# Bridges

## 10.1 Introduction

The primary function of bridges is to carry pedestrians, bicycles, and/or vehicles over various types of transportation facilities or natural features. Bridges come in a wide variety of configurations and structure types. This chapter provides a brief introduction into the topic of bridge planning and design including discussion of applications of bridges, contextual influences on bridge design, preliminary design guidelines, major bridge elements, and the inventory and management of bridges.

For detailed information on bridge design, please refer to the *MassHighway Bridge Manual* which, along with Chapter 2 of this Highway Design Manual, also provides information on process and roles and responsibilities.

## 10.2 Applications of Bridges

The various bridge applications are described in the following sections.

### 10.2.1 Pedestrian and Bicycle Facility Bridges

Bridges can be constructed to carry pedestrian and bicycle traffic over an obstacle, usually vehicular traffic, a railroad, or a watercourse. Given that extra travel distance is more acceptable for vehicular travel than for pedestrians and cyclists, it may be appropriate to include a separate bicycle and pedestrian crossing at locations where the existence of schools, churches, parks and open spaces, and other land uses generate large volumes of pedestrians or cyclists. Other factors affecting the decision to provide a pedestrian or bicycle bridge include:

- A large number of children crossing;
- Unacceptable traffic conflicts due to roadway width, high traffic speeds, and high traffic volumes; and
- Cost.

Pedestrian routes on bridges have the same requirements for accessibility for people with disabilities as other sidewalks. Slopes can follow the roadway alignment but cross-slopes cannot exceed 2 percent in the built condition (1.5 percent in design). Curb cut ramps are required at intersections. Where a bridge is not along the roadway right-of-way, its slope cannot exceed 8.33 percent in the built condition.

Preliminary design features such as vertical and horizontal clearance and cross-section should be considered. Pedestrian passages under a roadway are discouraged unless the highway lanes are on a fill section of 15 feet or more. This type of structure presents problems for drainage and lighting and creates a condition where policing is difficult.

### 10.2.2 Highway Grade Separations

A grade separation where a roadway passes over an intersecting roadway or railroad is called an ***overpass*** or over-crossing. A grade separation where a roadway passes under an intersecting roadway or railroad is called an ***underpass*** or under-crossing. These definitions apply for the roadway in question and are the opposite for the crossing roadway.

Most grade separations and interchanges are located on freeways or major arterials. These structures allow the highway to safely accommodate high volumes of traffic through intersections. Some controlling factors in the planning of a highway grade separation include highway geometry and the available right-of-way. Highway grade separations are often combined with ramp systems to form interchanges described in Chapter 7.

To present consistent visual cues to drivers, grade separation structures should conform to the highway alignment and cross section, and also provide the required vertical clearance. Its profile must be limited to grades that allow sufficient stopping sight distance. The transition from roadway to grade separation should be designed such that the driver 's behavior is not altered. Other considerations that should be integrated into the design of highway structures include the following:

- Generous lateral clearances to structural elements and other features;

- Structural elements of the bridge should be shielded from potential impact by errant vehicles either through grading of roadway medians and off-shoulder slopes, or through the provision of barrier systems and impact attenuators as described in Chapter 5;
- The design should support projections of activity levels by all users, consistent with state, regional and local plans and policies (see Chapter 3);
- Aesthetically pleasing highway architecture should be considered;
- Underpass structures should be as open as practical to allow light penetration, air circulation, and maximum visibility. In the case of long underpasses or tunnels, consideration must be given to the inclusion of rescue assistance areas, fire suppression, and ventilation;
- Bridges over navigable rivers should be as open as possible to recreational (canoe/kayak) passage.
- All structures should be designed with shoulders, curbing, lighting and other highway elements that exist on the approaching roadway or that may be expected to be provided on the approaching roadway with future improvements. Bridges should also include sidewalks and bicycle accommodation even where such facilities are not provided on the approaching roadway. These facilities are needed to provide pedestrian and bicycle access across barriers, such as water, railroads and highways and to assure facilities consistent with potential future roadway and sidewalk improvements on the approaching roadway.

With respect to highway operations, there is no minimum spacing or limit to the number of grade-separated cross streets, however, considerable savings can be achieved by terminating some of the less important cross streets or combining nearby streets into single crossings.

Engineering studies should be conducted to determine the effects of termination and the mitigation required to maintain continuity, safety and access requirements for area roads. In some instances, frontage roads may be installed along the mainline to provide connectivity for users from terminated street to through cross streets. Factors that may affect the number and spacing of cross streets include:

- Network connectivity and development characteristics;
- Activity levels (pedestrian, bicycle and traffic volumes);
- Location of schools, recreational areas, hospitals and other public facilities; and
- Emergency service routes.

The availability of adequate right of way may limit the possible structure types. Moreover, the construction process can also be adversely affected by the lack of right of way and can require staged construction. Additionally, considerations such as the bridge span length, soil characteristics, and skew may also affect the structure's design.

In some instances, particularly in developed areas, the grades of local roads cannot be changed due to the surrounding context. In these situations, it may be necessary to depress or raise the entire through roadway into a boat section, tunnel or viaduct. These facilities are much more expensive to construct than simple overpasses and underpasses and may require drainage pump stations, control of groundwater, underpinning of nearby structures, special lighting, and video systems for security monitoring.

### 10.2.3 Railroad Grade Separations

Structures that carry a roadway over railroad traffic are referred to as ***railroad overpasses***. Conversely, ***railroad underpasses*** are structures that pass roadways under railroads. Some considerations when planning a railroad overpass or underpass include the selection of the structure type, the horizontal and vertical clearance to the centerline of the track, the available right-of-way, drainage, train movements, and required coordination with the railroad company.

The selection of the type of structure, either overpass or underpass, usually depends on the existing topographical conditions. Railroad underpasses often present drainage problems, sometimes requiring the use of pump stations which can be costly and require ongoing maintenance.

Proper clearances are an important consideration in the early planning phase. In order to determine vertical clearance, it is important to determine the top of high rail elevation for approximately 500 ft. in each direction from the roadway and for a greater distance if a change in railroad grade is proposed.

Crossings of railroad right-of-way usually requires negotiating an agreement with the railroad company. In many cases, the structure must span the entire railroad right-of-way rather than just the active tracks. Train movements can also affect the construction process. Construction schedule and construction crew safety need to be addressed during the preliminary design phase.

### 10.2.4 Crossings of Streams, Rivers, and Other Natural Features

Bridges and culverts provide crossings over streams, rivers, and other natural features. Hydraulic analysis should take place early in project development to uncover unusual problems that become much more difficult to address at later stages. This is particularly important with respect to highway location. As discussed in Chapter 2, crossings of watercourses often require extensive permitting processes at the local, state, and federal level. When encountering streams, rivers, and other natural features the designer should reference the Massachusetts River and Stream Crossing Standards and Chapter 14 of this Guidebook. Where they exist, opportunities to replace substandard crossings should be considered.

***Culverts*** are usually pre-manufactured sections that can operate either with a submerged inlet (under pressure) or with free surface flow. The roadway cross-section is usually constructed on fill placed over the culvert. Culverts exceeding 20 feet in length along the roadway centerline are classified as bridges; however, despite this classification culvert design standards should be followed.

***Bridges*** are structures usually constructed in-place (although pre-manufactured elements are commonly used) which carry traffic directly on a deck surface. Bridges do not form inlet conditions or act as pressurized conduits since the flow line of a bridge is rarely fixed and the material along the flow line of a bridge is usually the same as the stream it crosses.

Bridges and culverts are vulnerable to damage from floods. To minimize the risk of damage, the hydraulic requirements of a stream crossing must be recognized and considered in all phases of project development, construction, and maintenance. Therefore, hydrologic and hydraulic analyses are required for all new bridges, bridge replacements, bridge widenings, and roadway profile modifications that may adversely affect the flood plain. These analyses are discussed further in Chapter 8. Typically the hydrologic and hydraulic analyses should include an estimate of peak discharge (sometimes complete runoff hydrographs), existing and proposed condition water surface profiles for design, check flood conditions, and consideration of the potential for stream stability problems and maximum predicted scour depth. These analyses should also consider recreational water users by ensuring that they are not precluded from using the waterway due to limits on vertical clearance under the bridge. The designer should also consider routes for recreation access to the waterway during the design process.

Both new and replacement bridges and culverts can also be used to improve the connectivity of habitat in certain locations, whether or not they are placed for a hydraulic function. The design of both bridges and culverts should consider the effects on wildlife habitat, fish passage, and other considerations described in Chapter 14.

## 10.3 Contextual Influences on Bridge Design

Bridges are highly visible elements of the transportation infrastructure in the surrounding landscape. Often they traverse environmentally and ecologically sensitive sites, culturally or visually significant areas, or are visually prominent features in communities and other developed settings. Although bridges can have negative impacts on these environments, they can also be designed in such a way that they are pleasing or welcome additions to the landscape.

Designing a suitable bridge requires that the designer pay careful attention to the details starting with an understanding of the setting in which the structure will be built and ending with the detailing of the bridge structure itself. Bridges can be designed to blend into the surrounding natural or built environment, if that is what is desired. Alternatively, bridges can serve as signature elements of the community by standing out from their surroundings. In either case, the designer must remember that the bridge can last many decades. The designer has the power to make the bridge a long-standing source of pride or of dissatisfaction. The role of the bridge in the built environment should be determined during the project development process with input from a broad range of interested individuals and groups.

### 10.3.1 Understanding the Context

The designer must understand the context of the site which the bridge will be built. If it is in a natural area, the designer should map the topography and natural features of the site. Usually a bridge in a natural setting will be designed to fit into its setting rather than have the setting altered to fit a bridge structure. In urban areas, the designer needs to understand the community patterns in the vicinity of the bridge and the bridge characteristics suitable for the community setting. Specific issues with both natural and developed settings are described below.

#### 10.3.1.1 Environmental Resources

*Bridges can – and should – be designed to fit into the context in which they are placed.*

Bridges often cross sensitive environmental resources such as wetlands, streams, and rivers. Although replacement of bridges (such as through the footprint bridge program) are exempt from the some permitting requirements, construction activities in these areas is usually regulated at the local, state, and federal level, as described in Chapter 2, and the permitting requirements for these projects can be extensive. MassHighway has established a footprint bridge program to of replace bridges roughly within their existing location to help expedite replacement of existing deficient structures.

The design of bridge projects needs to be based on an understanding of these resource areas and the potential short and long term impacts that the bridge may have on their hydrologic and ecological value. Design decisions such as crossing location, span length, substructure layout, and width can be adjusted to minimize impacts to these resources, regardless of the applicable regulatory requirements. Project design should also consider methods to provide erosion control and streambank restoration.

Although bridges may impact these resources, they may also be included in a project design to reduce the impacts that causeways or other filling of the resource area could have. As described in Chapter 14, the inclusion of bridges and culverts in roadway projects can maintain habitat connectivity for many different types of environments, and reduce habitat loss especially for crossings of open watercourses.

#### 10.3.1.2 Community Resources

In a developed or urban setting, the bridge is typically part of a grade separation. This change in elevation can result in either embankments or walls that create visual and functional barriers between different parts of the community. In some cases, the barrier effect of a grade separation can intensify the barrier effect of the roadway itself. On the other hand, longer grade separations, such as an elevated or depressed high-speed, high-volume roadway through a developed area can improve community connectivity if the crossings of the facility are well-designed and at appropriate locations.

Pedestrian and bicycle facility grade separations can have similar effects as the grade separation of two roadways. For these facilities to be successful, they must be well-integrated into the surrounding pedestrian and bicycle network to prevent extra travel due to long ramp systems needed to achieve the grade separation. Additionally, these facilities are usually used to cross freeways, or other high-speed, high-volume roadways where pedestrians and bicycles are prohibited by regulation. In other situations, properly designed surface crossings of roadways generally provide the desired connectivity for pedestrians and bicycles.

Grade separations of roadways or pathways and railroads is generally desirable. In many cases, railroads are developed along consistent grades and are often on embankments or below the surrounding grade. In these situations, grade separation is especially desirable to improve the safety and operating characteristics of both the roadway/pathway and the railroad. In locations where substantial modifications to the existing grades are required, the design considerations mentioned above are applicable. Similarly, paths built along railroad rights-of-way can often maintain grade separations at roadway crossings without adversely impacting the surrounding area.

The considerations for grade separation of transportation facilities are also discussed in Chapters 6, 7, and 11.

Bridge crossings of streams and watercourses can improve community connectivity and are less frequently associated with negative community impacts. However, in most cases, the aesthetics of the bridge crossings are very important due to their high visibility in the built environment, as discussed below.

### 10.3.2 Aesthetics

The visual quality of bridges can vary widely based on the type of structure, bridge profile and location, and the construction materials and details used. The aesthetics of a bridge start with the design of the structure itself. Those bridges that are considered to be the best examples of aesthetically-pleasing bridges are the ones whose primary structural systems represent the basic structural mechanics of how the structure carries the applied loads to the foundations. Therefore, a well-designed and aesthetically-pleasing bridge is not one that is based on an abstract physical form, but, rather, one that expresses the natural, physical properties to which people intuitively relate.

The expression of structure alone is not sufficient to make a bridge aesthetically successful. In order for a bridge to be truly successful, it must be attractive on the following three levels at which the public experiences a bridge:

- The overall bridge and how it relates to its setting;
- The human-level experience of a pedestrian, or bicyclist, or boater traveling over, under or beside the bridge; and
- The driver-level experience of someone driving over or under the bridge.

Each of these requires a level of detail to which a person can relate and with which a person can be visually engaged. Failure to adequately address the aesthetic expectations at any one of these levels will result in a bridge that people will find fault with, no matter how aesthetically successful the bridge may be on the other levels.

Aesthetics on all levels are achieved by attention to detail and consideration of how each element of the bridge relates to the others. The design of the bridge must present a coherent overall vision of what each component part does and all architectural surfaces should be consistent with this vision. A bridge’s aesthetics are vastly improved when all of the component parts (piers, abutments, railings, and the superstructure) are designed to work together and complement each other visually.

Therefore, the decisions that the designer makes regarding the structure type and substructure configuration will determine the aesthetics of the bridge more effectively than the application of superficial decoration after the basic bridge has been designed. MassHighway’s standard details contained in the *Bridge Manual* have been developed with this philosophy in mind.

### 10.3.3 Historically Significant Bridges

Older bridges have potential historical significance, which adds to their value as community assets, but also complicates the process of rehabilitation or reconstruction of structurally deficient or functionally obsolete bridges.

State and federal statutes recognize the importance of preserving significant elements of our cultural and engineering heritage. Historically significant bridges are listed or eligible to be listed in the National Register of Historic Places. A bridge that is of a rare type, is unusual from an engineering perspective, or has historic significance because of location or association with an important event or person is a candidate for classification as a historically significant bridge (historic bridge). A bridge that is 50 years of age or older may also be a candidate for the list.

As described in Chapter 2, historically significant bridges are addressed under the provisions of Section 4(f) of the Transportation Act of 1966 and may be demolished or moved only if it can be demonstrated that "there is no feasible and prudent alternative" to this taking of the historic property. Options that do not require the demolition of the bridge must be thoroughly considered including the no build option, as well as construction of a new structure at a new location or parallel to the existing facility. These alternatives need to be examined, evaluated, and thoroughly documented before any decision is made to demolish the bridge or to designate it for removal and transport to another location for non-vehicular reuse. Alternatives that keep the bridge in some level of vehicular service must also be examined; that is, rehabilitating the bridge in a way that does not destroy its historic integrity or retaining the historic bridge as part of a one-way pair or as an alternate scenic crossing.

The Federal Highway Administration (FHWA) makes the final determination about whether the conditions of Section 4(f) have been met, and whether it has been demonstrated that there is no feasible and prudent alternative to the action that will remove and dispose of the historic bridge. Additional cost and additional displacements do not necessarily render an alternative imprudent or infeasible.

Historic bridges that do not meet the criteria for vehicular use may be preserved for other uses. Preservation options include use for non-vehicular transportation purposes at the existing or relocation site, or use as a historical exhibit or monument at the existing or relocation site. Preservation for bicycle/pedestrian use or as a historic monument at the existing site may be a viable option if the replacement structure's horizontal alignment can be adjusted to bypass the historic bridge.

## 10.4 Preliminary Design Guidelines

Chapter 2 of the *MassHighway Bridge Manual* provides detailed guidelines and checklists for preliminary bridge engineering. The purpose of the guidelines is to ensure that sufficient information about the project parameters (obtained through site investigations, material testing, limited structural analysis, review of utility systems in the area, and hydraulic and geotechnical studies) is available to make an informed decision regarding the scope of a bridge project and the type of structure to be pursued. Chapter 2 of the *Bridge Manual* describes types of bridge projects (either new/replacement or rehabilitation), contextual and aesthetic considerations, guidelines for bridge type selection for new and replacement bridges, and guidelines for bridge rehabilitation projects.

## 10.5 Major Design Elements

A bridge consists of a superstructure and a substructure. The ***superstructure*** includes the bridge deck and beams. The ***substructure*** includes the cap and foundations of the abutments and the cap, columns, and foundations for bridge piers or support columns.

### 10.5.1 Superstructure

The superstructure is critical in the performance and cost effectiveness of a bridge. Many types of superstructures are commonly used. Choosing an appropriate superstructure depends on factors such as:

- Span length
- Vertical clearance
- Hydraulics (freeboard)
- Speed of construction
- Economics
- Aesthetics
- Accommodation of utilities

Span length requirements and vertical clearance are generally the controlling criteria when choosing the superstructure. Span lengths are determined based on bridge location, geography, and structural limitations. Vertical clearance is based on bridge location and federal and state requirements. Design criteria concerning span lengths, clearances, and other design features are discussed in the *MassHighway Bridge Manual*.

### 10.5.2 Substructure

The structural elements used in the superstructure often influence the design of the substructure. The substructure generally consists of either single or multiple reinforced concrete columns. Available construction space, right-of-way limitations, bridge width, clearance, stage construction, and aesthetics are often factors in this decision. The column configuration and subsurface conditions determine an appropriate foundation type. Choice of foundation type should remain as flexible as possible in preliminary design to allow an economic design in the detailed plan preparation stage.

### 10.5.3 Horizontal and Vertical Alignment

Bridge structures should be on a tangent alignment if such can be accomplished without sacrificing the overall geometric design of the highway. Tangent alignment affords easier plan preparation and easier bridge construction thereby resulting in lower structure cost. In areas where it is not feasible to build structures on a tangent alignment, curved structures are possible. Where curved structures are built, their geometry should fit the curve geometry for the roadway sections. Tightly curved alignments can significantly restrict the type of superstructure. Basic design criteria for horizontal alignment can be found in Chapter 4 of the Guidebook.

The vertical curvature of structures should generally conform to curvatures on sections of roadway for the same conditions of traffic and terrain described in Chapter 4 of this Guidebook. For bridge decks that would otherwise be flat, a small crest vertical curve is recommended throughout the bridge length to prevent an illusion of sag and to improve deck drainage. Basic design criteria for vertical alignment can be found in Chapter 4 of the Guidebook.

### 10.5.4 Cross-Section

The type of structure best suited to grade separations is one that blends smoothly into the surrounding environment and provides a seamless connection for all users of the transportation facility. For example, where motorists take practically no notice of a structure which they are crossing, driver behavior is the same or nearly the same as at other points on the highway, and sudden, erratic changes in speed and direction are unlikely. However, a different cross section on the structure from that on the approaching roadways may be appropriate where future changes in the roadway cross section are desirable. As noted earlier in Section 10.2.2, the structure should provide desirable bicycle and pedestrian accommodation irrespective of existing bicycle and pedestrian accommodation along the remainder of the corridor.

For any structure, a constant clear roadway width and a uniform protective railing or parapet should be provided. The multimodal accommodation and cross-section features found along the adjacent roadway segments should be included on the bridge cross-section. It is not usually necessary for the bridge deck to be substantially wider than the approaching roadway but the design of the bridge structure should include consideration of possible future widening such as by providing a wider abutment. Generally, the width of the travel way and shoulder lanes should be consistent with the existing or planned future cross section of the adjacent roadway. In terms of additional width, a 2-foot setback from the shoulder or bike lane to bridge rails or parapet walls is required. Additionally or alternatively, approximately 1 to 2 feet of additional sidewalk width is desirable to account for shy distance from the railing or parapet wall when sidewalks are provided.

For reconstruction and rehabilitation projects (such as footprint bridges), the designer should provide multimodal accommodation as close as possible to that found along adjacent roadway segments. During reconstruction or rehabilitation it is often possible to modify the structure to provide, or to allow for the easy addition of, pedestrian and bicycle accommodation on the bridge. Additionally, if multimodal accommodation is available along a corridor, except for a bridge, the designer should evaluate whether retrofitting the existing bridge to provide accommodation is possible in lieu of replacing the structure.

### 10.5.5 Curbs and Railings

Curbs, suitable barrier rails or combination railings are often provided between the roadway and sidewalk. The use of barrier rail to separate vehicle from pedestrian traffic is governed by the following criteria:

- Barrier rail between the roadway and sidewalk is recommended when the design speed equals or exceeds 50 mph.
- If the design speed equals or exceeds 40 mph but less than 50 mph, appropriate barrier rail may be considered where bridge-specific conditions will allow it without interference to pedestrian movements, traffic flow, or other features.
- Curbs are normally used on bridges in conjunction with sidewalks. If curbs are used, curb height should meet or exceed that of the approach roadway.
- Independent of the presence of a sidewalk, bridge railings or barriers is required on all bridges to prevent pedestrians, bicyclists and motor vehicles from falling off the bridge deck. Where appropriate, open railings should be used to provide views of water bodies or the surrounding landscape.

## 10.6 Inventory and Management of Bridges

MassHighway administers the state and federal reconstruction/ replacement program for bridges over 20 feet in length. MassHighway conducts necessary bridge inspections that place bridges into the following three categories:

- Meeting standards,
- Functionally obsolete, and
- Structurally deficient.

Structurally deficient structures have a defect in the structure that requires corrective action. There are different categories of deficiencies and urgency of repair. Functionally obsolete facilities have no structural deficiencies but do not meet standards to adequately serve current user demands.

MassHighway uses PONTIS, a system used by most state transportation departments, to record, organize and analyze bridge inventories and inspections. Based on this listing, MassHighway, with input from local cities and towns, and consideration of factors such as average daily traffic (ADT), selects bridges for reconstruction or replacement. The objective of MassHighway is preservation - to fix it now rather than later. MassHighway also inspects locally-owned bridges on a regular basis and provides a report to the city or town.

## 10.7 For Further Information

- *Bridge Design Manual*, Massachusetts Highway Department, 2005
- *Massachusetts River and Stream Crossing Standards*, University of Massachusetts – Amherst, 2004.