CHAPTER 7

CULVERT RETROFIT DESIGN

LIST OF FIGURES

7 CULVERT RETROFIT DESIGN

7.1 Design Method Applicability

The most effective solution for improving fish passage through an existing culvert is to replace it with a new structure designed using relevant fish passage design criteria. However, there are cases in which culvert replacement is difficult to justify, such as when the existing culvert is relatively new and has a significant remaining design life, or when there are plans to replace the culvert 5 or 10 years in the future as part of other planned roadway improvements. In such cases, a decision may be made to improve fish passage through the existing culvert to the extent possible, using culvert retrofit methods as described in this chapter.

When selecting a method for retrofitting a culvert to improve fish passage, the first step is to determine why the culvert is a fish passage barrier. If flow depths are too shallow in the culvert barrel, then baffles or weirs may need to be installed to create small pools (Figure 7-1a). If flow velocities are too high through the length of the barrel, then baffles may provide additional roughness and turbulence that disperses some of the excess energy (Figure 7-1b). In some cases, baffles can serve both functions, increasing flow depth during low flow conditions and reducing velocities under higher flow conditions.

a) b)

Figure 7-1. Applications for the use of culvert retrofit design include a) adding depth and b) adding roughness. (Photos courtesy of WDFW and Caltrans)

In some cases, poor passage conditions in the barrel may be further mitigated by increasing the level of the tailwater at the culvert outlet, using grade control structures such as rock weirs. Grade control techniques are also used if the culvert outlet is elevated above the water surface of the stream, due to original design intent or due to channel erosion or degradation occurring since original culvert installation. The design of grade control structures is addressed in Chapter 8. In extreme cases when the culvert outlet is several feet above the water surface of the stream, a fishway may need to be constructed at the downstream end of the culvert to allow fish to enter the culvert. An overview of fishways is presented in Chapter 9.

In engineering literature, the term “weir” is commonly applied to structures that divert the flow or control the level of a waterway. A “baffle” is a device used to control or impede the flow of something and reduce its force. When a structure is designed to serve as a weir within a culvert, it may act more as a baffle once it is submerged, and conversely a structure designed to serve as a submerged baffle may effectively become a weir under low flow conditions. In this chapter, an effort is made to use the precise term when it is important to distinguish the function or the design approach for the structure. In more general discussions, however, the terms may be used interchangeably as a means to avoid repetitive listings of the two types of structures.

Figure 7-2 shows two views of a culvert retrofit project completed at Crooked Creek in Mono County, California. The left photo shows a longitudinal weir installed through the length of the flat bottom culvert to narrow the low flows and increase depth for fish passage. The right photo shows concreted rock weirs at the outlet end that provide a stepped pool transition to the stream below.

Figure 7-2. Longitudinal channel weir and grade control rock weirs at the Crooked Creek retrofit project.

7.1.1 Retrofit Limitations

In the fisheries community, there is considerable debate as to whether baffled culverts are effective at improving fish passage on a long-term basis. A baffled culvert clogged with sediment or debris may temporarily reduce the fish passage effectiveness in comparison to the original open-barrel configuration (Figure 7-3a). Baffles installed with insufficient anchoring may dislodge during flood events and make the debris situation even worse (Figure 7-3b). Sites being evaluated for potential retrofit action that have high debris loading should give strong consideration to NOT construct baffles. Similarly, if there is a high degree of uncertainty as to whether there is available hydraulic capacity in the culvert, it may be better to reject any consideration of baffles.

a) debris caught on baffle

b) failure due to insufficient anchoring

Figure 7-3. Baffles can contribute to passage problems. (Photos courtesy of WDFW)

The following situations describe some of the potential limitations of a culvert retrofit that should be considered during the design process:

- Any obstruction inside a culvert, including baffles and weirs, generates the potential for accumulation of debris and sediment. Weirs constructed with sharp edges and Vs, in particular, will tend to trap organic matter. In general, the lower and smoother the weir, the lower the potential for debris accumulation.
- The space occupied by the baffles or weirs, in conjunction with debris and sediment accumulation, can significantly reduce the flow capacity of the culvert.
- Baffles should generally not be considered for circular culverts less than 3.6” in diameter, due to difficulties accessing the culvert interior for installation and maintenance.
- The design life of baffles is typically substantially less than for a new culvert. As a result, baffles may have to be replaced during the remaining life of the culvert. (At the same time, a factor that leads to baffle installation is frequently that the culvert is nearing the end of its design life, and the baffles are intended to enhance passage during the interim period until the culvert is replaced.)
- Baffled facilities will generally require more frequent monitoring and maintenance than open-barrel culverts. These increased costs should be included in any analysis of the life-cycle costs of the retrofit.

7.2 Retrofit Design Methods

7.2.1 Tailwater Control Weirs

Weirs located at the downstream end of an existing culvert are typically used to eliminate hydraulic drops at the outfall of the culvert. Additionally, tailwater control weirs are also used to increase flow depths in the culvert during periods of low flow to facilitate fish passage. Depending on the length and slope of the culvert and the height of the downstream weir, improvements can be realized for all or just a portion of the culvert.

Tailwater control weirs offer an advantage over baffles in that they are located outside the culvert barrel. Due to the more open expanse of a tailwater control weir, they are likely to exhibit lower risk of severe debris jamming than might occur with baffle weirs located inside the culvert barrel. In cases where debris jams occur, the maintenance requirement is likely to be more easily accomplished at the exterior tailwater control weir. As a first step in any retrofit design, it is strongly recommended that tailwater control weirs be evaluated first to determine whether they can accomplish the fish passage remediation without the need for baffles. Chapter 8 provides more information regarding the design of tailwater control weirs and other grade control measures to facilitate fish passage.

7.2.2 Baffles

Baffles can be installed in culverts to function primarily as weirs to increase flow depth, or to add roughness elements as a measure to reduce flow velocity. Regardless of their functional objective, it is important to recognize that baffles will exhibit different flow characteristic under low and high flow conditions. During low flow conditions, baffles will exhibit a step-pool effect with plunging flow characteristics. During high flow conditions, there will be streaming flow characteristics occurring in the flow above the baffle crests, while “hydraulic shadows” are created at the downstream face of the baffles (Figure 7-4).

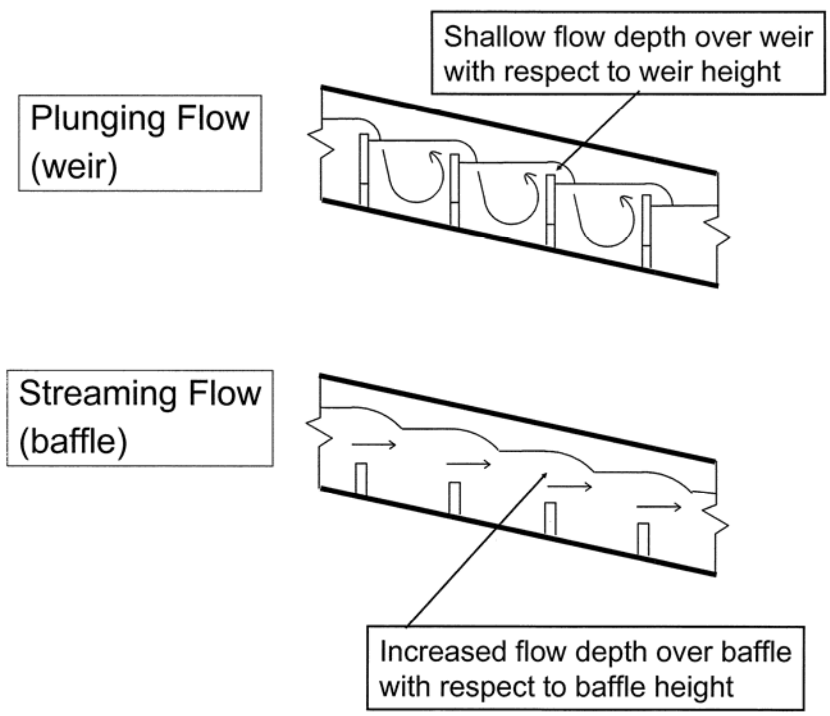

Figure 7-4. Baffles will exhibit plunging flow or streaming flow characteristics depending on the flow depth over the baffles. (WDFW 2003)

7.2.3 Roughened Channel within Culvert

Flow depths can be increased and average culvert velocities can be reduced through the introduction of bed material on the interior of the culvert. This process involves placing hydraulically stable material inside the culvert. This method requires considerable hydraulic engineering expertise, and the District Hydraulic Unit should be contacted early in the preliminary design stage if this design option is to be evaluated.

7.3 General Retrofit Design Process Overview

The design process for culvert retrofits consists of several basic elements, as shown in the list below. The broader design components as shown in the list are discussed in the following sections of this chapter. See Appendix M for a culvert retrofit design example.

1. Collect engineering data.
    - Confirm the maximum allowable headwater elevation.
    - Determine outlet pool and tailwater conditions
    - Determine the maximum acceptable 100-year flood discharge velocity for stability of the existing channel.
2. Identify the retrofit culvert design criteria.
3. Complete the design flow determinations for high fish passage flow, low fish passage flow, and 100-year flow.
4. Enter data regarding the culvert configuration being analyzed. (The existing conditions for the culvert and channel are used for the first iteration.)
5. Conduct the hydraulic analysis.
    - Identify flow depths and average velocities in the culvert at the high and low fish passage flows and compare to the limiting values.
    - Compute the 100-year discharge velocity and headwater depth and compare to the limiting value.
6. Evaluate the tailwater condition (i.e. develop a tailwater rating curve). Adjust tailwater configuration as needed through grade control measures. (Refer to Chapter 8 for guidance on grade control design.) Return to Step 4 unless no further tailwater adjustments are required.
7. Evaluate the barrel condition. Adjust configuration as needed by adding baffles. Return to Step 4 unless no further baffle adjustments are required.
8. Repeat steps 4 through 7 until the optimal configuration is identified.

The sequence for completing the first three steps can vary to some extent, as these steps include data collection and assessment activities that in some cases are independent of one another. Steps 4 through 8 reflect the iterative process that conducts the hydraulic analyses and optimizes the design. See Appendices F, G and J for detailed information for the design of baffles, in addition to Appendices K and N for detailed information on rock weir design.

7.4 Retrofit Design Elements

7.4.1 Data Collection

7.4.1.1 Existing Culvert Design Records

Many (but not all) of the culverts that become the subject of a Caltrans retrofit project should have documentation relating to their original design and installation. These documents should be reviewed initially to determine the extent of the information and to identify key design criteria used for the original design. While this information may provide insights in to the original design, none of the existing information should be used directly without a) completing a field verification of the existing condition of relevant items and b) reviewing the accuracy and current applicability of the methods and calculations used for design. Examples of existing culvert design data that should be obtained and verified include:

- Culvert length
- Culvert slope. Field assessment should investigate the presence of any settling or sagging within the culvert.
- Culvert diameter (or other relevant dimensions for non-circular culverts). Field assessment should investigate the presence of embedment material and any warping within the culvert.
- Culvert material and current condition of roughness. The depth and spacing of pipe corrugations should be verified when present.
- Culvert basin information, including any assumptions regarding land cover and developed area within the basin.
- The calculated or assumed elevation for allowable headwater.
- Calculated outlet velocity and assumptions used in designing slope protection, where present.

7.4.1.2 Site Assessment Data

Existing conditions at the project site must be assessed and, where appropriate, compared to conditions described for the original design. Prior to conducting field visits, it will be beneficial to review existing fish passage evaluations that may have been completed previously; the designer should check for their existence with the District Environmental Unit and obtain copies if available.

See Chapter 3 for guidance regarding data collection for the following items:

- Channel Topography
- Channel Stability
- Acceptable Outlet Velocity

7.4.1.3 Fish Passage Criteria

Fish passage criteria described by CDFG (2002) and NOAA-SWR (2001) classify culvert retrofit projects under the Hydraulic Design Option category. The fish passage criteria for this option require identification of the target species. Contact the District Environmental Unit early in the preliminary design stage if there is any uncertainty regarding the target species for a specific project.

Criteria for the Hydraulic Design Option also specify the methods for determining the low fish passage flow rate and high fish passage flow rate. The CDFG criteria are shown in Appendix B and the NOAA-SWR criteria are shown in Appendix C.

For a culvert retrofit project, however, it is recognized that velocity conditions within the existing culvert barrel may not be capable of being modified to the extent that would satisfy maximum average water velocity criteria used for new and replacement culverts. It is recognized that, in some cases, fish passage can be significantly improved for some species and life stages without fully meeting the hydraulic criteria. Therefore, for culvert retrofit projects, both CDFG (2002) and NOAA-SWR (2001) suggest that the same maximum average water velocity criteria used for new and replacements culverts should serve as the target for passage improvement and not the required design threshold. The velocity criteria are shown in Appendices B and C.

The existing conditions of a culvert retrofit project are unlikely to allow any significant reduction in the headwater level exhibited during the 100-year peak flood flow. As a result, if the HW/D ratio of the existing culvert is greater than 1.5, there is little likelihood of satisfying the CDFG criterion stating that the upstream water surface depth above the top of the culvert inlet for the 100-year peak flood shall not be greater than 50 percent of the culvert rise. Similar to the criterion for the maximum average water velocity, the HW/D criterion is generally considered a target for passage improvement and not the required design threshold.

7.4.2 Hydrologic Analysis

A hydrologic analysis needs to be performed using methodologies outlined in Chapter 3. As outlined in the fish passage criteria (CDFG 2002, NOAA-SWR 2001), design flows for high fish passage flow can be determined using either the Annual Exceedance Flow (AEF) or a percentage of the 2-year recurrence interval flow (Q2). If detailed stream records are available at the project area, the determination of AEF may be appropriate. However, in most cases flow records will not be available, in which case it will be necessary to determine the Q2 through other methods.

7.4.3 Hydraulic Analyses

Use of the hydraulic design option for culvert retrofit projects requires that hydraulic analyses be completed to assess water depths, drops in the water surface profile, and flow velocities in the culvert and the adjacent channel, and to determine the headwater elevation at the culvert entrance. Several types of hydraulic design methods are acceptable for these determinations, varying in their complexity and level of accuracy. See Appendices F and N for more information on hydraulics analyses associated with baffle and rock weir design.