Division of Planning Research On-Call (ROC) Task#10 - Deer Passage Through Rock Channel Protection (RCP) Designs and Options

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16. Abstract

One safety-related issue that has been identified by ODOT is deer crashes. ODOT OES is proposing to install a "deer passage" within the rock channel protection (RCP) underneath highway bridges that would allow for the deer to pass under the highway instead of going across on the surface. The purpose of this research was to analyze the feasibility of constructing passages within RCP installations under bridges, considering both the needs of the wildlife as well as the technical requirements for ODOT bridges. To meet the needs of wildlife, the passage should include minimum width: 3 feet; minimum vertical clearance: 6 feet; follow along natural stream bank; natural "look and feel" of approaches with minimal obstructions; and deliberate connectivity to habitats on both sides of the passage. Implementation costs were estimated to range between $21,800 and $84,100 depending on scope. It is recommended that the installation of the deer passage be pursued for any bridge location that experiences one or more recorded deer-involved crash per year within one-half mile of the bridge. Installation of the deer passage results in an benefit with 1 recorded deer crash in the last 3 years if a 90% effectiveness is assumed and 1 recorded deer crash in the last 2 years if a 50% effectiveness is assumed.

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PROBLEM STATEMENT

The primary goal of the Ohio Department of Transportation (ODOT) is to build and maintain a safe transportation system. One safety-related issue that has been identified by ODOT is deer-related vehicle crashes. Historic data indicate that approximately 18,000 deer-related crashes occur each year, on average, in the state. Many of these crashes occur in the vicinity of highway bridges that are in deer habitat or activity areas. The ODOT Office of Environmental Services (OES) is proposing, at least in part, to address the issue of deer-related crashes in the vicinity of highway bridges by installing a passage that would allow for the deer to pass underneath the highway instead of going across the highway on the roadway surface. Rock channel protection (RCP) is commonly used for erosion control and structure protection underneath bridge foundations. ODOT OES is proposing to incorporate the option for a deer passage into the existing RCP installations at affected bridge locations. The addition of a pathway through existing RCP is a simple improvement that is thought to be effective at encouraging deer to remain under bridges and stay off the roadways.

RESEARCH BACKGROUND

This project was carried out as Task #10 of the ODOT Office of Statewide Planning and Research (SPR) program project "Division of Planning Research On-Call Services" (PID 111440; SJN 136125). Researchers from the Ohio Research Institute for Transportation and the Environment (ORITE) at Ohio University, with assistance from MS Consultants, Inc., completed all Task #10 work. The goal of Task #10 was to analyze the feasibility of a proposal to incorporate deer passages within existing or new RCP installations in the vicinity of bridges. Accordingly, the following specific task objectives were established:

- Objective 1: Analyze the feasibility of the proposed deer passage with respect to engineering/technical requirements, the potential success of the installation from an ecological perspective, and the potential economic benefits of crash reduction compared to construction costs.
- Objective 2: Investigate a variety of bridge scenarios that exist on the ODOT highway system and propose methods/procedures that can be used by ODOT county garage work crews to install deer passages are RCP installations, both for existing bridges and at bridge replacement locations.
- Objective 3: Develop a technical brief describing all task activities, analysis results, and recommendations for installing deer passages through RCP.

Deer-vehicle crashes represent a significant traffic safety concern nationwide, particularly in rural areas. For example, data compiled by State Farm Insurance indicated that deer-vehicle crashes increased nationwide in 2022 and that Ohio is considered "high risk" for such crashes (State Farm, 2022). Additionally, it is estimated that the average cost of an insurance claim from a deer-related crash was over $4,000 based on recent data (OSHP, 2021). Considering the Ohio-specific experience, the average cost associated with a deer-vehicle crash is $19,558.61 (research team estimate, see Appendix A for details). While ODOT crash statistics indicate that more than 95% of deer-vehicle crashes result in only property damage, some fatalities and injuries do occur from these incidents, further adding to the urgency of action to deploy initiatives intended to reduce such collisions.

In the last 20 years, national-level research has been conducted to identify strategies and projects that can be deployed by State DOTs to reduce the impact of vehicle collisions with large mammals, including deer (e.g., Huijser, et al. 2007; Bissonette and Cramer 2008; Huijser, et al. 2008a; Huijser, et al. 2008b; Clevenger and Huijser 2011). Building on this work, State DOTs have conducted studies of their own to analyze issues in the individual states. ODOT OES has also engaged several research and consultant studies on highway ecology topics across all species and important contexts. Recent work includes the U.S. 33 Nelsonville Bypass wildlife study, which found that the mitigation structures added to this project resulted in a reduction in deer-vehicle crashes compared to similar highways without the features (Hopkins, et al., 2018). More recently, ODOT OES commissioned a statewide study (Gleaves, et al., 2022) to determine locations of deer-vehicle crash "hot spots" across the state highway network. The work of ODOT has contributed significantly to an improved understanding of how to construct highways that are sensitive to the surrounding ecosystem, particularly in the Eastern U.S. region. The "Infrastructure Bill" enacted in 2021 has revived the discussion of wildlife crossings and highway ecology with the inclusion of a $350 million pilot program for wildlife crossings. The proposed deer passage installation in existing RCP may represent a low-cost solution for improving deer crash safety that could be funded by the pilot program.

RESEARCH APPROACH

The research team approached the research goals and objectives with a work plan consisting of the following seven tasks, completed over a duration of six months. Additional details of the research approach components are described in this section.

- Task 10.1: Literature Review;
- Task 10.2: Technical Feasibility Assessment;
- Task 10.3: Establish Criteria for Site Selection;
- Task 10.4: Detailed Passage Design and Analysis;
- Task 10.5: Recommendations and Task Deliverables; and
- Task 10.6: Project Management.

Task 10.1: Literature Review

The objective of Task 10.1 was to conduct a comprehensive review of all existing research and literature associated with the project topics. Topics addressed in the literature review included: design and construction requirements for deer underpass structures and analysis parameters for the economic analysis (i.e., construction costs, benefits of crash reduction) of wildlife crossings. The focus of the literature review efforts was to identify details of the design (i.e., dimensions and materials) of deer underpass structures that have been shown to be successful at maximizing the use of the underpass from an ecological viewpoint. The following approach was used by the research team for the literature review:

- Review of academic literature and research studies;

- Outreach calls to other State DOTs to obtain implementation details; and
- Non-scientific assessment of deer passage locations in ODOT District 5.

Research documenting the extent and patterns of wildlife-vehicle crashes, as well as strategies to mitigate the impacts of highway development on wildlife populations, has been on-going in North America for many decades. It is known that highway construction and operations can result in increased mortality, loss or reduction in habitat, and reduced connectivity for wildlife populations in sensitive areas (e.g., Forman, et al., 2003). An increased interest in highway ecology in the late 2000s and early 2010s resulted in several national research studies and guidebooks being developed (e.g., Huijser, et al. 2007; Bissonette and Cramer 2008; Huijser, et al. 2008a; Huijser, et al. 2008b; Clevenger and Huijser 2011). These studies provide a concise snapshot of the state of the practice leading up to their publication. Lessons and design practices for wildlife crossings that are co-located with stream crossings were noted as being applicable to the needs of the current task. Design recommendations for wildlife crossing with waterflow included a minimum width of 6.5 feet and height of 10 feet; a recommended width of greater than 10 feet and height of greater than 13 feet; channelizing fencing to provide positive guidance to wildlife approaching the crossing; and replication of habitat conditions on the crossing approaches to the greatest extent possible (Clevenger and Huijser 2011).

Studies have become more detailed as modern tools for animal tracking, monitoring of wildlife structures, and more sophisticated analysis techniques have allowed for more nuanced examinations of design and operational details. Modern studies have focused on refining the significance of specific design elements (e.g., dimensions) and other features (e.g., materials, approach condition) of wildlife crossings. Larger passage dimensions positively correlate with usage (e.g., Ng, et al., 2004; Clevenger and Waltho, 2005; Dodd, et al., 2007; Seiler and Olsson, 2009; Cramer, 2012; Bhadraj, et al., 2020). The importance of mimicking the natural habitat on the crossing approaches is also noted by several studies (e.g., Dodd, et al., 2007; Gangon, et al., 2011; Cramer, 2012; Bhardwaj, et al., 2020). Finally, the use of channelizing fencing has been shown to promote usage by providing positive guidance for animals approaching the structure (e.g., Brudin, 2003; Gangon, et al., 2011).

The second element of the literature review task was outreach to State DOTs outside of Ohio to obtain crucial details of design and implementation insights from the perspective of the practitioner. Initial research conducted by the ORITE team indicated that the Minnesota Department of Transportation (MnDOT) was one of the earliest adopters of the deer passage through RCP concept. Other states, namely Indiana, Virginia, and Washington, were also identified as targets for additional inquiry. Additional work out of Arkansas, Massachusetts, and Pennsylvania also was identified and deemed useful in this review. In general, State DOTs have approached this problem in a practical manner, providing wildlife passage and habitat connectivity at locations where it is needed. Design guidelines exist for some states, but many states expressed a “provide what you can” approach to accommodating wildlife passage, working with the dimensions and conditions presented by the structural, hydraulic, and construction-related aspects of the bridge design.

The third element of the literature review task was a review of deer passages that ODOT has constructed on certain bridges in ODOT's District 5 area. A total of nine bridge locations in District 5 had deer passages installed underneath as part of bridge replacement projects. The research team conducted field visits to eight of the nine locations to glean more information about the installations and their functionality. Informal observations of usage and condition were recorded, but no usage monitoring or other scientific analysis was included as part of this research task. The results of this review and additional details of the deer passages constructed by ODOT in District 5 is presented in Table 1.

Although the ORITE research team did not undertake a robust scientific assessment of the deer passages constructed in District 5, the observations of the research team provided some useful details of the design and functionality of the passages as of May 2022. Three sites (as indicated in Table 1) exhibited "high" usage, as evidenced by extensive and numerous animal tracks of deer and other animal species traveling in both directions through the structure, as well as evidence of grazing underneath the structure. These three locations had good connectivity to the surrounding landscape, which was comprised of supportive habitat land uses.

Table 1: Summary of Deer Passages Constructed in ODOT District 5

Project Location	Year Built	Date Visited	Usage	Remarks
COS-79-1.60	2015	5/17/2022	Moderate	2-lane rural; mixed field/forest
COS-79-3.94	2015	5/17/2022	Low	2-lane rural; mostly field
FAI-256-9.95	2015	5/17/2022	Moderate	2-lane rural; mostly forest
LIC-37/161 12.25	2006	Did Not Visit	N/A	Accessible only from highway ROW.
LIC-37/161 14.05	2006	5/17/2022	High	4-lane expressway w/ frontage roads
LIC-62-3.69	2004	5/17/2022	High	2-lane arterial with bicycle path
MUS-146-20.92	2013	5/27/2022	Moderate	2-lane; mixed field/forest area
MUS-208-10.41	2014	5/27/2022	Low	2-lane; on curve; farm/forest area
PER-668-9.95	2012	5/27/2022	High	2-lane; edge of town; mostly forest

Three passage locations exhibited "moderate" usage based on the presence of recent deer and other animal tracks with substantial evidence of grazing underneath the structure, but relatively little evidence of movement through the structure observed. While the dimensions of the passage in these three locations did not appear to be hindering usage, some issues with landscape connectivity were observed. Connectivity issues could have been affected by skew angle, RCP placement on approaches, visibility through passage, and the presence of a roadside drainage channel. Finally, two sites were visited that were characterized as "low" usage as a deer passage. At these locations, there was no or very limited evidence of animal tracks for movement or grazing purposes. The vertical clearance measured at these two structures was noticeably lower than at the other locations. Additionally, the surrounding landscape was not supportive of deer habitat and there was poor connectivity between the structure and the adjacent lands along the stream bank.

Images of several deer passages constructed by ODOT in District 5 are presented in Figure 1. These images were obtained by the research team during this research study and do not necessarily represent the overall condition of the deer passages throughout their life span. The key findings of the Task 10.1 literature review are reported in the "Research Findings and Conclusions" section of this report. Complete details of the literature review task are presented in Appendix A.

LIC-62-3.69(High Use)

PER-668-9.95 (High Use)

FAI-256-9.95 (Moderate Use)

MUS-208-10.41 (Low Use)

Figure 1: Examples of Deer Passages in ODOT District 5

Task 10.2: Technical Feasibility Assessment

Task 10.2 of the research study focused on the technical (i.e., engineering) feasibility of the installation of deer passages in RCP. For the design to be successful, the intended function of the RCP (i.e., slope protection) must be preserved after the passage installation is carried out; it is assumed that some additional reinforcement or other modifications will be necessary. Relevant standards and practices used by ODOT for design and installation of RCP in the vicinity of bridges were consulted by the research team in this task. Additionally, relevant practices associated with erosion control, hydraulics, or regulatory considerations were also reviewed.

The proposed deer passage through RCP concept intends to construct a passage within existing rip rap installations underneath bridges. The function of rip rap in this application is for erosion control to ensure that the stream channel does not erode the bank to the point where the structural integrity of the bridge foundation is compromised. With respect to the installation of rip rap in this application, the research team found that there was no consistent statewide standard and that bridge designers deployed rock protection where it was necessary based on the overall bridge design and site-specific constraints. However, it is generally assumed that rock installations should not exceed a slope of 2H:1V. Furthermore, for the purposes of the deer passage installation, a vertical face of rock installation greater than 1 foot in height should have some type of additional reinforcement added to prevent the entire rock installation from slipping.

A typical hydraulic and hydrologic analysis for a project follows the ODOT's Location & Design Manual – Volume 2 (L&D Vol. 2) guidance. The design year frequency, or annual exceedance probability (AEP), is determined using the ODOT L&D Vol. 2, Section 1004.2 and is based on the roadway type. A summary of the requirements is presented in Table 2.

Table 2: Design Year Frequency for Roadways from ODOT L&D Vol. 2

Roadway Type	Design Year Frequency
Freeways or other multi-lane facilities with limited access	2% AEP (50 year recurrence)
Other Highways (3000 ADT and over) and Freeway Ramps	4% AEP (25 year recurrence)
Other Highways (under 3000 ADT)	10% AEP (10 year recurrence)
Bicycle Pathway (Unless other approved by OHE)	20% AEP (5 year recurrence)

Per FEMA guidance, any project in a floodway must be reviewed to determine if the project will increase flood heights. Instances where the project results in no increase in flood heights are referred to as a "no-rise situation". The hydraulic opening of the bridge will be increasing due to the crossing work being proposed; therefore, the water surface elevations should decrease or at most remain the same as the existing conditions. Thus, a no-rise situation should occur where deer paths are being implemented. However, the guidance for check storm controls (ODOT L&D Vol. 2, Section 1006.2.2 and Section 1006.4) should be consulted to ensure proposed changes comply with any regulations regarding no rise situations for a 2% AEP or 1% AEP storm. Per ODOT L&D Vol. 2, Section 1005.1.2, if proposed construction is performed within the floodway, a no-rise condition is preferred.

The allowable surcharge (i.e., rise in base flood elevation) for the National Flood Insurance Program is set at one foot according to the ODOT L&D Vol. 2, Section 1005.1.1. If the allowable surcharge required by the Local Floodplain Coordinator is not feasible, contact the Office of Hydraulic Engineering (OHE). The ODOT L&D Vol. 2, Section 1107.3 provides the guidance on required size of rock channel protection (RCP) (see Table 3).

Table 3: Recommended RCP Type by Channel Mean Velocity from ODOT L&D Vol. 2

Channel Mean Velocity (ft/s)	RCP Type	Thickness (inch)
0-8	C	24
8-10	B	30
Above 10	A	36

In addition to the various design parameters, permitting and compliance with applicable regulatory concerns is also a crucial aspect of the feasibility. Per ODOT L&D Vol. 2, Section 1005.1.2, if construction is within FEMA Zones AE or A1-A30, documentation is required through the ODOT self-permit process, coordinate with FEMA, ODNR, and the Local Floodplain Coordinator. If proposed construction within the floodway creates any rise in water surface elevation above the base flood elevation (BFE), a variance is required and approval through the appropriate FEMA map revision processes will be necessary. If there is no floodway established and proposed construction within the floodway causes the water surface elevation to exceed the BFE + allowable surcharge, a variance and approval through the appropriate FEMA map revision process is required. Base flood elevations (BFEs) are the computed elevation to which floodwater is anticipated to rise during the base flood. The base flood is the regulatory standard also referred to as the “100-year flood” or the “1% AEP flood”. They are shown in Flood Insurance Rate Maps (FIRMs). See the ODOT L&D Vol. 2, Section 1005.1.4 for the ODOT self-permit process for construction within the stated FEMA zones.

Finally, the technical feasibility associated with traffic control that may be required during construction was analyzed. Guidance on temporary traffic control will vary depending on the degree of work to be performed, its impact on vehicular or pedestrian traffic, and volume of traffic. The Ohio Manual of Uniform Traffic Control Devices (OMUTCD) Part 6 (Temporary Traffic Control) should be consulted when a lane should be closed to complete work. According to the OMUTCD Section 6E.04.04, Automated Flagger Assistance (AFADs) should be used where there is only one lane of approaching traffic in the direction to be controlled.

Task 10.3: Establish Criteria for Site Selection

The objective of Task 10.3 was to utilize data from the Literature Review and Technical Feasibility Assessment tasks to determine criteria for site selection and identify a subset of bridges from the ODOT inventory that could be suitable for deployment of the deer passage concept. The site selection criteria analysis addressed both engineering requirements for the RCP functions as well as the probability of success in attracting deer to use the passage instead of crossing over the roadway. Based on the initial tasks, several critical dimensions are necessary to examine to determine if a particular bridge is suitable for the installation of a deer passage. These dimensions included the vertical clearance under the bridge, the width between the base of erosion protection and the stream bank, the slope of the erosion protection, and the ordinary high-water mark (OHWM) for the stream.

The original vision for Task 10.3 was that such data could be analyzed on a statewide basis to determine the extent of various bridge configurations, thereby permitting a high-level assessment of the feasibility of statewide deployment of the deer passage retrofit concept. However, review of readily available data from the ODOT TIMS and other GIS data sets revealed very limited data present for this purpose. Data associated with the vertical clearance and stream width are only available for navigable waterways, which is a relatively small percentage of bridges in the ODOT system. Additionally, design details such as the erosion control slope are not available extensively and must be examined on a case-by-case basis. Similarly, the OHWM is a specific elevation associated with regulatory concerns for waterway permitting and established for a specific location, and not provided in a systematic manner for every bridge on the ODOT system. Considering these constraints, the research team concluded that a statewide assessment of the ODOT bridge inventory to determine the extent of feasible locations was not practical to undertake for this project. An alternative plan for feasibility planning which focuses on assessing bridges located in deer crash “hot spot” roadway segments on a case-by-case basis is recommended. The envisioned process for site selection is outlined in the “Research Findings and Conclusions” section of this report.

Task 10.4: Detailed Passage Design and Analysis

Task 10.4 of this study consisted of developing a detailed design and construction plan based on the critical technical specifications identified in previous tasks. The original vision for the project was to be able to identify a maximum of 2 to 3 bridge scenarios (based on the outcomes of Task 10.3) and to prepare a detailed design plan for each scenario. Because the data required to develop a classification scheme was not available from ODOT data sets, it was necessary for the research team to reimagine Task 10.4. For Task 10.4, the following issues associated with design and construction were addressed: 1) the minimum design dimensions, material requirements, and other key components of the deer passage; 2) the minimum required modifications needed to the RCP installation to maintain functionality while also providing a sufficient passage for the deer to utilize the feature; and 3) address the need for end treatments or retaining walls/curbs as appropriate.

Based on all factors examined in this research task, a three-tiered approach for design and construction of deer passage through RCP is proposed and outlined in the “Research Findings and Conclusions” section of this report. For all three construction scenarios, the research team has envisioned an installation/construction sequencing plan to provide ODOT or contractor crews with a vision for how the deer passage could be installed. Based on the design and construction concepts, a construction cost estimate was also prepared as part of Task 10.4, and an economic analysis was undertaken to determine the appropriate scenario(s) or context(s) in which the installation produces a positive ROI for ODOT.

Task 10.5: Recommendations and Task Deliverables

Task 10.5 of this study included the formulation of recommendations based on the results of the study as well as the development of this report. The recommendations address feasibility analysis for site selection, construction sequencing, and economic analysis of installation of deer passages.

RESEARCH FINDINGS AND CONCLUSIONS

Feasibility Analysis

The feasibility assessment conducted as part of this research task addressed concerns associated with the needs of the wildlife using the passage as well as the technical requirements for the design and functionality of ODOT bridges. This section addresses the key findings of the feasibility analysis.

Review of existing research and academic literature, as well as feedback from State DOT practitioners, indicated that most deer passage installations under highway bridges were constructed as part of a bridge replacement project. Crucially, replacement projects afford the opportunity to construct and shape the passage before the main bridge beams are installed, thus avoiding any issues associated with vertical clearance restrictions during construction. ODOT OES is proposing to retrofit existing bridges with deer passages without a bridge replacement. Therefore, the findings, conclusions, and recommendations from this research task are framed in the context of a retrofit under an existing bridge with vertical clearance limitations.

Wildlife Needs

To meet the needs of wildlife, the deer passage should include at least the following minimum dimensions and other characteristics:

- Minimum Width: 3 feet
- Minimum Vertical Clearance: 6 feet
- Passage should follow along natural stream bank
- Natural “look and feel” of approaches with minimal obstructions
- Deliberate connectivity to habitats on both sides of the passage

Site Selection

Regarding site selection, it is assumed that ODOT’s recent wildlife-vehicle crash “hot spot” analysis will be consulted to determine locations on the state highway system where wildlife-related crashes are of concern. Bridges within these highway segments of concern should be considered for installation of the deer passage. Minimally, the dimensions and features listed in the “Wildlife Needs” section above should be verified to determine if it is feasible to construct the deer passage at a specific bridge location. Desirably, additional vertical clearance (2 additional feet, 8 feet total) would be helpful for construction equipment access. If a new passage is to be constructed, the elevation of the OHWM and the two-year flood should be verified and the passage should be constructed above those elevations, as close to the stream bank as possible. Another aspect of site selection that is critical is to examine how the installation of a deer passage at a particular bridge location will promote habitat connectivity in the vicinity of the bridge. Other bridges adjacent to the subject bridge (e.g., frontage road) or immediately upstream or downstream from the subject bridge on an intersecting highway should be also evaluated for deer passage installation. It is desirable to promote as much habitat connectivity as practical to ensure the maximum usage of wildlife-oriented features at target locations. An example of this concern is shown in Figure 2, which displays an aerial view of the intersection of U.S. 62 and S.R. 657 in northwest Licking County. The location of bridges over the Lake Fork of the Licking River are indicated on the aerial imagery. In this example, if ODOT OES felt it was appropriate to consider installing a deer passage under the U.S. 62 bridge, it may be appropriate to also consider one under the S.R. 657 bridge to support full habitat connectivity in this area. The effectiveness of a particular installation may be lessened if a deer is able to go underneath one roadway but is forced to go over another one. Each situation should be analyzed on a case-by-case basis to determine if additional projects should be undertaken for connectivity purposes. This could also include constructing passages on non-ODOT roadways, as appropriate.

Figure 2: Example of Bridges on Intersecting Roadways

Erosion and Hydraulic Considerations

A typical ODOT highway bridge utilizes rock installations underneath the bridge in two ways. First, rock installations are utilized as slope protection underneath bridges against the foundations of the bridge itself to ensure that the stream channel does not erode the bank to the point where the structural integrity of the bridge foundation is compromised. The second application is the rock channel protection (RCP), which is used along stream banks where it is necessary to have additional stability along the edge of the waterway. The construction of a deer passage under an existing bridge should not compromise the functionality of either rock installation.

Regarding design practices, there does not appear to be any consistent statewide standard and that bridge designers specify rock protection where it is necessary based on the overall bridge design and site-specific constraints. However, it is generally assumed that rock installations should not exceed a slope of 2H:1V. Furthermore, for the purposes of the deer passage installation, a vertical face of rock installation greater than 1 foot in height should have some type of additional reinforcement added to prevent the entire rock installation from slipping. Therefore, for a path of 3-4 feet width, a slope that is approximately 3H:1V, or gentler, will not need additional reinforcement along the vertical face of the rock.

With respect to the hydraulic design needs, specific design parameters for ODOT roadways are outlined elsewhere in this report. For regulatory purposes, it is necessary to ensure that the elevation of the passage is higher than the ordinary high-water mark to avoid lengthy permitting time frames and other project development complexities. Additionally, based on feedback from other State DOTs, it may be useful to keep the elevation of the deer passage above the elevation of the two-year flood level to ensure that frequent washouts do not occur.

Material Choice and Availability

Existing research and feedback from State DOT practitioners revealed a wide range of viewpoints regarding the materials that are most suitable for the surface of the deer passage. Academic research indicates that natural materials are preferred, while State DOT personnel stated that anything that is walkable for humans is walkable for wildlife. Many states that have built passages utilize small aggregate to fill the voids around the larger RCP to form the passage itself. Minnesota uses a compost grout mixture of natural material and grout to help promote a natural look and feel while also remaining relatively secure from washout. It is anticipated that the materials used to construct deer passages for ODOT bridges will be readily available at the project sites or can be easily obtained from existing stockpiles. Based on the experience of other states, any material conforming with the specifications of ODOT Item 411 (Stabilized Crushed Aggregate) is suitable.

Travel Lane Disruptions

Based on the findings of this research and the proposed construction framework, it is anticipated that the construction of the deer passage will require no or minimal disruption to travel lanes over the bridge. It is anticipated that most construction activity will take place off the roadway. The only instance where travel lane closure may be necessary is if a dump truck is needed to haul away a significant quantity of rock to be removed at the installation. This is envisioned to be a low-frequency occurrence, as most rock moved will be recycled into smaller material for the passage surface or placed elsewhere around the site. For travel lane closures, all relevant OMUTCD and ODOT work zone requirements should be followed.

Construction Analysis

Proposed Framework

This section presents the research team's suggested framework for how to implement the deer passage in RCP concept as a retrofit under existing ODOT bridges. For the purposes of this discussion, it is assumed that a bridge site is already selected for construction of the deer passage through some type of process used by ODOT OES for identifying target sites. It is also assumed that the work for constructing the passage will be carried out by ODOT county garage work crews. Considering all the relevant design parameters to encourage usage by wildlife, engineering-related requirements for ODOT bridges, and the construction capabilities of a typical ODOT county garage work crew, the following three-tier framework is proposed:

- **Scenario #1: Aesthetics Modifications Only.** For this scenario, it is assumed that there is already evidence that wildlife is using the area under the bridge for movement or other habitat functions. It is possible that a suitable trail area for a deer passage already exists under bridges for these functions to take place, even with RCP installed for erosion control or hydraulics purposes. It is assumed that, for this scenario, no modifications to existing RCP installations are needed because the wildlife are already using the passage without modifications under the bridge. For Scenario 1, the construction work will primarily focus on cleaning up crossing approaches and improving the aesthetics of the viewshed for the crossing. This work may include strategic moving of large rock away from obvious wildlife movement paths, clearing and grubbing of small trees and other vegetation, and other minor site work to increase the connectivity of the passage with the surrounding landscape.
- **Scenario #2: Deer Passage in RCP, Slope Gentler than 3H:1V.** For this scenario, it is assumed that some work in the existing RCP installation will be necessary to construct the deer passage. With an RCP slope that is 3H:1V or gentler, it is not necessary to provide additional reinforcement of the vertical face of the rock after the path is cut in. Additional details of the passage installation are presented later in this section.
- **Scenario #3: Deer Passage in RCP, Slope Steeper than 3H:1V.** This scenario is like Scenario #2, except that additional reinforcement will be necessary to stabilize the exposed vertical face of the rock installation. The research team proposes the use of gabion baskets for this purpose. The gabion baskets will be filled with material obtained from the initial excavation activities. Additional details of the passage installation are presented later in this section.

For Scenarios #2 and #3, all work required for Scenario #1 (aesthetics and approach clearing) will be undertaken following installation of the passage. The basic procedure envisioned for the installation of the deer passage is outlined below. The suggested procedure is based on the ORITE research team's analysis of practices used by other State DOTs with ODOT specifications and practices considered as necessary.

- Following the determination of the specific elevation of the passage, all existing RCP is excavated above that point. Excavate an additional 1 foot of depth of RCP for installation of geotextile fabric along the length of the passage under the bridge. Fabric should be secured into remaining rock.
- For Scenario #2, the excavated width should be 3 to 4 feet wide. For Scenario #3, the excavated width should be at least 6 feet to allow for the placement of the gabion baskets along the vertical face of the remaining rock.
- For Scenario #2, place geotextile fabric along the length of the passage and replace excavated RCP to a depth of 6 inches. Add crushed aggregate (Item #411 or equal) using hand tools or mini-excavator bucket and compact until

there are no evident void areas. Repeat this process for remaining 6 inches of depth to complete passage.

- For Scenario #3, install gabion baskets by filling with the excavated RCP material. Crushing material may be required to comply with ODOT's requirements for gabion baskets (Item #838) based on the nature of the excavated RCP. Given the cross-section dimensions of ODOT's gabion basket specifications, it is anticipated that at least two baskets of 3 by 3 foot cross-section will need to be stacked to ensure stability of the RCP above the passage. Following installation of the gabion baskets, install the passage as described for Scenario #2 above.
- Ensure that the installed paths are tied into the surrounding landscape, paying close attention to the location of any drainage features, and ensuring that outflows do not wash out the installed passage. The established passage should be clear of all large rock and other sharp-edge materials. Gabion basket rows, if utilized, should be terminated where their use for support of the rock above is no longer needed and tied into the natural ground whenever possible.

Cost Analysis

This section presents the research team's estimates for the costs associated with construction of the deer passage in existing RCP underneath ODOT bridges. As noted previously, three construction scenarios are envisioned. The daily cost estimate for each scenario is presented in Table 4.

For the development of the cost estimates presented in Table 4, it is assumed that ODOT county garage maintenance personnel will be responsible for the construction activities for the deer passage. The ODOT "Force Account Assessment Form" was used by the research team to identify relevant unit costs for personnel and equipment, as well as applicable overhead rates for force account work. Materials costs were obtained from supplier contacts, except for the Type 47 fence costs which were sourced from ODOT bid tabs. Scenario #1 includes a five-person work crew and all equipment for clearing and grubbing and minor site work. The equipment used includes two work trucks, a trailer-hauled mini-excavator (operating weight under 20,000 pounds), and a pull-behind chipper. One work truck is a stake truck which can be used for carrying work tools and hauling away branches. This same crew and equipment spread is assumed to be used for Scenario #2, except that the chipper is eliminated, and a compaction roller is added to the spread. For Scenario #1, no materials are assumed. For Scenario #2, the daily output includes 10 square yards of geotextile fabric (ODOT CMS Item #204) and approximately 1 cubic yard of fine aggregate (ODOT CMS Item #411). For Scenario #3, the daily output includes the gabion baskets (ODOT CMS Item #838). It is assumed that the gabion baskets will be filled with the excavated rock material, and therefore no additional rock material is imported for this purpose. The costs associated with any mini-excavator attachments, such as a hydraulic rock breaker hammer, are not considered because such attachments are not "metered" for tracking of operating hours. The cost of an ODOT Type 47 fence installation is based on an assumed quantity of 150 linear feet of fence per bridge quadrant (300 feet for a passage along the stream on one side of the bridge). With respect to travel costs, it is assumed that the construction location is, on average. 25 miles from the ODOT county garage. Finally, it is assumed that all work is taking place off the shoulder away from the travel lanes, thereby only requiring a small-scale traffic control deployment (e.g., barrels).

Table 4: Estimated Daily Cost for Construction of Deer Passages

Cost Item	Quantity	Unit Cost	Extension
Scenario #1: Site Work Only			
Labor (5 persons, 8 hours per day) (1)	40 hours	$63.14	$2,526.05
Equipment: 1-Ton Stake Truck (231)	25 miles	$1.08	$27.00
Equipment: 1-Ton Pickup (223)	25 miles	$0.85	$21.25
Equipment: Trailer under 7 Ton (270)	25 miles	$3.50	$87.50
Equipment: Mini Excavator (469)	8 hours	$32.94	$263.52
Equipment: Chipper (340)	8 hours	$16.86	$134.88
Total Cost for 1 Day of Work			**$3,060.20**
Total Cost Including 15% Overage			**$3,519.23**
Scenario #2: 3H:1V Slope or Gentler			
Scenario #1 Daily Cost (2)	1 day	$3,384.35	$3,384.35
Equipment: Compaction Roller (750)	8 hours	$74.35	$594.80
Material: Item 204 Geotextile Fabric	10.0 SY	$5.75	$57.50
Material: Item 411 Fine Aggregate	1.0 CY	$26.45	$26.45
Total Cost for 1 Day of Work			**$4,063.10**
Scenario #3: Steeper than 3H:1V Slope			
Scenario #2 Daily Cost	1 day	$4,063.10	$4,063.10
Material: Item 838 Gabion Basket	4 each	$172.50	$690.00
Total Cost for 1 Day of Work			**$4,753.10**
Material: ODOT Type 47 Fence, Per Side	300 L.F.	$37.45	**$11,235.00**

Note 1: Labor cost assumed to be HT 3M @ $25.06 per hour plus additional $10.02 per hour for Fringe/BWC (40%). Total of $35.08 per hour then assume 80% overhead for comparison with private ($28.07), grand total is $63.15. Material subject to 15% overhead. Equipment not subject to overhead calculations.

Note 2: Daily crew cost is assumed to be Scenario 1 daily rate minus the cost of the chipper, which is only needed for the minor site work for other scenarios.

Based on the daily cost details presented in Table 4, the estimated duration and construction costs for the deer passage is presented in Table 5. The cost varies depending on the scenario, the length of the passage under the bridge, and the number of sides (one side or both sides) that will have the installation at a given location. The research team found no recommendations from literature or practices from other State DOTs that provides guidance on whether to install the passage on both sides of the stream or just one side. Accordingly, the determination of installing a passage on one or both sides of the bridge should be based on site-specific assessment of crash patterns and wildlife movements observed in site reconnaissance. Three passage length alternatives are analyzed: 1) 20-30 feet length, corresponding to a smaller two-lane bridge; 2) 30-45 feet length, corresponding to a three-lane bridge;

and 3) 45-60 feet, corresponding to a four-lane bridge. The estimated costs are rounded up to the nearest $100 to avoid an implied precision. The costs presented in Table 5 do not include any planning, permitting, engineering, or other “soft” costs.

Additional assumptions and details for the duration are as follows. For site work only (Scenario #1), it is assumed that the work will require 1 day per side. For Scenarios #2 and #3, the daily output (length of path) is assumed to be 10 to 15 feet per day, with an additional one day per side added for the installation of the gabion baskets as required in Scenario #3. The estimated duration of the site work necessary to tie the passage into the surrounding landscape (Scenario #1, 1 or 2 days) is included in the duration for Scenario #2 and #3 durations. Installation of the channelizing fence is assumed to require 2 days per side.

Table 5: Estimated Duration and Construction Costs

Scenario	Passage Length	Duration (# Days)		Construction Cost	
		One Side	Two Sides	One Side	Two Sides
Scenario #1	Any	3	4	$21,800	$36,600
Scenario #2	20-30 Feet (2-Lane Bridge)	5	8	$30,000	$52,800
	30-45 Feet (3-Lane Bridge)	6	10	$34,000	$61,000
	45-60 Feet (4-Lane Bridge)	7	12	$38,100	$69,100
Scenario #3	20-30 Feet (2-Lane Bridge)	6	10	$36,100	$65,100
	30-45 Feet (3-Lane Bridge)	7	12	$40,900	$74,600
	45-60 Feet (4-Lane Bridge)	8	14	$45,600	$84,100

Economic Analysis

Economic analysis is used extensively in highway safety project development. Comparing the costs of highway construction projects with the anticipated benefits associated with such projects ensures that the DOT considers only projects that have an economic benefit that exceeds the cost of the project over the life span of the project. In the case of highway safety, the “benefits” of a project are accrued primary from the value of anticipated reductions in traffic crashes due to the project’s features. Any reduction in traffic crashes that are anticipated to occur because of a particular project is assumed to generate cost savings to society as a whole. These costs are assumed to be the direct costs associated with an “average” traffic crash; commonly used values of costs per crash are widely available, as are techniques for updating values for future conditions. State DOT safety programs, including the ODOT highway safety improvement program (HSIP), utilize these crash cost values extensively in project-level and program-level analyses (ODOT, 2022).

Details of the process used by the ORITE research team to calculate the value of the average cost of a deer-vehicle crash in the State of Ohio are presented in Appendix B. Briefly, the assumed cost per crash for each severity type was averaged with a weighting factor to account for the relative occurrence for each severity type amongst Ohio deer-vehicle crashes during the three-year period between 2017 and 2019. This method was also used in a research study in Virginia for a similar purpose to determine the comprehensive cost of wildlife crashes (Donaldson and Elliott, 2020). Following these procedures, the research team estimated that the average cost of a deer-vehicle crash in Ohio is $19,558.61 per crash. The present value associated with the annual crash costs is also calculated and presented in Table 9 (Appendix B) for various annual deer crash frequencies within one-half mile of a particular bridge location. The economic benefits derived from the construction of deer passages will be realized in cost savings associated with deer-vehicle crashes that are avoided. This savings is related to the potential effectiveness of the deer passage as a safety feature (i.e., the percentage of deer crashes that are reduced by removing the deer movement from the roadway). A conservative estimate of the effectiveness of the deer passage is 50% (i.e., half of crashes at a location are reduced), but the effectiveness may be as high as 90% based on experience from Washington State DOT. If the present value of the crash cost savings divided by the construction costs plus the present value of the annual maintenance cost (i.e., the benefit-cost ratio) exceeds 1.0, the construction investment is expected to generate positive economic return and should be pursued as a good use of taxpayer funds. The higher the benefit-cost ratio, the greater the anticipated return on investment, and projects with a higher benefit-cost ratio should be prioritized. For this analysis, the costs include the anticipated construction costs (Table 5) plus the present value of annual maintenance (estimated to be $32,200 over 20 years based on $2,000 annual maintenance expense, 4 percent discount rate, 2 percent growth rate of costs).

Table 6 presents the minimum deer crash frequency that would need to be documented at a specific bridge location that would result in the construction of a deer passage being economically justified. Each combination of scenario, passage length, and 1 or 2 sides for construction is presented with the minimum frequency thresholds assuming effectiveness rates of both 50% and 90%. The results presented in Table 6 reveal that a relatively small number of reported deer crashes are needed at a particular bridge location to justify the construction costs of the deer passage. For a conservative estimate of effectiveness (50%), installation of a deer passage at any bridge location with at least 1 deer crash per year is justified. If a 90% effectiveness rate is assumed, any bridge location with a reported deer crash in the previous three-year period is a candidate for the deer passage retrofit construction. These results are themselves conservative in a sense that they do not account for any potential traffic growth and do not account for any under-reporting of deer crashes. If either of these factors are considered, the potential crash cost savings increases dramatically, while the construction costs remain the same.

The results in Table 6 are provided as a quick reference for determining potential retrofit sites. If a the actual benefit-cost ratio for a specific situation is desired, the present value of estimated benefits for various crash frequencies and the present value of construction costs can be referenced in Appendix B, Table 9 and Table 10, respectively, and the benefit-cost ratio can be easily calculated. An example of the benefit-cost analysis is presented in Table 7. The input parameters for the example are as follows: passage length (bridge width): 40 feet; crash frequency: 6 deer crashes in the last 3 years; deer crash and related activity detected on both sides of stream; assumed effectiveness: 50%; and the installation to occur in an existing rock slope of 4H:1V. Based on the given information about the rock slope, Scenario #2 with installation on both sides of the stream is assumed for this example. As reported in Table 7, the proposed installation has a benefit-cost ratio of 2.85, which indicates a return of $2.85 for every $1.00 invested in the project.

Table 6: Minimum Annual Deer Crash Frequency for Positive B/C Ratio

Scenario	Passage Length	50% Effectiveness		90% Effectiveness	
		One Side	Two Sides	One Side	Two Sides
Scenario #1	Any	1 per 2 years	2 per 3 years	1 per 3 years	1 per 3 years
Scenario #2	20-30 Feet (2-Lane Bridge)	1 per 2 years	2 per 3 years	1 per 3 years	1 per 2 years
	30-45 Feet (3-Lane Bridge)	2 per 3 years	1 per year	1 per 3 years	1 per 2 years
	45-60 Feet (4-Lane Bridge)	2 per 3 years	1 per year	1 per 3 years	1 per 2 years
Scenario #3	20-30 Feet (2-Lane Bridge)	2 per 3 years	1 per year	1 per 3 years	1 per 2 years
	30-45 Feet (3-Lane Bridge)	2 per 3 years	1 per year	1 per 3 years	1 per 2 years
	45-60 Feet (4-Lane Bridge)	2 per 3 years	1 per year	1 per 3 years	1 per 2 years

Table 7: Benefit-Cost Analysis Example

Analysis Parameter	Value	Source/Discussion
Passage Length/Bridge Width	40 feet	Given
Crash History	2 per year	Given as 6 in past 3 years, only relevant crash history included.
Assumed Effectiveness	50%	Given
Existing Rock Slope	4H:1V	Given; Scenario #2
Number of Sides	Both	Given
Estimated Initial Cost	$61,000	Table 5
Estimated 20-Year Life Cycle Cost	$93,200	Table 9
Estimated Crash Reduction Benefit	$265,807.38	Table 10
Estimated Benefit-Cost Ratio	2.85	Crash Reduction Benefit ÷ Life Cycle Cost
Anticipated Construction Duration	10 Days	Table 5

RECOMMENDATIONS FOR IMPLEMENTATION

Recommendations

This research study examined the feasibility of constructing deer passages within rock installations located under existing ODOT system bridges, with specific interest in the case where the passage construction is being undertaken as a “retrofit” case (i.e., with the bridge beams in place). Review of existing research and academic literature on wildlife passages, interviews of State DOT personnel, technical requirements for ODOT bridges, and observations of the functionality of eight deer passages constructed in ODOT District 5 formed the basis of the research team’s conclusions and recommendations. Three scenarios of construction are proposed based on the extent and complexity of work required to install the passage underneath the bridge. The cost of construction was estimated for various scenarios, accounting for the extent of work required, the slope of any rock installations present, the length of the passage, and whether the passage would be installed on both sides of the stream. All cost estimates and construction procedures were developed assuming that ODOT county garage work crews and ODOT equipment would be used for the work. The estimated construction cost ranges from $21,800 for minor site work only on one side of the bridge to $84,100 for a 60-foot-long passage constructed on both sides of the bridge with a 2H:1V cross-slope of rock installation. The estimated duration of work ranges between 3 days and 14 days.

An economic analysis conducted by the research team compared the present value of the construction costs (plus a small amount of annual maintenance cost) with the cost savings associated with the potential reduction in deer crashes due to separating deer movements from the highway along stream corridors. **Based on the economic analysis, it is recommended that the installation of the deer passage be pursued for any bridge location that experiences one or more recorded deer-involved crash per year within one-half mile of the bridge.** Depending on the specific scenario and bridge configuration being considered, installation of the deer passage results in an economic benefit with as little as 1 recorded deer crash in the last 3 years if a 90% effectiveness is assumed and as little as 1 recorded deer crash in the last 2 years if a 50% effectiveness is assumed. All the personnel capabilities, equipment, and tools are readily available within a typical ODOT county garage and the required materials are easily available statewide. **It is further recommended that a channelizing fence be installed near the bridge approach to provide positive guidance to the deer that are grazing along the stream.** This recommendation is based on experience from several states, which have found that fencing increases the effectiveness of various types of wildlife crossing structures. For this study, the cost estimates presented assume a length of fence of 150 feet on each bridge approach.

Implementation Plan

Based on the recommendations of this research study, the following implementation plan is proposed. ODOT should immediately pursue a pilot implementation of the deer passage construction utilizing its in-house county garage maintenance forces. The time and resources required to complete the construction should be documented in detail to determine if the resource requirements and construction costs assumed by this study are realistic. ODOT OES will need to work with ODOT waterway permitting and maintenance operations groups to ensure that all necessary permits are secured, and that construction work can be scheduled and carried out as envisioned in this study. Work should be scheduled to take place during low water periods of the affected stream, such as late summer. Timing the work in this manner will allow for the passage to be constructed and operational before the late fall/early winter active period for deer. The estimates provided in this research study assume that all work activities will be undertaken by ODOT county garage work crews. It may be desirable for ODOT to utilize a contractor for fence installation if the county garage maintenance personnel are not experienced with the installation of the Type 47 fence. The fence costs reported in this study are obtained from ODOT bid tabs, which represent contractor-provided pricing, so the costs are not anticipated to change substantially if this option is used.

Based on the economic analysis conducted as part of this research study, the benefits of deer passage construction should be substantial, and will be realized immediately upon completion of the construction activity. In particular, bridge locations where there is already evidence of deer grazing or movement activity along streams are ideal targets for investment in minor site work and other cleanup needed to tie the stream bank passage with the surrounding landscape on both sides of the highway. This option (Scenario #1) provides the greatest potential benefit and return on investment for ODOT. Scenario #3 presents the greatest risk to the department. Bridge locations where rock installations are already at the most critical slope (2H:1V) may present other unique challenges for construction that cannot be anticipated by the generalized cases of this research study. Another potential risk to the success of the deer passage in RCP concept is the proximity of installations to other bridges that are in the deer grazing or movement areas but do not have the passage installed. Cases such as nearby intersecting bridges (see Figure 2) should have special attention paid to them to ensure full habitat connectivity. If the intersecting bridge is on a non-ODOT road, the local public agency will need to be engaged to determine if construction under the nearby bridge is feasible. Finally, the creation of an entirely new asset type within ODOT will create some risk for the Department's overall asset management strategy by introducing new maintenance requirements.

Future research should examine more progressive methods for construction of the deer passage. Alternative materials or construction techniques, such as "blown" gravel or "compost grouting" for the passage, may hold some promise for future implementation and should be studied in more detail. Future research should also attempt to quantify the effectiveness of the deer passage installation in terms of deer crash reduction. To evaluate the effectiveness of the deer passage installation, ODOT OES should monitor the crash history and carcass removal at locations where the deer passage is constructed after construction is complete. Comparing this experience with the pre-construction history will aid in determining the success of the passage in crash reduction. This study presented the economic analysis results assuming effectiveness rates of 50% as a conservative crash reduction outcome and 90% effectiveness as an aggressive outcome.

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APPENDIX A: LITERATURE REVIEW

Summary of Literature Findings

Task 10.1 of the research study was a comprehensive literature review. The review focused on past research studies, academic journal articles, and State DOT experience with deer passage construction. The research team conducted an extensive review of the academic literature associated with the design and construction of wildlife crossings. The focus of the review was primarily on identifying dimensions, materials, and other conditions that have been shown to promote usage of crossings among target species. Certain research studies conducted by State DOTs are addressed in state-specific discussions presented in this section. A summary of the relevant academic literature is provided below.

Guidebooks, notably, the FHWA publication *Wildlife Crossing Structure Handbook: Design and Evaluation in North America* (Clevenger and Huijser 2011), provide excellent design guidance for wildlife crossings. The scenario analyzed in this publication that is most applicable to the current research task is the “Underpass with Waterflow” situation. Design recommendations for wildlife crossing with waterflow included a minimum width of 6.5 feet and height of 10 feet; a recommended width of greater than 10 feet and height of greater than 13 feet; channelizing fencing to provide positive guidance to wildlife approaching the crossing; and replication of habitat conditions on the crossing approaches to the greatest extent possible. Larger dimensions, expressed in terms of the “openness ratio” of the structure (width times height, divided by length), has been shown to positively correlate with usage (e.g., Ng, et al., 2004; Clevenger and Waltho, 2005; Dodd, et al., 2007; Seiler and Olsson, 2009; Cramer, 2012; Bhadraj, et al., 2020). The importance of mimicking the natural habitat on the crossing approaches is also noted by several studies (e.g., Dodd, et al., 2007; Gangon, et al., 2011; Cramer, 2012; Bhardwaj, et al., 2020). Finally, the use of channelizing fencing has been shown to promote the use of crossing structures by providing positive guidance for animals approaching the structure (e.g., Brudin, 2003; Gangon, et al., 2011).

State DOT Experience

The second element of the literature review task was outreach to State DOTs outside of Ohio to obtain crucial details of design and implementation insights from the perspective of the practitioner. Initial research conducted by the ORITE team indicated that the Minnesota Department of Transportation (MnDOT) was one of the earliest adopters of the deer passage through RCP concept. Other states, namely Indiana, Virginia, and Washington, were also identified as targets for additional inquiry. Additional work out of Arkansas, Massachusetts, and Pennsylvania also was identified and deemed useful in this review. In general, State DOTs have approached this problem in a practical manner, providing wildlife passage and habitat connectivity at locations where it is needed. Design guidelines exist for some states, but many states expressed a “provide what you can” approach to accommodating wildlife passage, working with the dimensions and conditions presented by the structural, hydraulic, and construction-related aspects of the bridge design.

Arkansas

The Arkansas Department of Transportation (ArDOT) is currently undertaking a research study to examine the usage of culverts and bridges on the state highway system. An update presentation (ArDOT, 2018) indicates that several passage benches have been installed on Interstates and U.S. routes in the state in recent years. The research study is on-going, and no results are available as of this writing. One passage bench location on U.S. 67 north of Little Rock was visited by the Principal Investigator while on a separate trip through the region. Photos of this installation taken by the Principal Investigator are displayed in Figure 3. The passage detail is shown on the left side, indicating the presence of a very adequate passage while also providing the necessary erosion control for the foundation. There was no evidence of usage of the passage at the time of the visit. One possible explanation for the lack of apparent usage is that there is no suitable passage under the adjacent frontage road (see Figure 3, right side), which serves as a barrier between the passage and the nearby forested area. Follow-up with ArDOT is recommended after the on-going research study is completed.

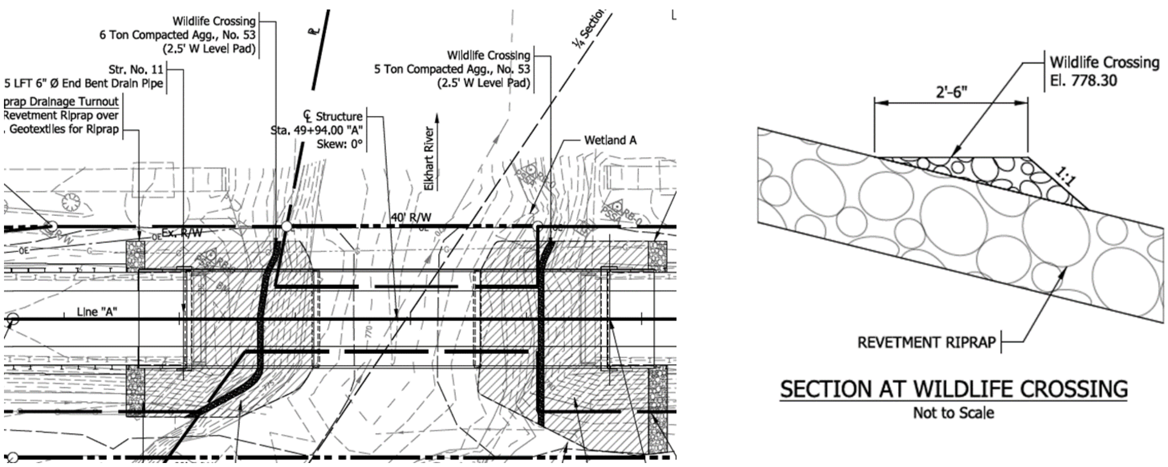
Left: Deer passage under U.S> 67 Main Lanes
Right: Lack of Connectivity Under Frontage Road on Left of Image
Figure 3: Deer Passage Installation on U.S. 67, Jacksonville, AR

Indiana

The Indiana Department of Natural Resources (IDNR) has been promoting the use of wildlife passages under bridge structures for many years. Recently the Indiana Department of Transportation (InDOT) has taken on a more substantial interest in providing wildlife passages. Outreach to IDNR indicated the following items with respect to dimensions and other design issues:

- Desired height of the structure is 8 feet, as measured from the elevation of the low chord of the bridge to the elevation of the OWHM. However, a clearance as low as 5.5 to 6 feet can accommodate a full-size buck and is suitable.
- Desired pathway width is 3 to 4 feet, but 1 to 2 feet is acceptable.
- Pathway should mimic the natural ground along the stream bank as much as possible and should not be against the bridge pier if possible.
- Passage surface material can be any fine aggregate (InDOT #2, #53, or #73) – approximately equivalent to ODOT Item 411.

An example of how InDOT portrays the wildlife crossing in a set of bridge plans is presented in Figure 4, showing a two-lane bridge replacement on S.R. 119.



Left: Plan View of Wildlife Crossing Under Bridge
Right: Cross-Section Detail of Wildlife Crossing Installation
Figure 4: Design Plan Details for InDOT Wildlife Crossing, S.R. 119

Massachusetts

The Commonwealth of Massachusetts developed standards for dimensions associated with wildlife crossings along streams (Jackson, et al., 2011). In addition to their use in Massachusetts, these standards have been cited by other states as inspiration for their own guidance. The following standards are suggested:

- If there are conditions present that significantly inhibit wildlife passage over the roadway (e.g., physical barriers to at-grade crossing), the minimum height is 8 feet and the openness ratio should be greater than 2.46.
- If there are no issues that inhibit wildlife passage over the roadway, a minimum height of 6 feet and an openness ratio of at least 1.64 should be used.
- Tie constructed banks into upstream and downstream banks. The passage should follow the natural alignment of the stream bank wherever possible.

Minnesota

The State DOT experience reviewed by the ORITE research team indicated that the Minnesota Department of Transportation (MnDOT) seems to be the earliest adopter of the deer passage through RCP concept, with evidence of implementation as early as 2005. The MnDOT experience appears to be the most mature among all states, as they have evolved the deer passage (also called "passage bench") concept into standard design guidance. This guidance, plus a research poster explaining some of the design practices and lessons learned, was supplied to the research team during this study. Building on the initial installations in 2005, the passage bench was installed at three bridge locations in northern MN in 2009. From these early installations, the following lessons learned were emphasized:

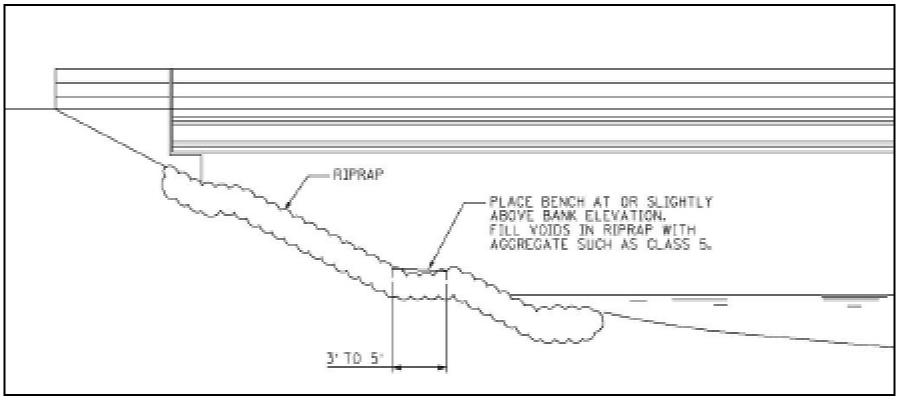
- Coordination across disciplines is needed for siting and design.
- Oversight of construction and grading is needed to ensure correct installation.
- Installation on new bridges should be carried out before beam placement.
- Set drainage outflow and associated structures below the bench elevation.
- Passages are installed in locations with low clearance to benefit smaller species.
- Three-foot minimum width is essential.
- Fencing not a required feature.
- Some human usage has been observed but no problems reported.

More recent insight was provided to the research team via telephone interview conducted as a part of this research task. MnDOT staff reported that, due to runoff issues and clay content in material, the passage bench specification has evolved to provide more options for gravel or other cheaper material that cannot be economically used for other purposes. Good sight lines on the crossing approach, as well as through the crossing itself, was strongly emphasized. Finally, MnDOT has utilized a new material, known as compost grouting, to fill gaps in the RCP. The compost grout is a mixture of grout material and natural compost. The material provides a natural look and feel while also being more resistant to washout. Additionally, some vegetation can grow in this installation, which provides a more natural look and feel to the otherwise rocky area.

Examples of the most current MnDOT guidance for construction of passage benches under highway bridges are pasted on the following pages. The following key points are noted from the MnDOT guidance:

- Any size aggregate will work for the passage surface if it is walkable.
- No minimum height clearance is specified; widths of 2-3 feet are successful.
- Bench elevation should be set near to the elevation of the top of the stream bank, simulating the natural stream bank and providing continuity.
- Tie the passage benches to the natural ground lines outside of the bridge.
- Fencing may be used to encourage or train the animals on use of the passage, including fencing in the median of divided highways to prevent animals from coming up onto the roadway.

Passage Bench Design



NOTE: A PASSAGE BENCH MAY BE SIZED TO ACCOMMODATE ANY OR ALL OF THE FOLLOWING ISSUES COMMON TO WATERCOURSE CROSSINGS: SPECIES MOVEMENT, RECREATIONAL TRAILS, BRIDGE MAINTENANCE, AND HYDRAULICS.

IN SOME CASES THE DNR MAY REQUIRE CROSSINGS BE DESIGNED FOR SPECIES MOVEMENT. IF THE CROSSING IS LOCATED AT A SIGNIFICANT WILDLIFE TRAVEL CORRIDOR, AS DETERMINED BY DNR WILDLIFE OR ECOLOGICAL SERVICES STAFF, THE CROSSING SHALL BE DESIGNED TO MINIMIZE CONCERNS. THE DNR PREFERS BRIDGES OVER CULVERTS BECAUSE THEY ACCOMMODATE WILDLIFE MOVEMENT AS LONG AS THERE IS ADEQUATE CLEARANCE FOR PASSAGE BENEATH ROAD DECKS, AND/OR THE PRESENCE OF A STREAM BANK (DRY GROUND) AT NORMAL FLOW CONDITIONS.

The specifications above are from the original manual
'Best Practices for meeting DNR General Permit 2004-0001, March 2006'

Additional design considerations have been determined, they are:

1. Typical bridge riprap can be a barrier to animal movement along streambanks (see figure 3). Passage Benches allow for movement of animals under the bridge, thereby increasing road safety of bridge approaches.
2. The bench elevation should be at the approximate streambank elevation and be connected at either side of the road to allow for animal movement.
3. Use of Class 5 aggregate is a recommendation only. Any size aggregate will do as long as the surface is 'walk-able'. Note figures 1 & 6 show class 5 aggregate while figures 2 & 5 show larger aggregate (all meet design criteria).
4. The bench width need only be the width of a typical game trail. Wider benches may be desired for other criteria such as formal hiking trails. There is no minimum height clearance and widths of 2' to 3' have been successful for animal movement.
5. Bridge length is not necessarily increased. MnDOT has altered their typical cross-section design (lowering a flat area that was set next to the abutment) and has found that placing a 2' - 3' bench lower down, may add about 2' to the length of shorter bridges. This will vary depending on the hydrology of the stream and the overall length of the span.
6. It has gained support due to other benefits and is now included in the standard plans for riprap at bridge abutments (standard fig. 5-397.309 is included on page 19):
   - Increases road safety by getting animals off of bridge approaches.
   - Safe footing for bridge inspection and maintenance
   - Adds flexibility in design for normal channel and flood profile
   - Virtually no extra time/costs to install

Examples of Passage Benches

Figure 1.
Completed Passage Bench

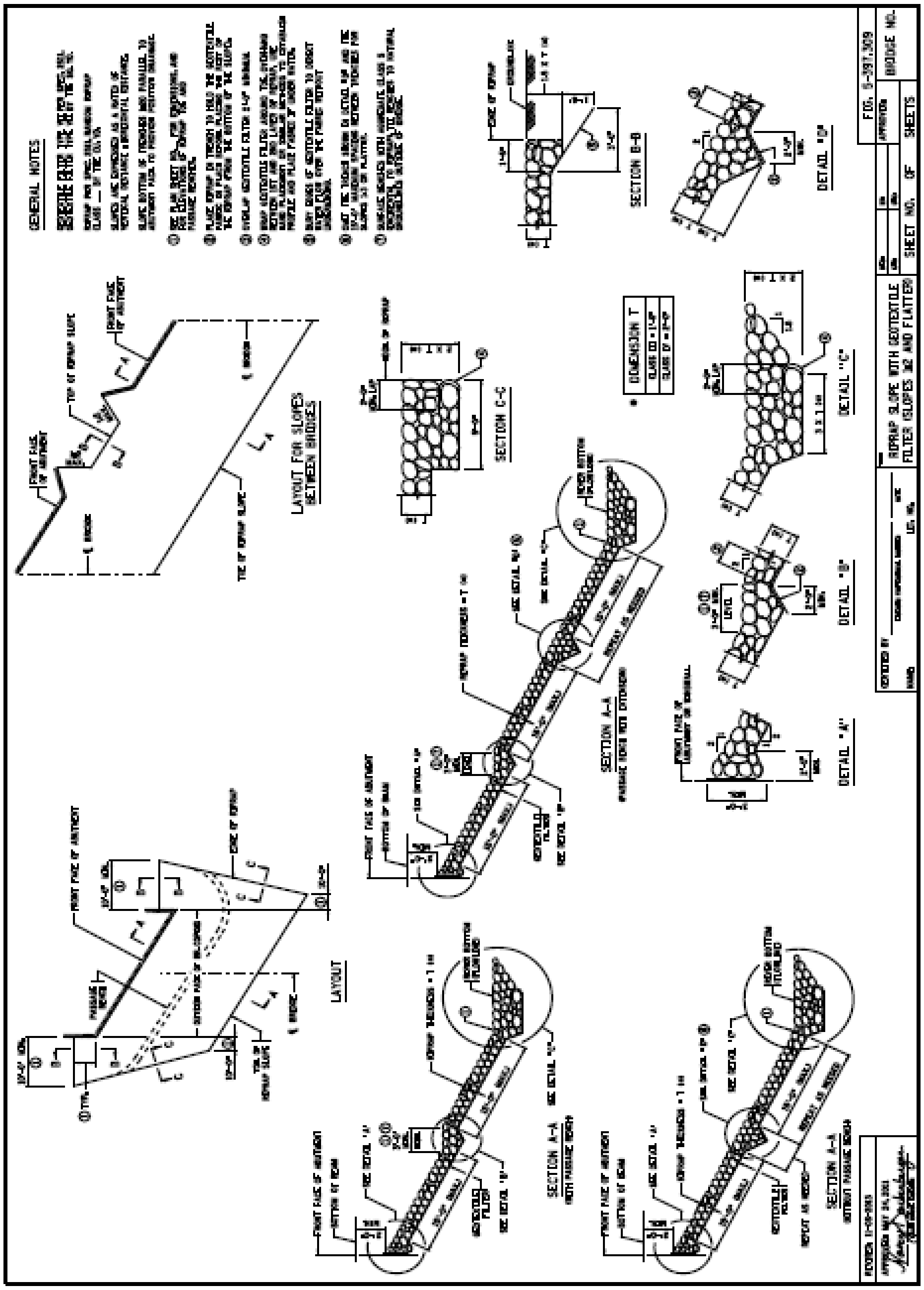
Figure 4.
Passage Bench is set to mimic shoreline game trail

Figure 2. Bench may be constructed of any size 'walkable' aggregate

Figure 5.
Bench must connect to surrounding topography

Figure 3.
Traditional Riprap is not passable by many animals

Figure 6.
Required in some areas, successful everywhere



The standard 11 x 17 plate is located in the appendix, or can be downloaded from:
DGN file: http://www.dot.state.mn.us/bridge/pdf/cadd/files/bdetailspart2/dgn/fig7309e.dgn
PDF file: http://www.dot.state.mn.us/bridge/pdf/cadd/files/bdetailspart2/pdf/fig7309e.pdf

General notes #1 (on plan sheet fig. 5-397.309). Passage bench elevation should be set near to the elevation of the adjacent top of the streambank. This is to simulate a natural streambank, providing continuity to any game movement along the waters edge.

(TH1 Flint Creek, St Louis County MN)

(TH60 Canon River, Rice County MN)

General notes #7 (on plan sheet fig. 5-397.309). Tie benches to the natural groundlines outside of bridge. It is essential that the adjacent area also have a bench included in plans. This is often a roadside ditch that outlets to the stream. Frequently the ditch design is in the grading plan and not addressed in the bridge plan. Be aware of this potential discrepancy, and be sure to have the bench mimic the natural streambank across the entire area.

(TH30 Bucksnort Bridge, Fillmore County MN)

(TH8 in Lindstrom, Chisago County MN)

Bench is to be carried through to adjacent streambank. These two examples show riprap blocking the bench.

In order to avoid passage bench washouts, roadside drainage and/or outfalls should be placed below the bench.

(I-94 Crow River, Hennepin County MN)

The bench elevation should be set at or just above the vegetation line. Generally, this is readily visible on site.

Note: Fencing may be required to encourage or 'train' animals to utilize the bench. Outside ROW fencing should be turned up installed tight to the abutment. On divided highway bridges with a median gap, the bridge gap should be fenced to prevent animals from making their way up onto the median.

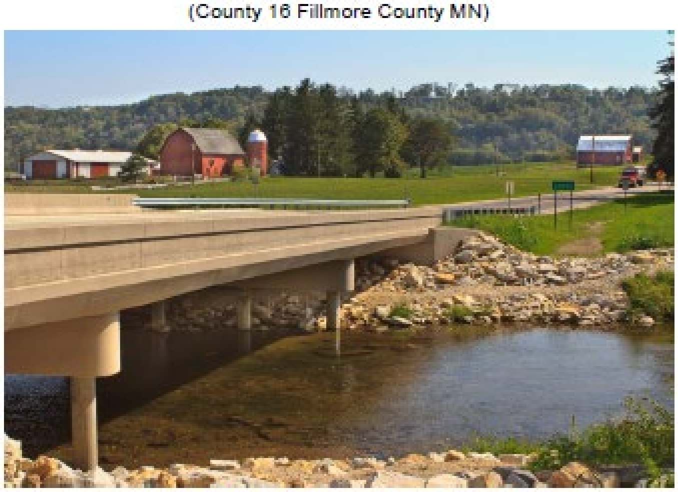
Fencing on the right of way line should of been turned up at the abutment. With the standard practice of running the ROW fence to the waterline, there is no encouragement to go under the bridge (note the fence also caught flood debris).

Fencing of the medians is needed to prevent animals from coming up on to the roadway.

Examples of completed Passage Bench installations carried through to adjacent lands.

(I-35 Straight River, Steele County MN)

(County 16 Fillmore County MN)



(TH43 Choice Bridge, Fillmore County)

North Carolina

The North Carolina Department of Transportation (NCDOT) has been involved with wildlife crossings for many years. However, one recent project was noted as being the first-ever project in the state to utilize the passage bench concept. The project is located at the Interstate 40 interchange with Harmon Run Road in the western part of the state. NCDOT's primary concerns at this location included the safety of species such as deer, black bear, elk, and smaller mammals. Insight provided by the NCDOT project manager indicated that animals cross the highway only on one side of the stream and that the passage would only be installed on that side. Wildlife advocacy groups suggested a path width of 10 feet but that was not feasible for the bridge design. No specific calculations or guidelines were used in the final determination of the design plans. The basic approach was to use the widest possible passage given the other bridge dimensions present. The large riprap would be backfilled with a stone base for the passage material.

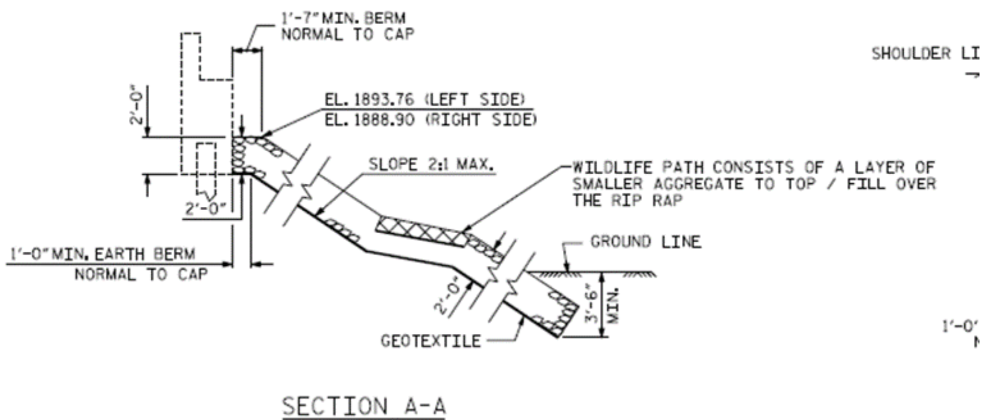


Figure 5: Cross-Section of NCDOT Wildlife Passage, Harmon Run Road

Pennsylvania

The Pennsylvania Department of Transportation (PennDOT) has a chapter in its design manual dedicated to wildlife crossings. The PennDOT design guidance indicates that, for wildlife crossings with water flow, a minimum width of 6.5 feet of dry pathway and 10 feet of height is desired. The recommended dimensions are a dry pathway of at least 10 feet width and 13 feet height. The guidance also indicates that the use of fencing in conjunction with crossings is crucial to success. In addition to the design manual guidance, Brudin (2003) analyzed existing bridges (18) and culverts (28) for use as wildlife underpasses across Pennsylvania. The analysis indicated that a minimum width of 15.3 feet, minimum height of 8.2 feet, and a maximum length of 286 feet was recommended for maximum usage by wildlife. Other features that appeared to promote usage of underpass structures included channelizing fencing, location of crossings in known animal movement areas, and the use of open and natural-looking approaches where possible.

Virginia

The Virginia Department of Transportation (VDOT) has been a leader among Eastern U.S. states on the development of highways in ecologically sensitive areas. For many years, VDOT has engaged numerous research studies intended to address the nuances of highway projects in wildlife habitats. One study of seven underpass locations (Donaldson, 2005) found that a height of 12 feet was most successful at facilitating deer passage. Other design features, including a higher openness ratio, natural floors, level approaches, clear visibility, and forest cover near the underpass openings, were found to promote usage. Donaldson and Elliott (2020) analyzed one large bridge underpass and one large box culvert along Interstate 64 to determine the effectiveness of fencing existing underpass structures. A before and after study was conducted with two years of crash experience pre- and post-construction. After construction of the fence, deer crossings increased by 410% at the culvert and 71% at the bridge location. Deer-vehicle collisions decreased by 92% after fence construction, resulting in the conclusion that the safety benefits of the fencing exceeded the cost of the installation after just 1.8 years of service. Following the success of the research initiatives, VDOT has inserted guidance in its bridge design manual to aid the deployment of deer passages under bridges. Drawing inspiration primarily from the MnDOT experience, the VDOT Bridge Design Manual specifies that passage benches shall be a minimum of 3 feet wide, 6 feet tall, level, and following the natural terrain closely both on approaches and underneath the structures. An example cross-section for VDOT wildlife crossings is displayed in Figure 6.

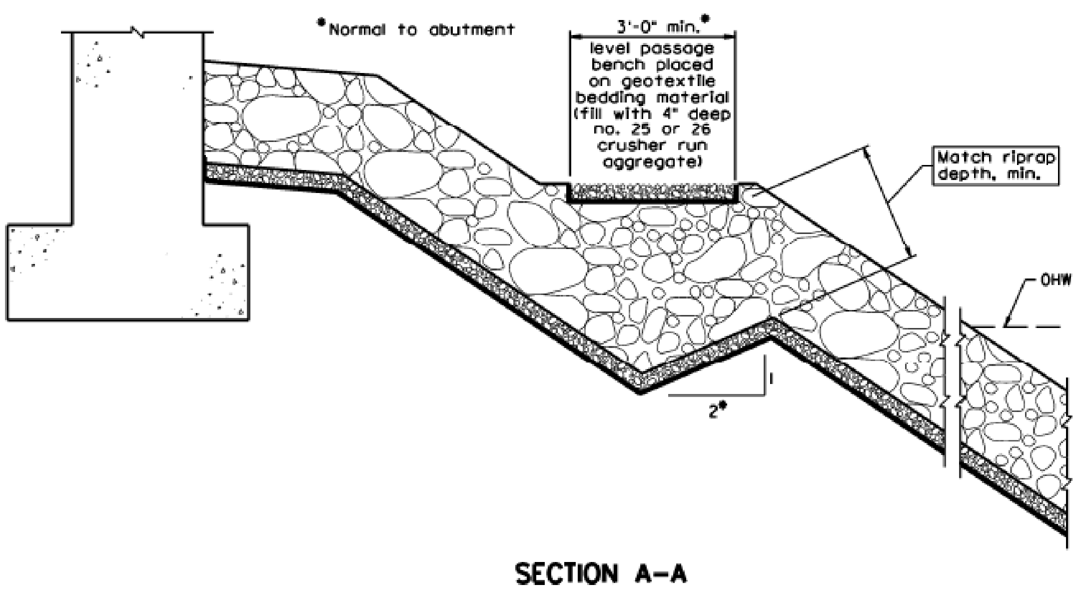


Figure 6: Example Cross-Section for Wildlife Crossing, Virginia DOT

Virginia DOT formalized its guidance for wildlife mitigation strategies in an April 2022 report (Donaldson, 2022). Figure 7 displays guidance from this report on optimal size and design features to promote high usage. Regarding size, it is noted that optimal dimensions for bridges are 8-foot height and a minimum width is a 3 foot dry path. It is also noted that clear visibility, unobstructed path to entrances, and fencing are features that are expected to increase the usage of the structures.

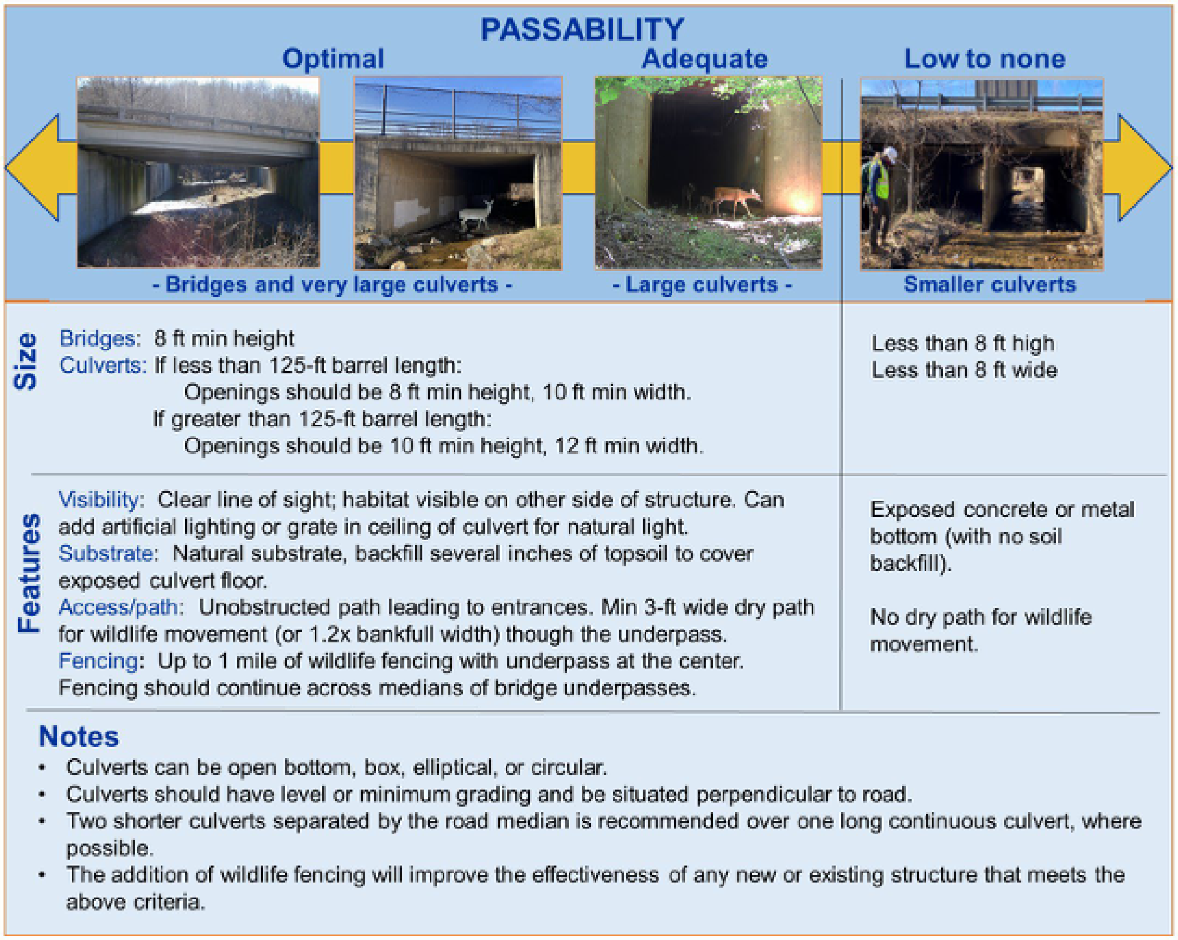


Figure 7: Virginia DOT Spectrum of Wildlife Crossing Design Features

Washington

Washington Department of Transportation (WSDOT) has been a national leader in wildlife mitigation for major highways. Wildlife crossings and other mitigation features on the Interstate 90 Snoqualmie Pass project has been highlighted in numerous venues as an example of how to manage highways in sensitive habitat areas. Another highway segment in the state with significant deer crash issues is U.S. 97 near the Janis Bridge. WSDOT personnel were contacted about a deer passage that was installed at the Janis Bridge location as a retrofit case. WSDOT personnel revealed that at one end of the bridge, there were indications that wildlife (including deer) was already moving through the area underneath the bridge along naturally established paths. To further promote the use of the naturally established pathway, WSDOT added channelizing fencing and cleaned up the approaches to the crossing to improve the viewshed through the structure. In the two years following the relatively minor improvements at the Janis Bridge location, recorded deer crashes decreased by more than 90 percent. The success of the Janis Bridge retrofit project has motivated WSDOT to pursue additional retrofit projects across the state. The objectives for future projects are to maintain as much habitat connectivity as possible and maximize the viewshed through the structure. Regarding design parameters, the target for future passages is for the passage elevation to be above the two-year flood level and to have a minimum openness ratio of 2.0 (corresponding approximately to a 20-foot width, 10-foot height, and less than 100 feet in overall length).

Wyoming

The Wyoming Department of Transportation released a preliminary data report in August 2019 of wildlife use of existing structures along Interstate 25 near Kaycee (Huijser, et al., 2019). Nine structures that were not originally intended for wildlife use were monitored between April 2018 and January 2019. Structures included bridges with widths ranging between 75 and 227 feet, as well as two 10-foot by 10-foot box culverts. Monitoring data showed that 95% of white-tailed deer and 74% of mule deer used the structures for passage under the highway. The report also noted that installation of channelizing fences at existing underpass structures would immediately address some concerns with collisions on the highway.

APPENDIX B: ECONOMIC ANALYSIS CALCULATIONS

This section presents the calculation details for the economic analysis presented in this report. Comparing the costs of highway construction projects with the anticipated benefits associated with such projects ensures that the DOT considers only projects that have an economic benefit that exceeds the cost of the project over the life span of the project. Economic analysis is used extensively in highway safety analysis. In the case of highway safety, the "benefits" of a project are accrued primary from the value of anticipated reductions in traffic crashes due to the project's features. The economic costs associated with traffic crashes include expenses associated with emergency services at crash scenes, medical services for injured persons, insurance and legal costs, costs to repair damaged property, and loss of productivity/wages due to lost work time (Harmon, et al., 2018). For fatal crashes, the crash cost values also address the average value of an individual's contributions to society over an average life span. Any reduction in traffic crashes that are anticipated to occur because of a particular project is assumed to generate cost savings to society. These costs are assumed to be the direct costs associated with an "average" traffic crash; commonly used values of costs per crash are widely available, as are techniques for updating values for future conditions. State DOT safety programs, including the ODOT highway safety improvement program (HSIP), utilize these crash cost values extensively in project-level and program-level analyses (ODOT, 2022). Because the costs associated with various aspects of crashes (e.g., medical care) increase with worsening crash severity, it is necessary to use a range of values depending on the type of crash being analyzed.

One issue associated with using these values for wildlife-related crashes is that only the comprehensive costs related to human activity are considered. For crashes associated with wildlife, additional values could be considered for the effects on the specific wildlife populations involved. Valuation of wildlife to society has long been a complex issue, affecting a broad range of subject areas beyond analyzing safety projects. Valuation of wildlife to society includes both use and non-use values (Schuhmann and Schwabe, 2000; Duffield and Neher, 2021). Valuation associated with the use (i.e., direct contact) of specific wildlife species include both consumptive use and non-consumptive (e.g., fishing, bird watching). Valuation associated with non-use of wildlife species include existence value (i.e., the value of the knowledge of continued existence of a species) and bequest value (i.e., the value of preserving a particular species for future generations). It is quite difficult to estimate the value associated with a specific wildlife species and also impractical to apply this concept for the evaluation of transportation safety project. One recent attempt to quantify these issues in Minnesota found that the direct costs associated with traffic crashes (i.e., the traditional crash costs) accounted for 63% of the overall costs to society while the wildlife-associated costs accounted for 37% of the costs (Duffield and Neher, 2021). The application of use and non-use values in the context of wildlife-vehicle crashes is not well-established, and thus will not be used here.

The calculations for an updated cost per deer-vehicle crash for ODOT use are displayed in Table 8. The values in the far-right column of Table 8 represent the typical values used by ODOT for crash costs and are not specific to deer crashes of a particular severity. As noted previously, it is difficult to ascertain with available data if specific values exist for crashes involving wildlife. Practically speaking, unless comprehensive data on property damage values are collected for each type of crash, it is impossible to ascertain the specific values associated with deer-related crashes. Additionally, any safety projects focused on deer-vehicle crashes will be evaluated against the economic benefits of other safety projects being considered by ODOT. For those reasons, this analysis uses the standard per-crash cost values and does not consider deer specifically. To determine the final value of the average cost of a deer-vehicle crash in the State of Ohio, the average cost per crash for each severity type was averaged with a weighting factor to account for the relative occurrence for each severity type during the three-year period between 2017 and 2019 (data obtained from ODOT and highway patrol crash records). This method was also used in a research study in Virginia for a similar purpose to determine the comprehensive cost of wildlife crashes (Donaldson and Elliott, 2020). Following these procedures, the research team estimates that the average cost of a deer-vehicle crash in Ohio is $19,558.61 per crash. This value can be used by the Department for any deer crash related analyses and is also used elsewhere in this report to analyze the potential benefits of deer passage installation.

Table 8: Updated Estimated Deer-Vehicle Crash Costs for Ohio

Crash Type	3-Year Total (2017-2019)	3-Year Percent (2017-2019)	ODOT HSIP Value (Cost per Crash)
Fatal (K)	18	0.032%	$ 6,733,380
Disabling Injury (A)	192	0.345%	$ 357,038
Evident Injury (B)	1,427	2.561%	$ 130,433
Possible Injury (C)	1,144	2.053%	$ 73,536
Property Damage Only (O)	52,934	95.009%	$ 11,896
Total	**55,715**	**100.0%**	**$ 19,558.61**

In addition to the values presented in Table 8, analysis of the proposed deer passage installation follows ODOT HSIP guidelines to ensure consistency in statewide application. In particular, a discount rate of 4 percent is used per HSIP guidelines and a service life of 20 years, common for transportation projects, is assumed. Given these parameters, the anticipated cost of deer-vehicle crashes can be easily calculated for various crash frequency scenarios. To ensure an even comparison of the anticipated benefits with the construction costs, the present value of the annual crash costs is calculated for a 20-year service life and a discount rate of 4 percent. The "series present worth factor" commonly found in engineering economy textbooks (often denoted as $(P/A, i\%, n)$) is utilized for this purpose. For a discount rate of 4 percent and analysis period of 20 years, the series present worth factor is estimated to be 13.5903. This value is multiplied by the cost per crash and the assumed annual crash frequency to obtain the present value of the crash costs. These calculations are presented in Table 5 for a range of expected crash frequencies. The benefits that accrue to society as a result of the implementation of a specific safety project are related to the anticipated effectiveness of the specific project. For example, if a project is anticipated to reduce certain crashes by 50%, then the benefits to society resulting from the project (i.e., savings) are half of the total costs. Similarly, a project which reduces crashes by 90% will have a savings equal to 90% of the crash costs. Following this procedure, the 20-year anticipated crash reduction benefits assuming an effectiveness of 50% and 90% are also presented in Table 5 for reference. For example, implementing a safety project with a 90% effectiveness rate in a location which experiences an average of 4 deer-vehicle crashes per year is estimated to generate a savings of $956,906.56 over a 20-year analysis period. The figures presented in Table 9 can be used to compare the present value of the construction cost for deer passages with the anticipated benefits.

Table 9: Estimated Crash Cost Savings for Various Scenarios

Average Number of Crashes	Present Value of 20-Year Crash Costs	Benefits Assuming 50% Effectiveness	Benefits Assuming 90% Effectiveness
1 per 3 Years	$88,602.46	$44,301.23	$79,742.21
1 per 2 Years	$132,903.69	$66,451.84	$119,613.32
2 per 3 Years	$177,204.92	$88,602.46	$159,484.43
1 per year	$265,807.38	$132,903.69	$239,226.64
2 per year	$531,614.75	$265,807.38	$478,453.28
3 per year	$797,422.13	$398,711.07	$717,679.92
4 per year	$1,063,229.51	$531,614.75	$956,906.56
5 per year	$1,329,036.89	$664,518.44	$1,196,133.20
6 per year	$1,594,844.26	$797,422.13	$1,435,359.84
7 per year	$1,860,651.64	$930,325.82	$1,674,586.48
8 per year	$2,126,459.02	$1,063,229.51	$1,913,813.12
9 per year	$2,392,266.40	$1,196,133.20	$2,153,039.76
10 per year	$2,658,073.77	$1,329,036.89	$2,392,266.40

The final component of the economic analysis is the present value of the construction costs plus annual maintenance. It is anticipated that some annual maintenance (assumed value of $2,000) will be necessary to keep the passage in good working condition. Assuming a 20-year analysis period with a discount rate of 4% and an inflation rate of 2%, the present value of these annual costs is $32,200 (rounded up to nearest $100). This amount is added to the construction costs (reported in Table 5) to yield the present value of the total investment.

Table 10: Present Value of Construction and Maintenance Costs

Scenario	Passage Length	Present Value of Costs	
		One Side	Two Sides
Scenario #1	Any	$54,000	$68,800
Scenario #2	20-30 Feet (2-Lane Bridge)	$62,200	$85,000
	30-45 Feet (3-Lane Bridge)	$66,200	$93,200
	45-60 Feet (4-Lane Bridge)	$70,300	$101,300
Scenario #3	20-30 Feet (2-Lane Bridge)	$68,300	$97,300
	30-45 Feet (3-Lane Bridge)	$73,100	$106,800
	45-60 Feet (4-Lane Bridge)	$77,800	$116,300