms.	N/A	N/A
DE	Evaluate steel members for wind loads, design for 20 mph wind load during paint operations	N/A	Fire codes and protection measures considered during design and inspection
NC	Wind loads follow AASHTO LRFD	AASHTO LRFD Bridge Design Specifications, seismic analysis required	N/A
CA	Design wind speed based on AASHTO Table 3.8.1.1.2-1, wind pressure for bridge elements calculated	Caltrans Seismic Design Criteria (SDC), seismic analysis controls column designs	N/A
FL	Wind load design for 150 mph wind, catenary wire support for dead and wind load	N/A	Coordination with fire authority required for hydrant access and fire prevention measures
LA	Wind forces according to AASHTO, truss design velocity 70-100 mph	Standard specifications for low-magnitude earthquakes, follow AASHTO guidelines	N/A
AK	Strength III load combination for severe wind, wind on live load at 6 feet above roadway	AASHTO Guide Specifications for LRFD Seismic Bridge Design, detailed seismic detailing practices	Detailed fire damage assessment and cleaning methods for timber and concrete

<b>State</b>	<b>Wind</b>	<b>Earthquake</b>	<b>Fire</b>
WS	Compute LRFD-BDS design wind pressure, consider wind shear and maximum wind speeds	LRFD-SGS for seismic design, classify bridges as "Critical" or "Recovery"	N/A
OH	Wind-induced loads on noise barriers, design railings for wind pressure	All bridges in Seismic Performance Zone 1, follow BDM seismic geotechnical requirements	Material design considers environmental variables like UV, temp., moisture, freeze-thaw, fire
IL	Wider flanges for wind loads, nominal design wind load for bridge/structure mounted noise walls	Classifies SPZ 1 to 4 for seismic performance, design for 1000 (SPZs 1-3)/2500-year (SPZ 4) return period earthquake	N/A
GA	Design for 140 mph wind speed for diaphragms, lateral wind loads considered	Use 2007 AASHTO Seismic maps for acceleration coefficients, follow LRFD seismic design requirements	N/A

Table 15 – Summary of State DOT’s Practices 2 (Vehicle Collision, Vessel Collision, and Blast)

<b>State</b>	<b>Vehicle Collision</b>	<b>Vessel Collision</b>	<b>Blast</b>
NJ	Risk analysis required for vessel collision. Employ AASHTO methodologies and Energy Absorbing Fender Systems	Follow AASHTO LRFD Bridge Design Specifications, conduct vessel risk analysis	General guidance on assessing blast force effects, AASHTO Bridge Security Guidelines
NY	Standard vehicle collision design, repairs do not require railing replacement evaluation	Design for vessel collision according to NYSDOT LRFD Bridge Design Specifications Article 3.14	Limited specifications
CT	Classified as Extreme Event II, detailed analysis required	Classified as Extreme Event II, detailed vessel collision events evaluated	Classified as Extreme Event II
PA	Horizontal loads from vehicle collision considered, repair guidelines for railing collision damage	Design for navigable waterways, consider vessel collision forces based on AASHTO Guide Specifications	Standard specifications
MI	Bridge rail height for vehicle stability, detailed collision damage investigation	N/A	N/A
DE	Detailed collision damage investigation, vehicle impact analysis	N/A	N/A
NC	Detailed vehicle collision guidelines, specify concrete barrier and crashwall requirements	Assess vessel collision risk and design impact resistance	N/A
CA	Design loads for vehicle collision, refer to AASHTO Section 13, barrier rails and impact resistance	Fender system for bridges over navigable waterways, design piers to withstand CV force	Design based on importance of the bridge, AASHTO Bridge Security Guidelines
FL	Standard vehicle collision design, consider traffic barriers and crashwall requirements	Follow U.S. Coast Guard guidelines for vessel collision, design piers to prevent collapse	N/A
LA	Standard vehicle collision design, directional slip bases for high-speed collision	Follow U.S. Coast Guard guidelines, consider vessel size and impact requirements	N/A
AK	Standard vehicle collision design, consider substructure protection and collision loads	Follow AASHTO Guide Specifications, site-specific vessel collision consideration	Standard blast design based on bridge importance, follow AASHTO guidelines
WS	Consider collision risk for abutments and piers, provide structural resistance, or redirect collision load	Provide collision protection or design for collision loads for piers with one or two columns	Limited information, standard specifications

<b>State</b>	<b>Vehicle Collision</b>	<b>Vessel Collision</b>	<b>Blast</b>
OH	Investigate cost and feasibility of connecting single column substructure units for impact resistance	Follow AASHTO Guide Specifications, design piers for navigable waterways	N/A
IL	Design abutments and piers for vehicle collision, follow LRFD Article 3.6.5	Design piers for vessel collision based on navigable waterways, follow AASHTO guidelines	N/A
GA	Detailed vehicle collision design, use concrete barriers and crashwalls	Design for vessel collision according to AASHTO, consider operational characteristics of directional slip bases	N/A

Table 16 – Summary of State DOT’s Practices 3 (Scour, Flood, Storm Surge, and Hurricanes)

State	Scour	Flood	Storm Surge	Hurricanes
NJ	Section 39 of BDM, references AASHTO LRFD and Model Drainage Manual, qualitative and quantitative analysis levels	Design for 100-year flood, consider history of erosion, or scour at site	Large storm drains should not discharge through culvert walls	Design based on AASHTO LRFD Bridge Design Specifications Section 3 Extreme Events II
NY	Detailed analysis including temporary structures and waterways; Q50 design flow (50-year return period).	Design vertical clearance over Floodway Project Design Elevation, consider Q500 floodplain	Minimum of 2-year storm event for temporary streambank protection, rainfall intensity based on ten-year period	N/A
CT	Detailed analysis, hydraulic study required, design to resist scour for 100-year flood. Scour design flood and scour check flood must be determined, detail riprap and sediment control measures	Hydraulic study required within floodplain, avoid encroachment into floodway	Design for storm surge levels using historical data and projected sea level rise.	N/A
PA	Scour analysis for Q25 flood, scour protection provided	Superflood analysis for 500-year flood event, consider maximum scour depth at Service I limit state	N/A	N/A
MI	Evaluate and adjust footings or cut-off walls (prevent or reduce seepage and erosion) for scour potential, complete scour analysis required	Design for 100-year flood, consider FEMA floodplain regulations	Design storm for "100-year Storm", maintain adequate drainage and sediment control	Flood response program and inspection guidelines
DE	Detailed scour monitoring system, complete scour analysis required	Elevation data and floodplain cross sections required	Design for stormwater and sediment control, erosion control measures required	Detailed hurricane response guidelines for bridge inspection and maintenance
NC	Geotechnical analysis for stream crossing structures, rock embankment design for stability	100-year flood design, include design high water elevation and overtopping flood data	Detailed stormwater management and sediment control measures	N/A

State	Scour	Flood	Storm Surge	Hurricanes
CA	100-year flood for scour analysis, geologic material consideration, two conditions (design and check flood)	50/100-year flood for waterway conveyance, minimum of 200-year flood for check flood	Design based on AASHTO guidelines for coastal and tidal areas, considering historical data and projected sea level rise	Design based on AASHTO guidelines, last hurricane in 1939
FL	Detailed scour evaluation and hydraulic analysis, riprap rubble ditch lining	Design for 100-year flood, comply with environmental permits and sediment control	Comply with NPDES Stormwater Pollution Prevention Plan, erosion control measures	Submit containment system design for tropical storms and hurricanes
LA	Detailed hydraulic studies, consider scour protection and predicted scour depths	Hydraulic studies and flood hazard summary required, design for 25-year and 100-year floods	Comply with EPA stormwater regulations, NPDES General Permit for construction sites	Design for storm surges and secure federal funds for bridge construction post-Hurricane Katrina
AK	Hydraulics Report according to Alaska Highway Drainage Manual, design for 100/500-year flood	Design flood frequency determined by hydraulics engineer, consider 50/500-year floods	Deck drainage analysis by hydraulics engineer, follow AASHTO guidelines	Consideration for damage inspection post-hurricane, timber and concrete deck conditions evaluated
WS	Total scour at scour design flood, consider lateral migration and total scour conditions	Consult State Hydraulics Office for walls in floodplain, preliminary design stage review	Design detention vaults for stormwater storage, follow ACI 350.3-06 for seismic effects	BPO responsible for damage assessments post-hurricane, bridge load rating and scour programs
OH	Design for service limit states, consider scour-resistant materials and pile support	Design for 100/200-year flood, follow L&D Volume 2 for design flood frequency	Identification of design storm event water elevations, follow stormwater control guidelines	Detailed inspection requirements for hurricane impact, ensure bridge stability post-event
IL	Hydraulic Report for scour calculations, design for 100-year event, consider soil and rock type	Design for 100/200-year flood, hydraulic report and scour estimation required	Hydraulic unit responsible for report review, follow Drainage Manual for H&H studies	Design for hurricane conditions, ensure structural stability against extreme events
GA	As-Built foundation information critical for hydraulic structures, scour analysis for MSE (Mechanically Stabilized Earth) walls	Floodplain cross sections and elevation data required, consider USGS maps for flood conditions	Follow sediment and stormwater control regulations, design for stormwater management	Detailed hurricane response guidelines for bridge inspection, ensure structural stability post-event

## APPENDIX B: CLIMATE PROJECTION TOOLS AND SOURCES

- Coastal Flood Exposure Mapper: <https://coast.noaa.gov/floodexposure/>
- Sea Level Rise Viewer <https://coast.noaa.gov/digitalcoast/tools/slr.html>
- National Water Prediction Service: <https://water.noaa.gov/>
- National Hurricane Center Storm Surge Risk Maps:  
<https://earthquake.usgs.gov/hazards/interactive/>
- USGS NSHM Risk-Targeted Ground Motions (RTGM):  
<https://earthquake.usgs.gov/ws/designmaps/aashto-2023/#/>
- ASCE 7 Hazard Tools: <https://ascehazardtool.org>
- National Hurricane Center Storm Surge Risk Maps:  
<https://www.nhc.noaa.gov/nationalsurge/>

## APPENDIX C: RESILIENCE RELATED NATIONAL PROJECTS AND PROGRAMS

- NCHRP Research Report 1098: Guide for Response Planning, Assessment, and Rapid Restoration of Service of Bridges in Extreme Events
- NCHRP Report 750, Volume 2 (2014) documented software tool and spreadsheet that provided specific, region-based information on incorporating climate changes adaptation into planning and design of infrastructure assets.
- FHWA-HEP-17-082 (2017) Synthesis of Approaches for Addressing Resilience in Project Development:
  - FHWA started pilot studies to incorporate resilience into the development of engineering projects, covering the coastal hydraulics, pavement and geotechnics, riverine and wildfire, and economic assessment.
- NCHRP 08-36, Task 146 (2019) Incorporating Resilience into Transportation Planning
- NCHRP 15-61 (2016) Applying Climate Change Information to Hydrologic and Hydraulic Design of Transportation Infrastructure
  - Developed a design guide to provide hydraulic engineers with the tools needed to account for climate changes
  - NCHRP 20-44 is intended to determine the effectiveness and ease of Guide produced in NCHRP 15-61.
- NCHRP Research Project 938 (2020) was conducted to fill the gaps identified by DOTs in using cost benefit analysis (CBA) as decision-making tool for extreme weather events and climate change.
- USDOT has published CMIP Climate Data Processing Tool, Vulnerability Assessment Scoring Tool, and Transportation Climate Change Sensitivity Matrix.
- Transportation Security Administration (TSA) also has the Vulnerability Assessments and Security Plans.
- FHWA bridge and tunnel safety and security program
  - Bridge Security Design: Overview, Practice, & Future Needs – Course Flyer
  - Anti-Terrorism Planner for Bridges Fact Sheet (U.S. Army Engineer Research and Development Center)
  - Primer on Impact Protection for Critical Transportation Infrastructure (December, 2018)
  - Multiyear Plan for Bridge and Tunnel Security Research, Development, and Deployment
  - Blue Ribbon Panel on Bridge and Tunnel Security
  - Cable-Stay Strand Residual Strength Related to Security Threats
  - Steel Truss Retrofits to Provide Alternate Load Paths for Cut, Damaged, Or Destroyed Members
  - Bridge Security Design 1-Hour Training: Needs and Practices