CHAPTER 8

GRADE CONTROL DESIGN

LIST OF FIGURES

8 GRADE CONTROL DESIGN

8.1 Grade Control Applicability

Grade control structures are used in fish passage culvert projects to enhance fish passage conditions in the stream channel upstream and downstream of the culvert, as well as in the culvert itself. The four most common uses of grade control structures are to:

- Increase the water depth a channel or culvert barrel,
- Raise the downstream channel up to the level of the culvert, or bridge and
- Stabilize the channel streambed near the culvert or bridge.

A frequent reason for having to increase water depth is when the geometry of the stream channel or culvert barrel has a large cross sectional area, producing shallow water depths. This condition can be especially prevalent with existing culvert facilities having broad, concrete outlet aprons (Figure 8-1a); and with box culverts or any large diameter culvert, whether new or existing. Placement of a grade control weir can help insure a minimum water depth upstream of the weir. A low flow notch, sized to contain the fish passage low flow, is commonly used to focus the flow pattern and encourage sediment transport through the low flow fish passage condition.

Grade control structures are also used to raise the downstream channel up to the level of the culvert. A common condition requiring this type of remediation is when existing culverts have been undersized, resulting in scour holes at the culvert outlet (Figure 8-1b). The two approaches generally used to correct these elevation differentials are 1) grade control weirs, which use a series of separate structures to produce incremental small drops in the water surface, and 2) roughened channels.

a)

b)

Figure 8-1. Applications for the use of grade control design include a) sites with concrete outlet aprons and b) perched culverts.

A third condition requiring grade control measures may occur when the existing streambed channel has potential to rise (agrade) or lower (degrade) over the life span of the project. A common need for this may occur with culvert replacement projects, where a substantial amount of sediment has accumulated upstream of the existing culvert over many years. When a larger culvert replaces the existing culvert, there is potential that the accumulated sediment will wash away during high stream flow events, resulting in downcutting of the channel from its pre-remediation condition. In such cases, grade control structures might be installed at the time of culvert replacement to promote stabilization of the revised channel configuration.

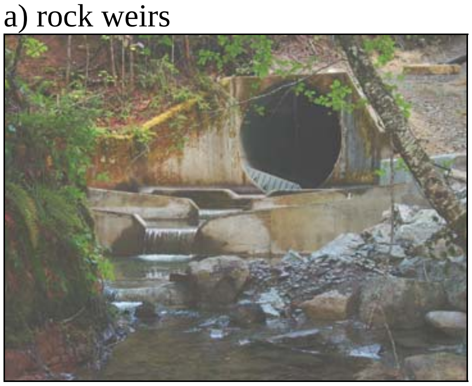
Retrofitting an existing culvert with grade control measures can be an attractive alternative to full culvert replacement. However, retrofitting an existing culvert with grade control structures may have unintended consequences. As an example, a project may propose the use of downstream weirs to improve stream depths at the outfall during periods of low flow. This downstream grade control structure may recruit bed material at the bottom of the culvert. While recruitment of this material may enhance fish passage, the conveyance capacity of the existing culvert may be reduced. This reduction can result in more frequent roadway overtopping and upstream flooding. Additionally, the ability for the existing culvert to pass debris during periods of high stream flow may also be reduced. Therefore, design criteria such as conveyance capacity and maintenance must be evaluated prior to full design and construction.

8.2 Control Structure Types

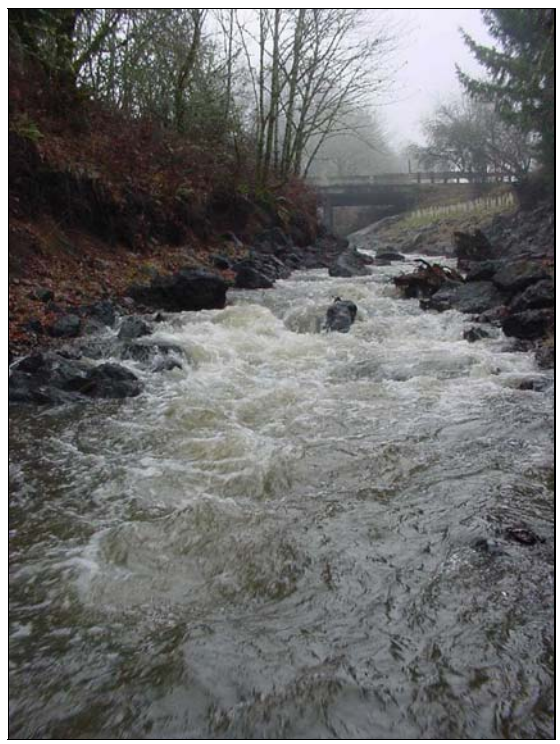
Three types of grade control structures most likely to be used for Caltrans projects (Figure 8-2):

- two types of grade control weirs: rock weirs or concrete weirs, and
- roughened channels.

a) rock weirs



b) concrete weirs



c) roughened channel

Figure 8-2. Common types of grade control structures.

8.2.1 Grade Control Weirs

Weirs are a common type of structure built in the channel to control the water surface profile. Weirs for Caltrans projects must be constructed to be as durable and long lasting as the road crossing structure they are associated with. Any loss or lowering of the grade control structures could result in a new fish passage barrier, or it could negatively affect the structural integrity of the culvert or road crossing structure.

Any grade control structures must anticipate future conditions and the probability that continuing channel incision will occur. Scour may occur below grade control structures. When grade control structures are built downstream of a perched culvert, some of the energy that was dissipated at the culvert is moved to the grade control structures. Downstream scour can be exacerbated if there will be substantial bedload infilling between grade control structures upstream. The last grade control structure downstream should always be at or below the existing streambed grade. Additional buried controls are recommended where there is significant variability in bed elevation or possible future incision is expected. Those controls would become exposed and effective only as the downstream channel incises.

When required, control structures upstream may either have rigid elevations or they might be designed with the expectation that they will gradually adjust over time. The choice depends on project objectives and considerations from the profile design section of this manual. All or part of the upstream headcut may in some cases be allowed to occur uncontrolled. Grade control structures must not be placed near the culvert inlet. If the energy dissipated below the structure scours the culvert bed, the entire culvert bed can be affected and in some cases, entirely washed out of the culvert. The recommended distance to the nearest upstream control is a function of channel width and slope. In channels with slopes up to about four percent and with widths between ten and twenty feet, the upstream control should be thirty to forty feet from the culvert inlet. In steeper channels, pools are naturally more closely spaced. Spacing upstream of a culvert might be three times the stream width or a minimum of 25-feet apart.

8.2.1.1 Rock Weirs

Rock weirs have been used in recent years to backwater perched culverts and low dams. Their durability and passage effectiveness depends to a very large degree on the size and quality of material used, the care and skill of the hand labor or equipment operator, supervision, and equipment used to place the rocks. It should be noted that boulder weirs carry the risk of domino failure. If one weir within a series of weirs fails, the risk of additional weir failures is increased. Due to the potential for a domino style failure, construction quality at each structure is critical.

To create a permanent structure, rock should be durable and of a shape that allows individual rocks to be keyed together. Boulders with somewhat of a rectangular form are much more stable than round boulders. Specific rocks should be selected for boulder weirs, and the placement of each rock should be done carefully with an understanding of the design concept. See Appendix N for rock weir profile and cross section examples, as well as design procedures.

8.2.1.2 Concrete Weirs

Concrete weirs are grade control structures that can be used to control the channel profile quite precisely. An advantage of concrete weirs is they can often be built at a steeper slope than rock weirs, therefore minimizing the footprint of a project. Concrete weirs are usually considered less desirable for fish passage than rock weirs, due to the lack of complexity and diversity in their structure. Full channel-spanning concrete weirs lack the variety of passageways that stream simulation provides and therefore do not comply with the premise of stream simulation.

Precast concrete weirs are a subset of the concrete weir grade control design. Advantages of a precast design are they can be precisely manufactured so that they seal well, have a varied cross-section similar to the natural channel, and have a crest shape that is specifically designed for fish passage. Another precast concrete design includes a weir, stilling basin, and wing walls in a single precast unit.

8.2.2 Roughened Channel

A roughened channel is a steep section of channel that has been engineered and constructed to provide sufficient roughness and hydraulic diversity to enable fish passage despite its steepness. A roughened channel provides grade control at a gradient steeper than the natural stream channel.

The bed material of a roughened channel is not intended to evolve as a natural channel with bed material scouring and replenishing; it is a fixed semi-rigid structure. Individual rocks are expected to adjust position and location but the larger grain sizes are not expected to scour out of the reach. As a result it may be steeper and have more severe hydraulic conditions than other sections of the stream.

Roughened channel designs use channel dimensions, slope, and material to create depths, velocities, low turbulence, and a hydraulic profile suitable for a target species to pass through. The rock used to provide a roughened channel must conform to rock sizing found in the *California Bank and Shore RSP Design* report.

8.3 Grade Control Design Process Overview

The design process for grade control design consists of several basic elements as follows:

1. Collect engineering data.
2. Identify the grade control design criteria.
3. Determine high fish passage flow, low fish passage flow, 50-year flow, and 100-year flow.
4. Conduct a hydraulic evaluation of the culvert conditions, focusing on the conditions at the culvert or bridge outlet and in the channel just downstream of the culvert/bridge.
5. Conduct a hydraulic analysis based on preliminary the preliminary configuration.
6. Size grade control material.
7. Re-assess hydraulic conditions based on final configuration.
8. Finalize design.

Note: See Appendix N for detailed steps in the rock weir design process.