Fact Sheet 1.4: Bridges

The mitigation objective of this Fact Sheet is to prevent or minimize damage to bridges from flooding, erosion and scour, and debris strikes resulting from floods and hurricanes.

Mitigation for bridges depends on which part of the bridge is damaged and what caused the damage. Figure 1.4.1 shows basic bridge structure.

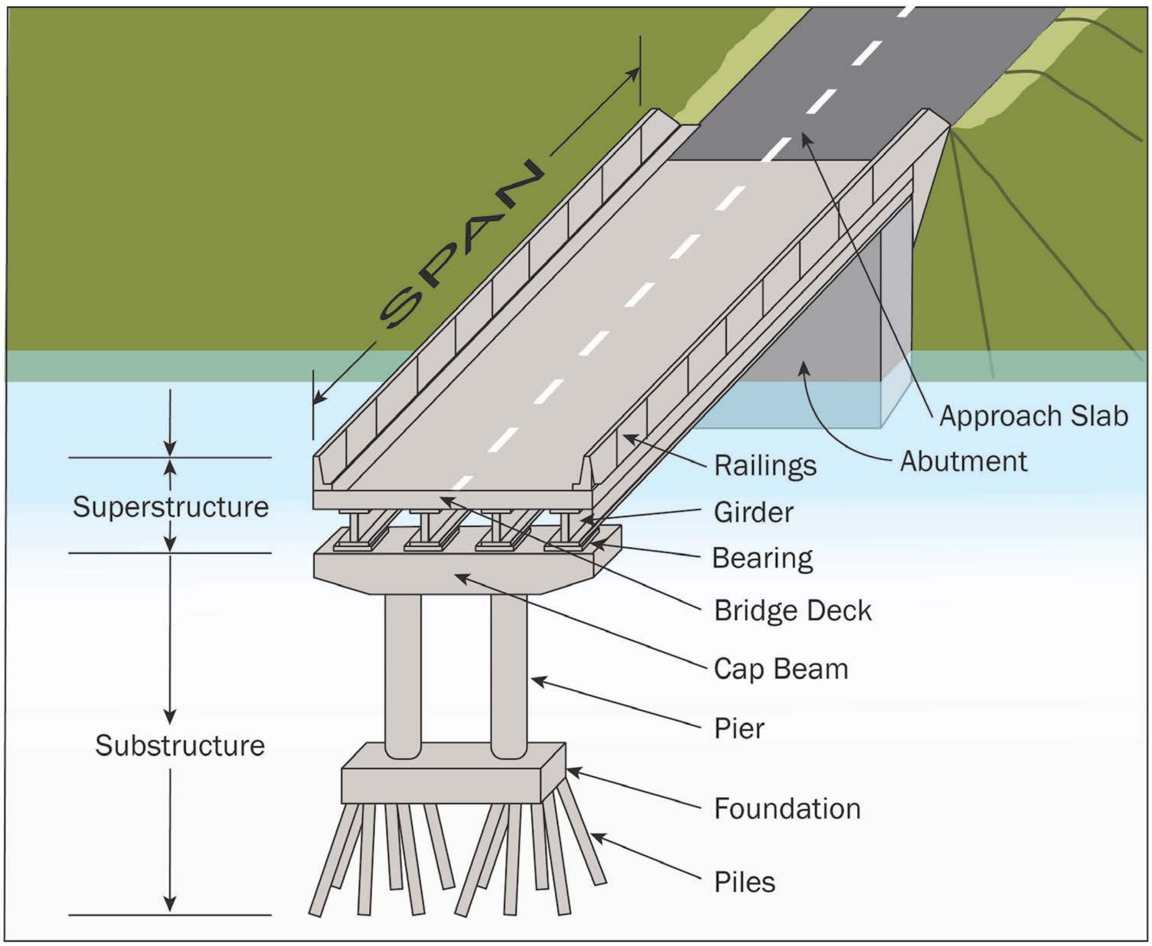


Figure 1.4.1. Basic bridge structure.

Table 1.4.1 summarizes some common mitigation strategies for reducing the likelihood that floods and hurricanes might damage bridges and bridge components.

Table 1.4.1. Common Mitigation Solutions for Various Types of Bridge Damage

Solutions and Options	***Erosion and Scour***	***Flooding and Washout***	***Debris Blockage and Impact***
Mitigation Solution: Improve Flow under the Bridge Crossing			
Option 1: Replace Multi-Spans with a Single-Span Bridge	✓	✓	✓
Option 2: Elevate the Bridge Deck	✓	✓	✓
Option 3: Increase the Bridge Length	✓	✓	✓
Option 4: Build a Relief Opening	✓	✓	✓
Option 5: Use a Low-Flow Crossing	✓		✓
Mitigation Solution: Construct Erosion and Scour Countermeasures			
Option 1: Install Riprap	✓		✓
Option 2: Construct Bridge Wingwalls	✓		✓
Option 3: Construct Spur Dikes	✓		✓
Option 4: Realign Piers and Abutments	✓		✓
Option 5: Increase the Footing Depth	✓		✓
Option 6: Install Flow Deflectors	✓		✓
Mitigation Solution: Reduce Debris Damage			
Option 1: Install Debris Deflectors	✓		✓
Option 2: Install Semicircular or Triangular Endnoses	✓		✓
Option 3: Install Batters	✓		✓
Option 4: Replace Timber Pile Bent Pier Structure with Solid Concrete Column Pier	✓		✓
Option 5: Replace Steel Truss Bridges with Open Deck Bridges	✓		✓
Option 6: Construct Debris Catchments	✓	✓	✓
Option 7: Install Debris Sweepers	✓	✓	✓
Mitigation Solution: Relocate the Bridge			
Option 1: Relocate the Bridge	✓	✓	✓

Mitigation Solution: Improve Flow Under the Bridge Crossing

If the opening under a bridge is too small or is blocked, the bridge can flood, damaging the bridge deck, railings and trusses. Increasing the amount of water that can pass through a bridge opening or modifying the bridge deck design to help control the water flow can prevent damage to the bridge.

Option 1: Replace Multi-Spans with a Single-Span Bridge

Replacing bridges built from multiple spans with one clear span eliminates the number of piers within the floodwater area (Figure 1.4.2), providing additional space for the water to flow.

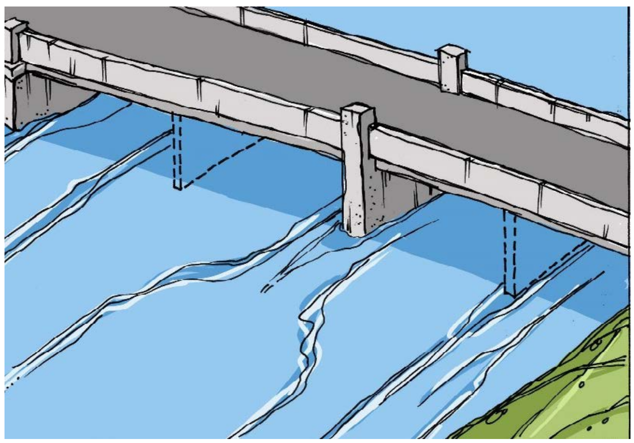
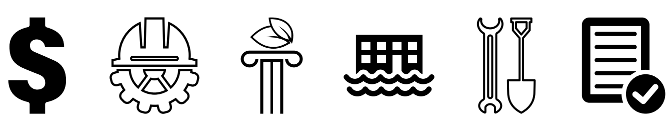


Figure 1.4.2. Reducing the number of spans can increase the flow amount under the bridge. In this figure, the dashed piers would be removed to accomplish this.

When evaluating this option, keep these considerations in mind:

- This mitigation method can increase the amount of floodwater that can safely move under the bridge while reducing upstream backwater and damming.
- Redesign of the bridge may be required with this option to thicken the substructure and increase the roadway profile and approach slab.
- An engineer should evaluate hydraulic conditions to determine if increased flow also will increase water velocity and scour.

CONSIDERATIONS:



Option 2: Elevate the Bridge Deck

Increasing the size of the bridge opening by raising the bridge deck will increase the space available for floodwater to pass through, which can decrease the likelihood of damage from flooding (Figure 1.4.3). Generally, if a bridge has been damaged by overtopping or fast water velocities in the past, it is a good candidate for increasing the size of the bridge opening. Make sure to raise the bridge deck and superstructure above the estimated level of the potential worst-case scenario future flood.

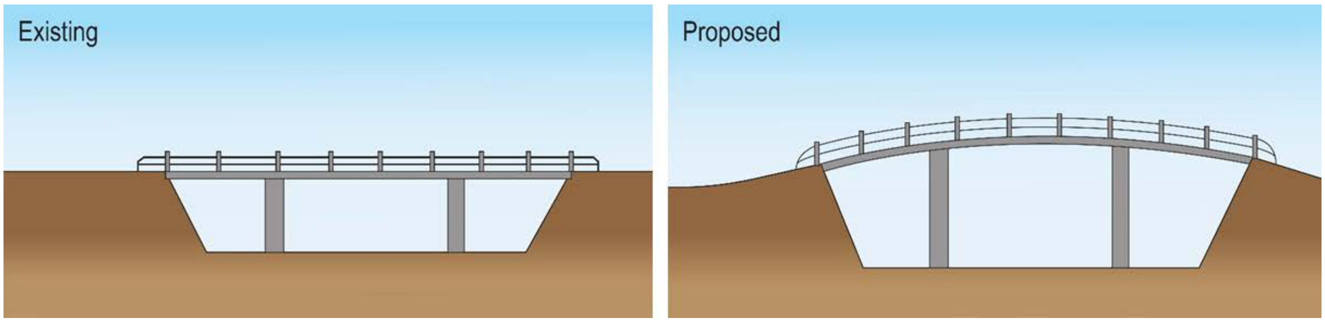
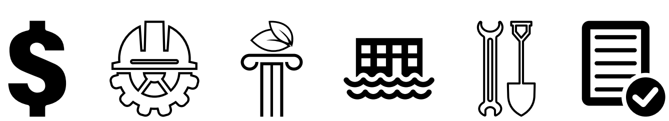


Figure 1.4.3. Increasing the size of a bridge opening by raising the bridge deck can increase flow volume under the bridge.

There are multiple considerations when evaluating this option:

- Adjust the bridge approach slab to meet the new height of the bridge deck. This could involve making the approaches to the bridge longer and higher.
- The piers and abutments may need to be redesigned and rebuilt to support the raised bridge deck. If the bridge deck will only be raised one or two feet, it may be possible to jack up the bridge beams and install pedestals. Abutments may require taller end walls and a new approach slab.
- If raising the bridge structure leads to a larger amount of floodwater going under the bridge rather than overtopping the roadway, this could increase flow velocities under the bridge, which could increase the likelihood of scour.
- The ends of the bridge at the crossing and the stream channel geometry must be evaluated to determine if this option is feasible.
- An engineer should complete hydraulic and hydrologic (H&H) studies to evaluate if and how a bridge opening size could be increased. If elevating the deck is feasible, the design should be done by a licensed professional engineer.
- If the bridge must be lengthened in addition to raising the deck, the project may not be cost effective unless the bridge is an older structure and due for replacement soon.

CONSIDERATIONS:



Option 3: Increase the Bridge Length

Lengthening a bridge by installing additional bridge openings or bridge spans can increase the flow volume below a bridge (Figure 1.4.4).

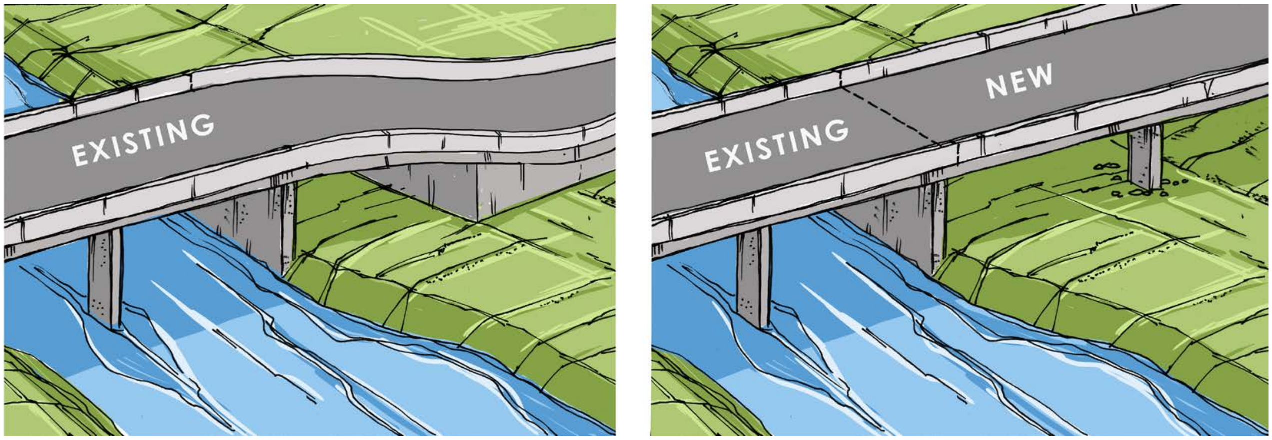
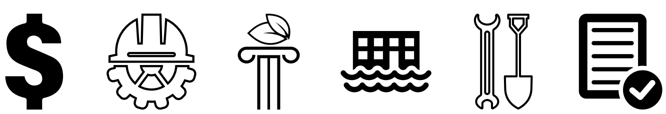


Figure 1.4.4. Lengthening a bridge can provide additional overflow capacity beneath the bridge.

When evaluating this option, keep these considerations in mind:

- Place additional openings or spans where past or future stream alignments cross the site.
- This measure can mitigate the effects of a widening streambed or the formation of sand bars or other temporary islands (referred to as “braid bars”) in the waterway beneath the bridge.

CONSIDERATIONS:



Option 4: Build a Relief Opening

Building one or more relief openings beneath the road surface and embankments (also known as the road prism) can increase the flow volume of the crossing. Place the extra opening at the appropriate height and location. The water level downstream of the bridge must not block water flowing through the crossing (Figure 1.4.5).

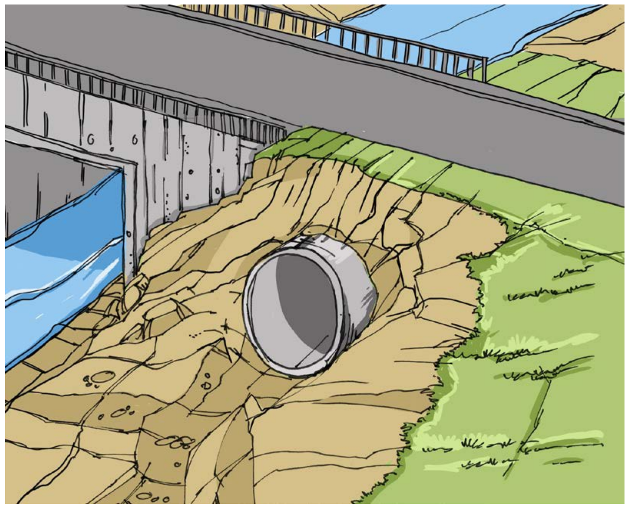
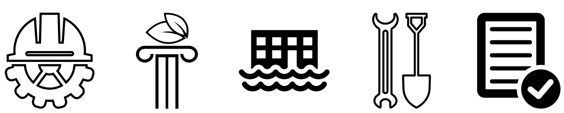


Figure 1.4.5. Building a relief opening can help prevent flooding of bridges.

When evaluating this option, keep these considerations in mind:

- The relief opening may be a culvert, box culvert, bridge, or a combination of culverts or bridges. See Mitigation Fact Sheet 1.3, *Drainage and Culverts,* for more information on culverts and drainage.
- Locate the opening at natural side channels and in line with heavy flow areas in the stream.

CONSIDERATIONS:



Option 5: Use a Low Water Crossing

Low water crossings allow water to flow over the bridge (Figure 1.4.6). The road and bridge will be impassable during flooding events.

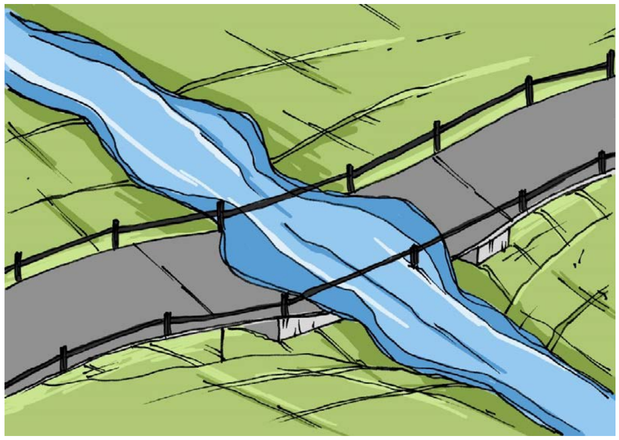
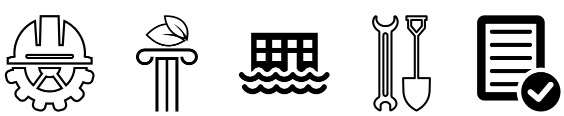


Figure 1.4.6. Low water crossings can be cost effective in areas with low traffic where flooding is seasonal.

When evaluating this option, keep these considerations in mind:

- Do not consider this option if the roadway connects to a critical facility.
- This measure works best in areas where flooding is seasonal.
- It is appropriate only for corridors with low traffic counts.
- Signs and barricades are necessary when water exceeds a depth that is safe for vehicles to pass.
- Design and construct roadway embankments to withstand anticipated water flows.
- The profile of the crossing should match the shape of the stream crossing as closely as possible.

CONSIDERATIONS:



Mitigation Solution: Construct Erosion and Scour Countermeasures

High-velocity water flows, flooding, and overtopping can erode and damage bridge approach slabs and abutments. These flows also can cause scour around piers and abutments, which can damage the bridge and even cause structural soundness problems. Reducing flow velocities and eliminating overtopping and erosion can help prevent flood damage to bridges.

Option 1: Install Riprap

Placing riprap at bridge approaches, abutments and piers can reduce erosion during high-velocity water flow from flooding (Figure 1.4.7).

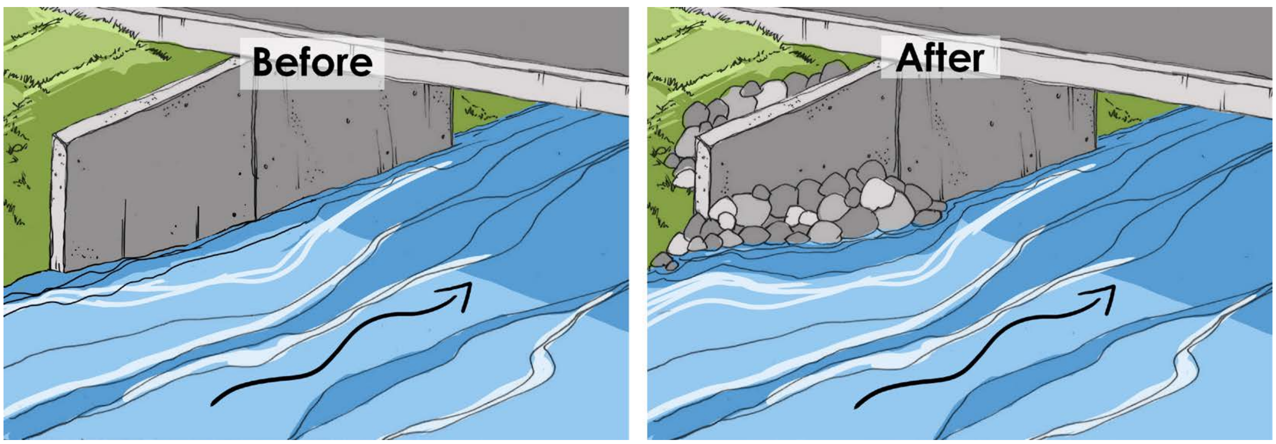
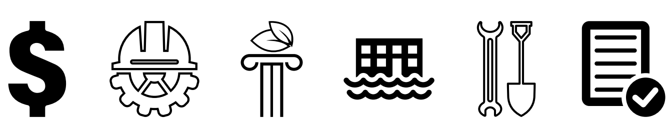


Figure 1.4.7. Riprap can protect bridge piers and abutments against erosion and scour.

When evaluating this option, keep these considerations in mind:

- Size the riprap so it will not slide or be dislodged by fast-flowing water.
- Riprap should be supported at the base of the slope to prevent sliding.
- Riprap may be required to meet environmental regulations.
- Riprap may need to be designed by a licensed professional engineer; verify with the local Department of Transportation.
- Riprap also can protect piers and abutments against debris impacts.
- See Mitigation Fact Sheet 1.2, *Road Shoulders and Embankments*, for additional riprap design and placement information.

CONSIDERATIONS:



Option 2: Construct Bridge Wingwalls

Installing bridge entrance and outlet wingwalls to redirect the flow into the bridge opening can reduce or eliminate erosion under the bridge piers, abutments and embankment (Figure 1.4.8).

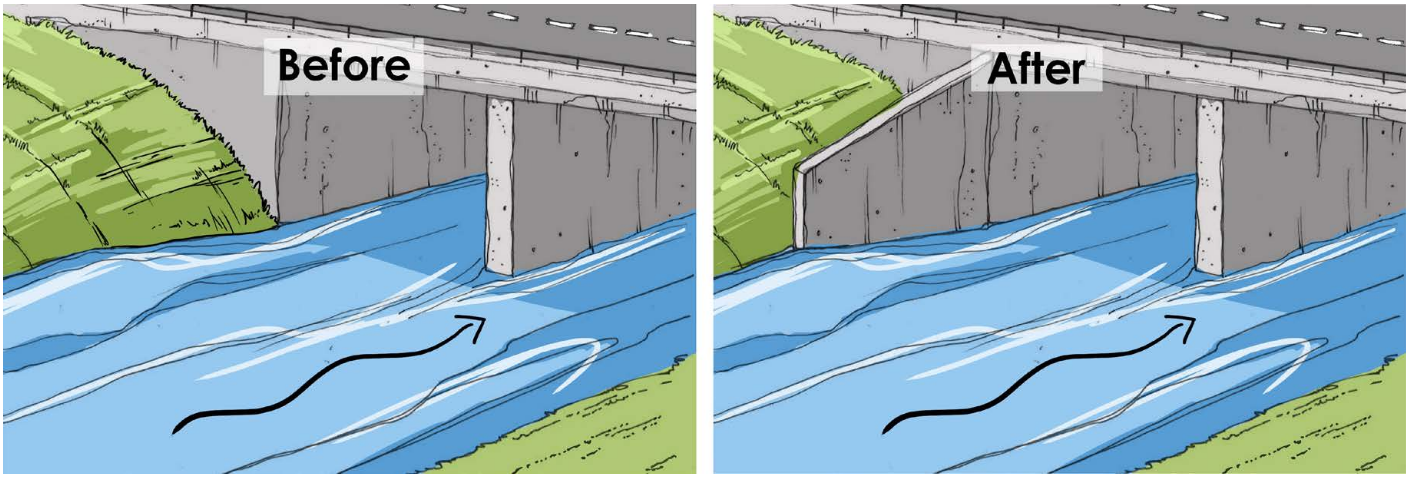
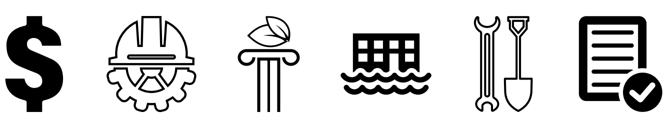


Figure 1.4.8. Wingwalls can help direct the flow of water and prevent erosion and scour at the bridge.

When evaluating this option, keep these considerations in mind:

- Angle flared wingwalls in the direction of the stream. Depending on the angle of wingwalls, flow volume may increase, which helps decrease flooding potential. Protect embankments against erosion from increased flows using riprap or bioengineered methods (discussed in Fact Sheet 1.2 *Road Shoulders and Embankments)*.
- This measure could require deep bridge foundations or permanent sheet pile installation to avoid scour.
- Rounding or beveling abutment corners may increase flow volumes.
- If stream velocities are high, lateral scour of embankments may result from eddies at the ends of wingwalls. Wingwall shape and angles relative to the stream can reduce eddies.

CONSIDERATIONS:



Option 3: Construct Spur Dikes

Spur dikes are embankments designed to direct flood flows into a bridge opening (Figure 1.4.9). They are "tied into" the road embankment at an appropriate point landward from the bridge opening and then extend upstream.

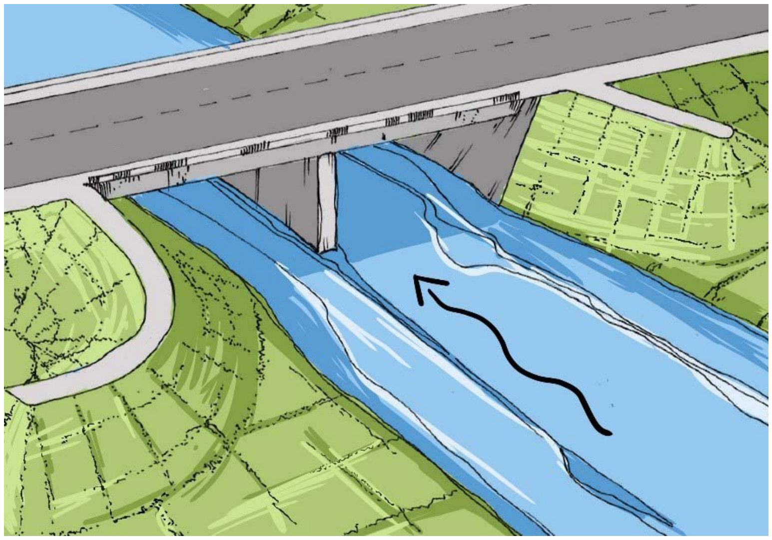
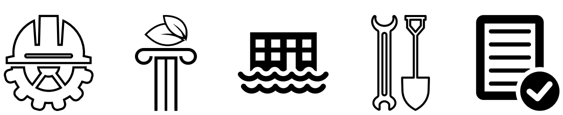


Figure 1.4.9. Spur dikes can direct flood flows, reducing erosion and scour around bridges.

When evaluating this option, keep these considerations in mind:

- The typical shape of a spur dike is either straight or elliptical.
- Install spur dikes at an angle to redirect the flow into the bridge opening, thereby eliminating the potential for erosion along and under the bridge piers and abutments and along the bridge embankment.
- Place spur dikes on the stream overbanks, so water surface elevations are not increased significantly.
- If stream velocities are high, scour of spur dike embankments may result from eddies at their upstream ends and along their sides. Design spur dike shapes and angles to reduce eddies.

CONSIDERATIONS:



Option 4: Realign Piers and Abutments

Realigning bridge piers and abutments to be parallel to flood flow can reduce or eliminate erosion along and under the bridge piers and abutments and along the embankment (Figure 1.4.10).

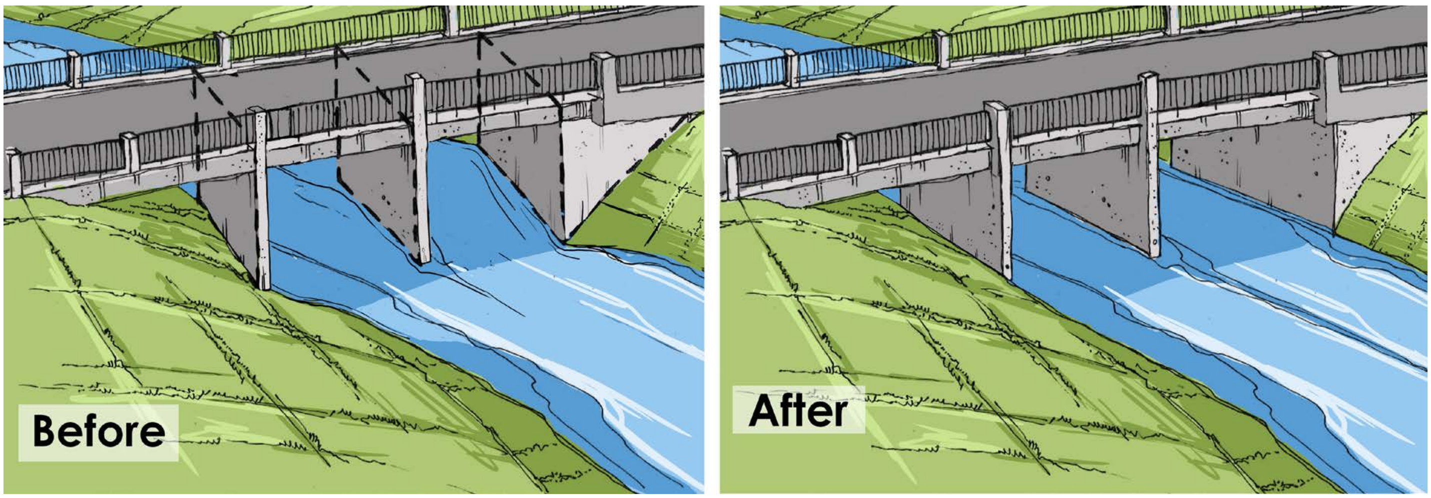
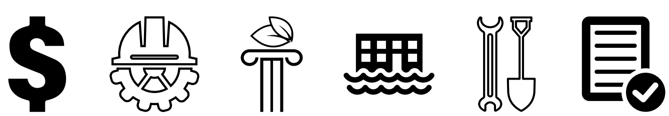


Figure 1.4.10. Realigning piers and abutments can decrease the damage from erosion and scour.

When evaluating this option, keep these considerations in mind:

- Realigning the bridge may mean moving it to the area of the current stream channel and aligning the bridge opening to the centerline of the stream.
- Flow volumes may increase when piers are aligned.
- It may be most cost-effective to replace the bridge.

CONSIDERATIONS:



Option 5: Increase Footing Depth

Increasing the depth of the footing used to support the bridge structure can help mitigate the damage from scour on bridge foundations (Figure 1.4.11).

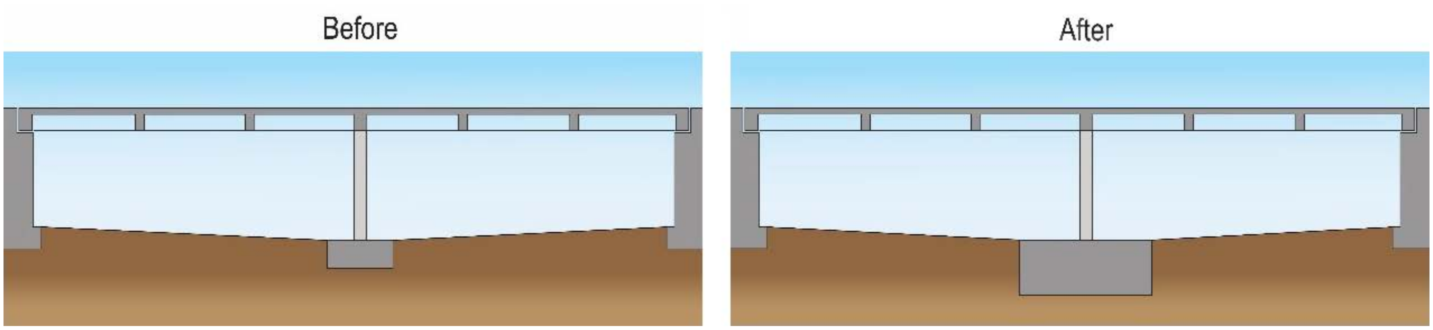
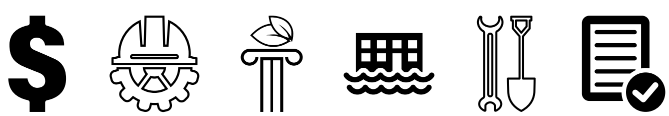


Figure 1.4.11. Increasing footing depth can protect bridge foundations against scour.

When evaluating this option, keep these considerations in mind:

- Extend the depth of pier and abutment footings below the scour depth of the 0.2%-annual-chance flood or bedrock. Thickening the footing or lowering the top of the footing and increasing the column length are ways to make this happen.
- The depth of scour depends on flood flow velocities and flow depth along the footing and the makeup of the streambed materials.
- Streambed characteristics may limit the depth of the pier and abutment footings. If the depth of footings cannot be increased, or if the cost is too great, consider changing the foundation type to deep foundations such as drilled shafts or piles.
- Inspect footings periodically after floods for erosion and scour.

CONSIDERATIONS:



Option 6: Install Flow Deflectors

Installing “V”-shaped flow deflectors on or immediately upstream from the upstream sections of piers and abutments can help reduce velocities of flow that directly contacts each pier or abutment. They can protect footings from scour (Figure 1.4.12).

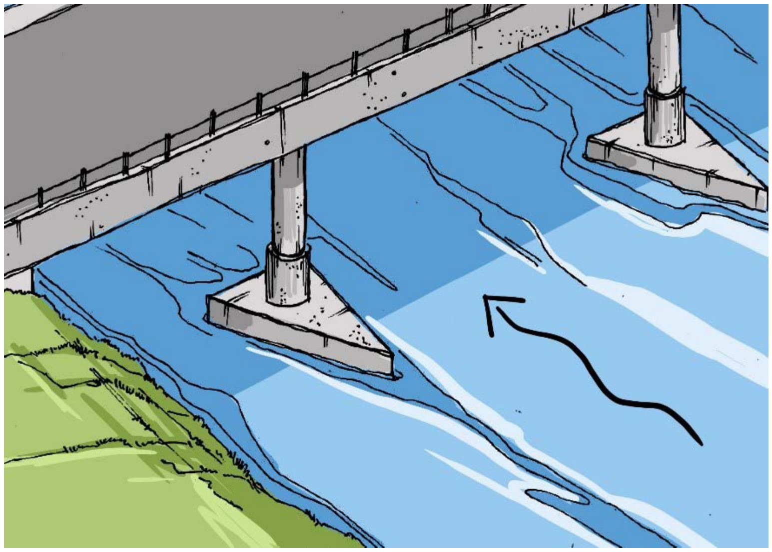
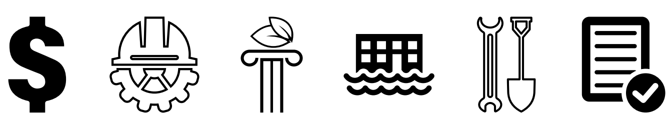


Figure 1.4.12. Installing flow deflectors immediately upstream of bridge piers can help protect them against scour.

When evaluating this option, keep these considerations in mind:

- Flow deflectors are very effective for high-speed flood flows.
- Install a concrete collar on the lower section of piers immediately above the footings.
- Extend the bottom sections of abutments and wingwalls to help deflect flood flows away from them and to reduce streambed scour along and under them.
- Pier collars and abutment subwalls are moderately effective. When used with extended abutments and wingwalls, they may provide additional protection from rock and debris impact.
- A qualified engineer should review hydraulic models with these changes included to evaluate potential impacts on the hydraulic capacity of the stream.
- Inspect flow deflectors periodically after floods for impact damage and erosion.

CONSIDERATIONS:



Mitigation Solution: Reduce Debris Damage

Flood-borne debris can lead to damage and even failure of bridges from impacts and debris accumulation, which result in flooding and washouts. Directing debris around and away from bridge piers and abutments can prevent impact damage, debris accumulation, and scour.

Option 1: Install Debris Deflectors

Debris deflectors or debris fins installed on the upstream ends of piers and abutments angled to direct floating debris into areas of high flood flow velocities can reduce damage (Figure 1.4.13).

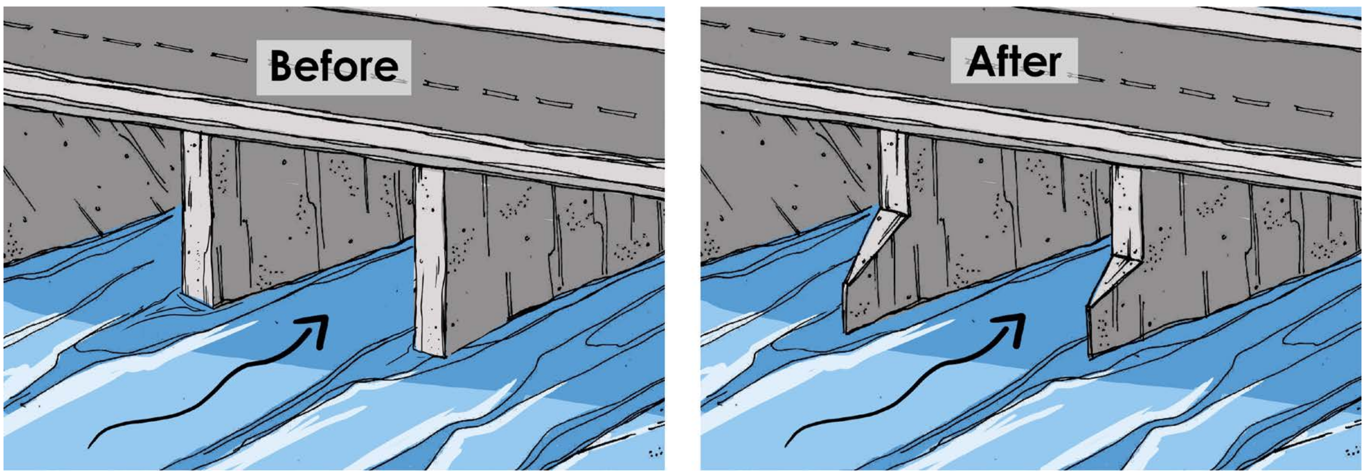
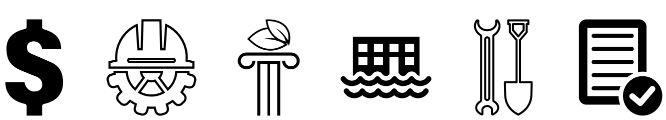


Figure 1.4.13. Debris deflectors can protect bridge piers and abutments from impact damages and debris accumulation.

When evaluating this option, keep these considerations in mind:

- Debris deflectors and fins should be “V”-shaped and extend upstream far enough to orient the floating debris for easy passage through the bridge.
- Design debris deflectors or fins to prevent debris accumulation and protect the piers and abutments from being struck by floating debris.
- Design dbris deflectors so that they do not push debris farther downstream to another location. This is more effective when the flood flow velocities are high, and the area is known to have large amounts of debris in the watershed.
- The bridge deck must be high enough to pass floating debris.

CONSIDERATIONS:



Option 2: Install Semicircular or Triangular Endnoses

Semicircular or triangular endnoses are typically sheet metal attached to the pier on the upstream end to redirect flood flow (Figure 1.4.14).

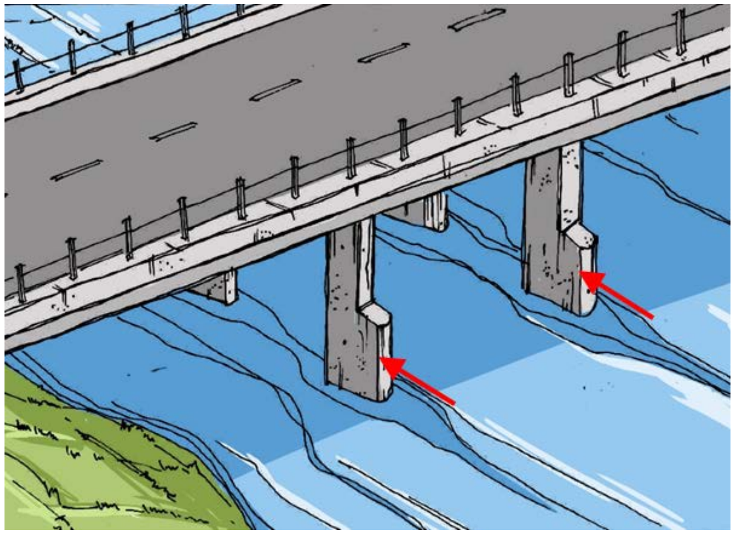
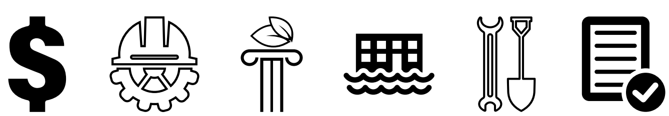


Figure 1.4.14. Endnoses installed on the upstream end of piers (shown by red arrows) can protect piers from debris impacts.

When evaluating this option, keep these considerations in mind:

- Endnose design should prevent debris buildup and protect piers and abutments from being struck by floating debris.
- Bridge decks should be high enough above flood stage for floating debris to pass under the bridge.
- Remove any debris that builds up in the bridge opening as soon as it is safe following the flood.
- Periodically inspect piers after floods for signs of streambed erosion.

CONSIDERATIONS:



Option 3: Install Batters

Install steel plate batters on the upstream ends of concrete piers with semicircular or “V”-shaped endnoses, or on wingwall ends and wingwall-abutment junctions, to protect them from the impact of floating debris (Figure 1.4.15).

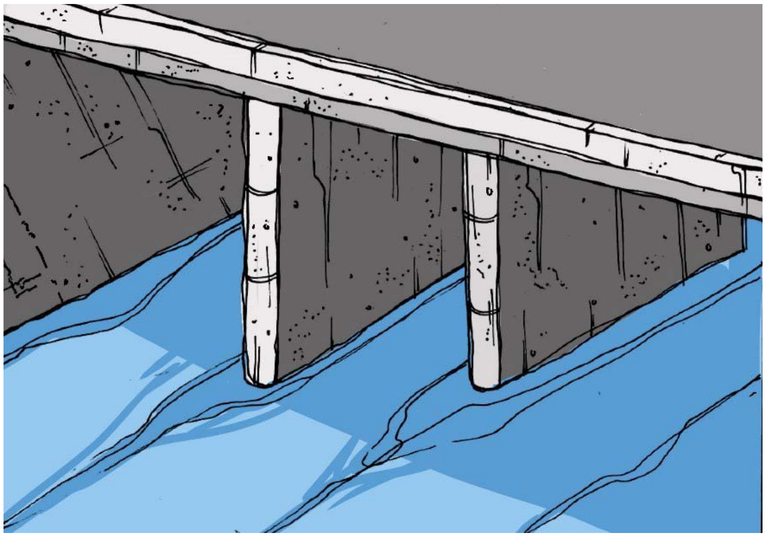
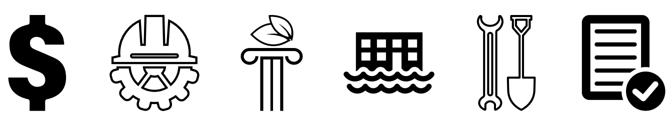


Figure 1.4.15. Steel plate batters protect piers from the impact of floating debris.

When evaluating this option, keep these considerations in mind:

- Steel plates are welded or bolted to the piers.
- Cathodic protection, which is a technique used to control erosion of a metal surface, may be required to protect the steel against corrosion.

CONSIDERATIONS:



Option 4: Replace Timber Pile Bent Pier Structure with Solid Concrete Column Pier

Replacing a multiple timber piling or pier configuration, called a timber pile bent pier structure, with a single solid concrete column pier (Figure 1.4.16) can prevent debris accumulation in the pile bent pier area and protect the pier from debris impact.

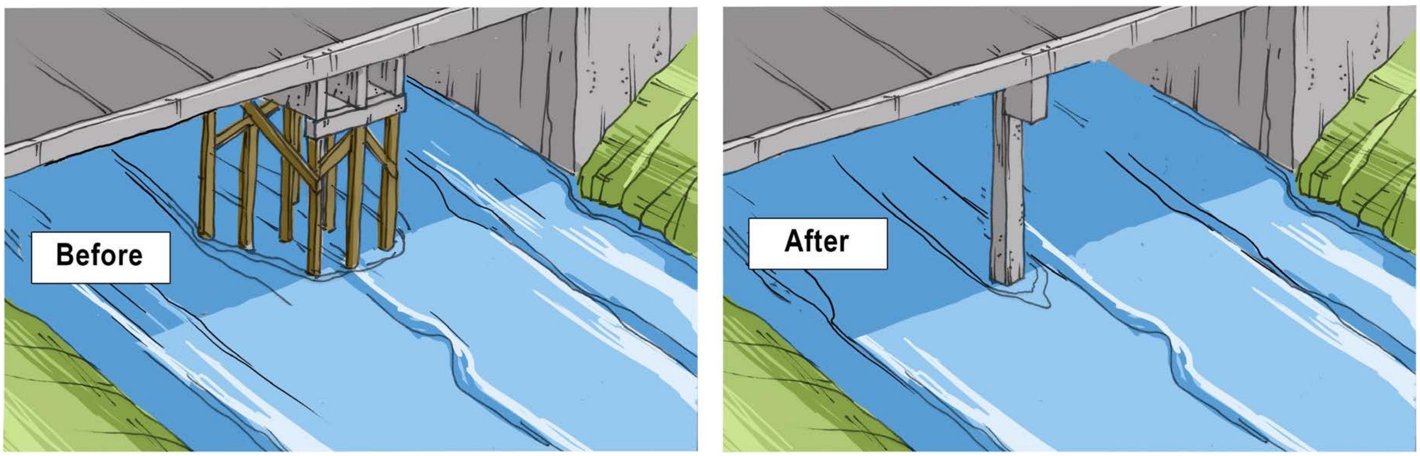
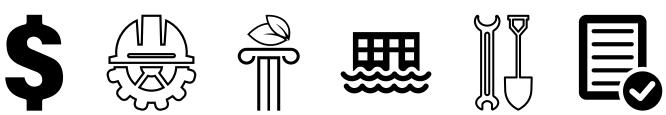


Figure 1.4.16. Replace a multiple timber pier structure with a concrete column to protect against debris impact.

When evaluating this option, keep these considerations in mind:

- This measure is effective in areas that have a large amount of debris upstream of the bridge.
- The concrete pier is assumed to be larger than the timber pilings, decreasing the flow area. A qualified professional engineer should complete a hydraulic and hydrology analysis to evaluate the effect of the pier replacement on the flow area.

CONSIDERATIONS:



Option 5: Minimize Below-Deck Framing

An open deck bridge will not trap floating debris to the same extent that a steel truss bridge will when overtopped (Figure 1.4.17). Minimizing the framing underneath the bridge can reduce trapped debris.

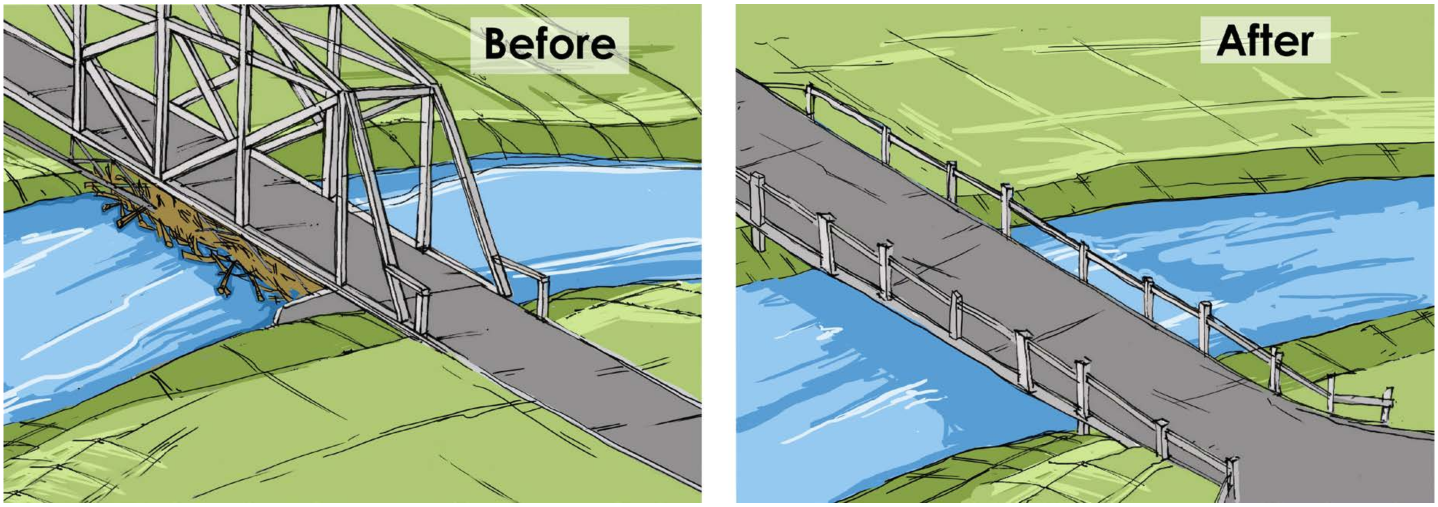
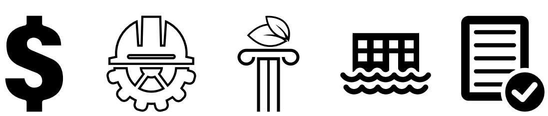


Figure 1.4.17. Replacing a solid deck with an open deck can reduce trapped debris.

When evaluating this option, keep these considerations in mind:

- Bridge piers and abutments may require redesign to adapt to an open deck bridge. A licensed professional engineer will need to evaluate the feasibility of this measure and prepare the design.
- The roadway may need to be raised to keep the lower steel at or above the truss's bottom (low chord) elevation.
- This method can be costly.
- A licensed professional engineer will need to evaluate the feasibility of this measure and prepare the design.
- This method requires permits and compliance with environmental regulations.

CONSIDERATIONS:



Option 6: Construct Debris Catchments

Debris catchments, such as debris barriers (trash racks) or low-height dams, may be constructed on small branch streams upstream from a bridge (Figure 1.4.18).

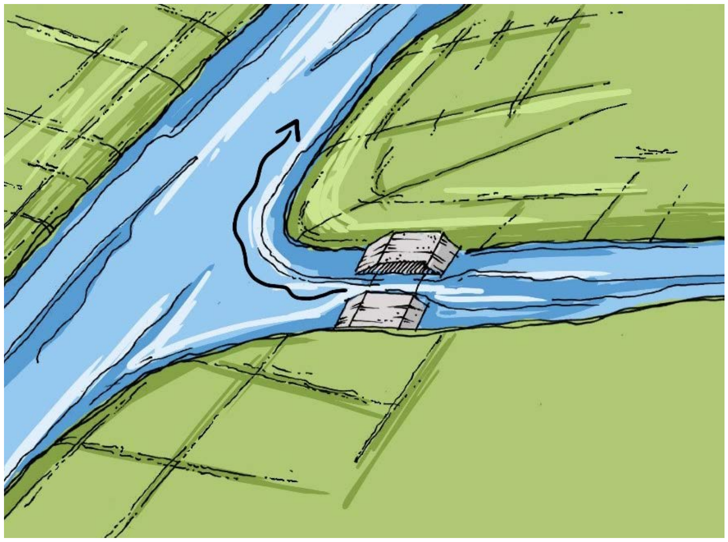
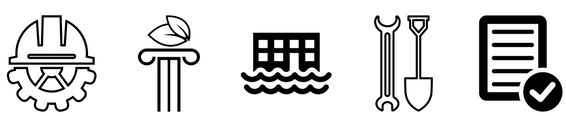


Figure 1.4.18. Debris catchments trap debris before it reaches bridge piers and abutments.

When evaluating this option, keep these considerations in mind:

- Design the catchment structures to trap debris while passing the stream flow.
- If a debris catchment dam is constructed, it must include an emergency spillway.
- This approach is less effective on larger streams.
- This method is effective where the source of debris is from heavily vegetated drainage areas upstream of the bridge where there are adequate storage areas above the catchment structures.
- Debris that builds up upstream of the catchment structures must be removed as soon as it is safe after the flood peak has passed.

CONSIDERATIONS:



Option 7: Install Debris Sweepers

Debris sweepers are cylinders with vertical vanes that rotate and float up and down with the water surface to sweep debris away from bridge piers and through bridge openings (Figure 1.4.19 and Figure 1.4.20).

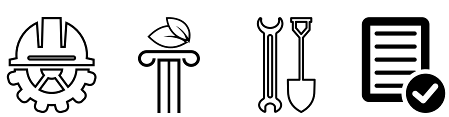
Figure 1.4.19. A debris sweeper can be attached directly to a pier to deflect debris (FHWA, 2005).

Figure 1.4.20. Pile-mounted debris sweepers can effectively direct debris away from bridge piers (FHWA, 2005).

When evaluating this option, keep these considerations in mind:

- Water flow causes the sweeper to rotate on its vertical axis.
- The sweeper can be attached directly to the pier or a pile driven into the streambed.
- Sweepers are less effective when flow speeds are low and can get clogged. Additionally, sweepers attached directly to piers are more likely to fail than sweepers mounted on piles.
- Piles are driven into the streambed likely will require special permits and compliance with environmental regulations.

CONSIDERATIONS:

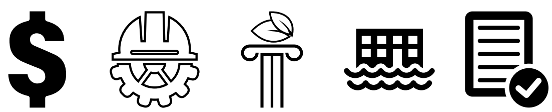


Mitigation Solution: Relocate the Bridge

Option 1: Relocate the Bridge

Bridge relocation to a site with less exposure to damaging flows can be cost effective in areas with repeated coastal storms, surge and flooding as long as access is still maintained. This measure is used most often where more-frequent floods regularly overtop the bridge deck, where the flood level is above the roadway surface for a short distance, and when the necessary right of way is available. Moving the bridge allows access during emergencies and storm events.

CONSIDERATIONS:



REFERENCES:

Detailed technical information on bridge mitigation methods, considerations and general design practices can be found in these publications.

Federal Emergency Management Agency (FEMA). 2007. FEMA P-543, *Design Guide for Improving Critical Facility Safety from Flooding and High Winds: Providing Protection to People and Buildings*. Available at: https://www.fema.gov/sites/default/files/2020-08/fema543_design_guide_complete.pdf

FEMA. 2013. *Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards*. Available at: https://www.fema.gov/sites/default/files/2020-06/fema-mitigation-ideas_02-13-2013.pdf

FEMA. 2020. FEMA B-797, *Hazard Mitigation Field Book, Roadways.* Available at: https://www.fema.gov/sites/default/files/2020-07/b797_hazmit_handbook.pdf

Federal Highway Administration (FHWA). 2005. HEC 09 *Debris Control Structures, Evaluation and Countermeasures, Third Edition.* Available at: https://www.fhwa.dot.gov/engineering/hydraulics/pubs/04016/hec09.pdf

Pennsylvania Department of Transportation (PennDOT). 2012. *Debris Control for Bridges and Culverts*, Technical Information Sheet #152. Available at: https://gis.penndot.gov/BPR_pdf_files/Documents/LTAP/TS_152.pdf