Final Report

IDOT TR-750

DOCUMENTING THE DESIGN AND USE OF DIFFERENT TYPES OF GRADE CONTROL AT CULVERTS

Submitted to:

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Research and Technology Bureau
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This "state of the practice" report evaluates and summarizes current methods of grade control at culverts with photographic examples of each type of culvert grade control. It is intended to be used as a reference to help engineers in the preliminary design stage select the most cost-effective and constructible type of culvert grade control based primarily on the amount of grade needing controlled. While some culvert projects are designed to include grade control to achieve hydraulic efficiency and capacity at the inlet or to dissipate energy at the outlet, here we give engineers an end product to shoot for to reverse engineer a culvert that requires a significant drop in elevation. This publication does not replace other design considerations, methodologies, guidance, or manuals.</td></tr>
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1. INTRODUCTION

1.1 Problem Statement and Background

Counties in western Iowa are affected by widespread stream channel degradation, and due to time, staffing, and budgetary restrictions, often don't have the time to research the most cost-effective method of grade control appropriate for small drainage basins, generally associated with roadway culvert crossings. While existing literature is sufficient in analyzing how to properly design a culvert after choosing what type of grade control will be used, there are no preliminary design aids available to easily compare different types of grade control for culverts.

The Hungry Canyons Alliance (HCA) was formed locally to research and implement solutions to widespread stream channel incision and erosion in a 19-county area of the deep loess soils region of western Iowa. Since 1992, the HCA has provided state and federal cost share to build grade control structures to protect county infrastructure. Over that time, the HCA has cost-shared on at least 175 culvert grade control structures. While weir structures have been the primary method of stream channel grade control on larger drainage basins, generally those associated with roadway bridge crossings, the method of grade control appropriate for smaller drainage basins, generally associated with roadway culvert crossings, is less clear. It is apparent that county road departments often consistently use the same types of culvert grade control, becoming experts at one or two types of culvert grade control, probably because they have become comfortable with those types of practice, but also because time, staffing, and budgetary restrictions deny them the ability to research other cost-effective methods. Regardless, roadway managers have found significant benefits to both the roadway and adjacent lands when stream channel grade control is incorporated in roadway culvert crossings, and the practice has been gaining in popularity over the last ten years.

A review of current culvert design manuals shows a wealth of information on how to properly design a culvert before choosing what type of grade control will be used, however there are no simplified preliminary design aids available to help engineers easily compare different types of grade control for small drainage basins (Iowa DOT, 2018, FHWA, 2006 and 2012). The USDA-NRCS has a simplified chart of the most economical grade control structure for small drainage basins as a function of grade controlled and discharge (USDA-NRCS, 1984) (Fig.1). Having a similar simplified chart or decision-making tool would help engineers select a cost-effective type(s) of culvert grade control in the preliminary design stage. This could be especially useful for engineers who are unfamiliar with all of the options available.

Roadway culvert grade control can either be added to an existing culvert installation or included as an integral component of a culvert replacement project. Grade control associated with a culvert can be accomplished in one of three methods: 1) at the inlet utilizing some form of a riser, 2) through the culvert itself, or 3) at the outlet utilizing some form of a flume and/or stilling basin. There are also three scenarios when grade control needs to be considered at culverts: either 1) the culvert being replaced/amended already controls a significant amount of grade, 2) the culvert is supposed to create a ponded condition upstream of the culvert, or 3) erosion upstream or downstream of the culvert makes controlling grade a necessary or reasonable function of the culvert.

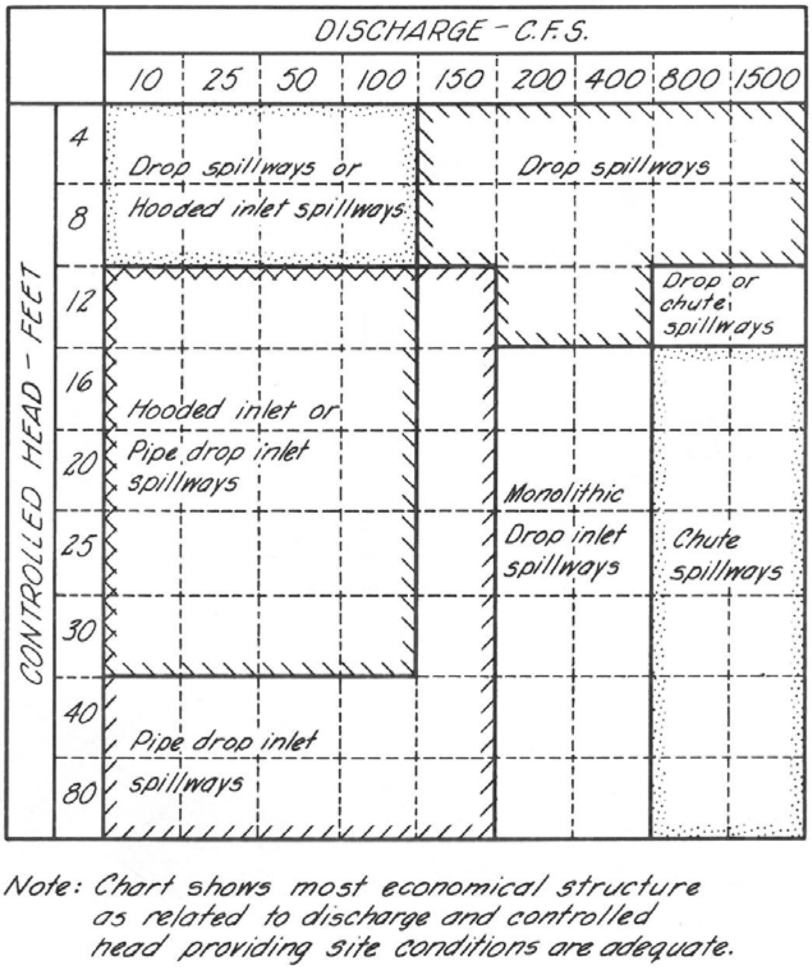


Figure 1. General guide to waterway grade control structure selection.
From the USDA-NRCS National Engineering Manual, Part 650 –
Engineering Field Handbook. Chapter 6 – Structures, figure 6-4.

Engineers have a number of variations of grade control associated with culverts that they can, and should, consider:

1. Variable slopes within all culvert types
2. Drop inlets on a culvert (3 material types)
3. Reinforced concrete weir inlet on an RCB culvert
4. Broken-back culvert (2 material types)
5. Sloped or slope-tapered inlet RCB culvert
6. Flume outlet RCB culvert
7. Slope-tapered inlet and flume outlet RCB culvert
8. Armored sloped outlet (often with grouted riprap) and stilling basin
9. Weir/drop spillway/chute downstream from culvert outlet
10. Low-water crossing with culvert(s)

An analysis of 175 HCA cost-shared culvert grade control projects, grouped and graphed as a function of drainage area (a proxy for discharge) and the amount of grade controlled, yields Figure 2. This document will not break out examples of variable slopes within all culvert types.

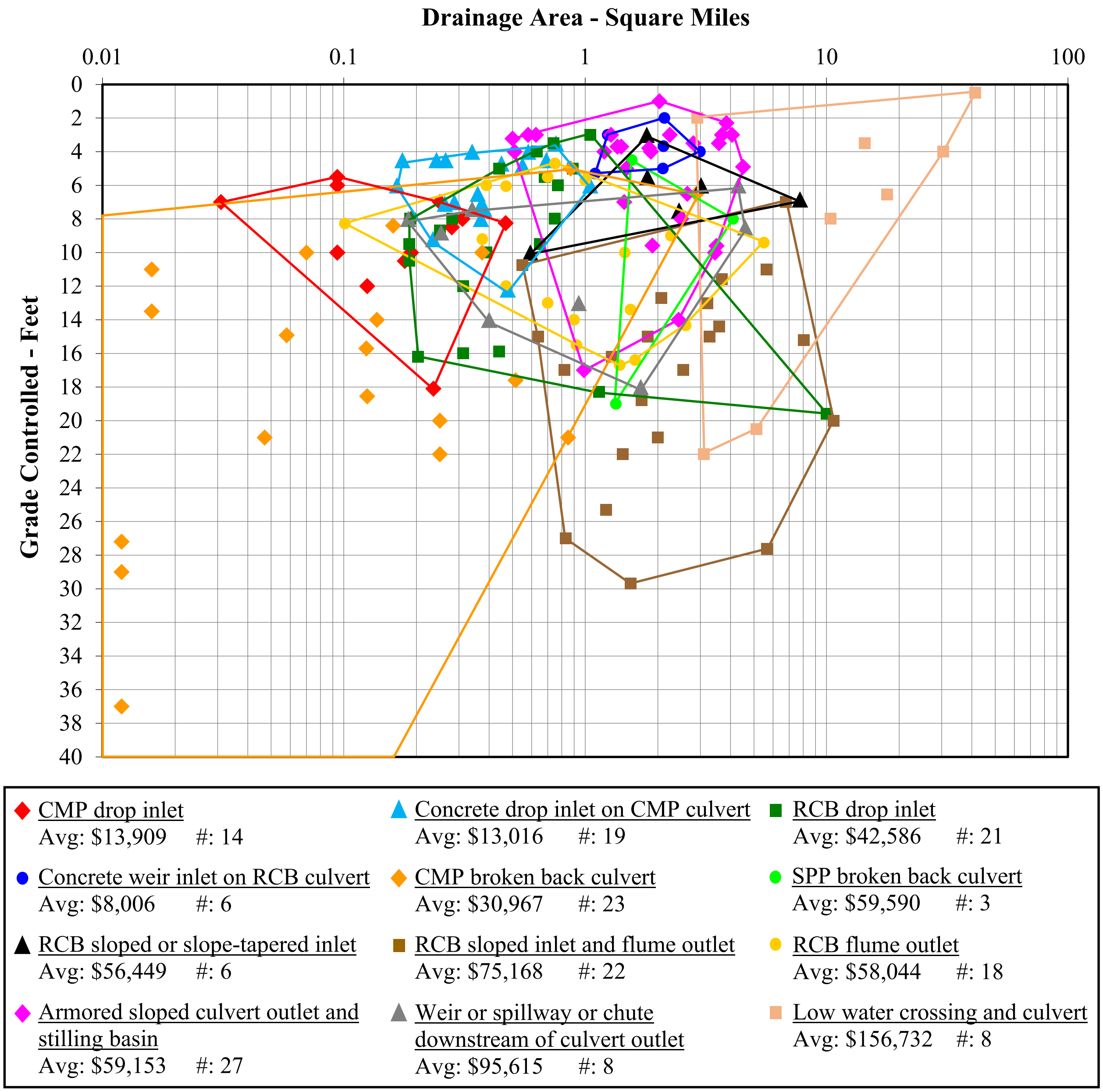


Figure 2. Minimum convex polygons outline the range of observed values of drainage area and grade controlled by culvert grade control type. Avg is the average grade control cost for that project type. # is the number of projects of that type the HCA has cost-shared on.

However, recommending a specific type of culvert grade control based on discharge (drainage area) and grade controlled alone is not feasible because there are many other factors that should be considered when deciding which method to choose, including but not limited to: roadway type and ADT, replacement vs. add on to existing, material costs, site conditions, total project costs, constructability, anticipated structure life expectancy, and anticipated long-term maintenance. Although, it does beg the question if there are ways to assist engineers with type selection in the early decision-making process.

1.2 Purpose

The purpose of this publication is to create a “state of the practice” report evaluating and summarizing current methods of grade control at culverts with photographic examples of each type of culvert grade control. It is intended to be used as a reference to help engineers in the preliminary design stage select the most cost-effective and constructible type of culvert grade control based primarily on the amount of grade needing controlled. Many culvert projects are designed with grade control to achieve hydraulic efficiency and capacity at the inlet or to dissipate energy at the outlet; here, we instead give some guidance on how to reverse engineer a culvert that requires a significant drop in elevation by giving the designer an end product to shoot for as they continue through the design process. This publication does not replace other design considerations or guidance, such as hydraulic, hydrologic, geomorphic, or structural methodologies or manuals.

2. EVALUATION OF TYPES OF GRADE CONTROL AT CULVERTS

Each type of culvert grade control will have sections on general description, best usage, advantages, limitations, and examples. The statements regarding each type are generalized based on the HCA’s and member county engineer’s experiences using these structures in loess soils. Some structures represented in Figure 2 will fall outside these generalized guidelines, but typically the reason for this is that they combine multiple types of culvert grade control, whereas this analysis has lumped structures based on the dominant structural type.

However, recommending a specific type of culvert grade control based on discharge (drainage area) and grade controlled alone is not feasible because there are many other factors that should be considered when deciding which method to choose, including but not limited to: roadway type and ADT, replacement vs. add on to existing, material costs, site conditions, total project costs, constructability, anticipated structure life expectancy, and anticipated long-term maintenance. Although, it does beg the question if there are ways to assist engineers with type selection in the early decision-making process.

The projects selected for inclusion in this report are representative of similar ones done of that type in that county. Preference for inclusion was given to projects completed recently and those with good before and after photos. However, not all projects have good photographs of the site before construction. Many of the examples shown herein have drainage areas between 0.25 and 2.5 square miles – an order of magnitude – to better compare project types to show tradeoffs between initial costs, constructability, and long-term maintenance costs.

A new regulatory tool entitled the State of Iowa Stream Mitigation Method (ISMM) was enacted in June 2017 by the U.S. Army Corps of Engineers and was developed to help standardize mitigation decisions during the COE permit process (USACE, 2017). Culvert projects that cause the loss of stream function, such as creating a pool more than 300 feet in length where there was once stream corridor and/or preventing fish passage, will likely require compensatory mitigation. At this time, existing culverts are considered “grandfathered in” and could only be subject to compensatory mitigation if significant modification or new construction requires USACE review as part of a permit application.

2.1 Variable slopes within all culvert types

The most basic form of culvert grade control can be accomplished with culverts by sloping the culvert barrel through the roadway. Generally, the slope of a culvert approximates the natural stream slope. When the slope of a box culvert exceeds approximately 2%, some type of energy dissipater, such as a drop inlet, flume outlet, or basin, should be considered to minimize outlet velocities. Most culverts are designed with a barrel slope for hydraulic reasons. As such, this publication will not go into further detail on this type of culvert grade control.

2.2 Drop inlet on a culvert

Description

A drop inlet is a pipe or rectangular box open at the top and directly connected to a culvert. Storm runoff enters, and drops to an apron, and empties into the culvert. A drop inlet can be installed on the upstream end of a culvert as part of a new culvert, or it can be attached to the upstream headwall of an existing culvert.

Uses

1. Grade stabilization of small ephemeral streams, like grassed waterway outlets at the edge of fields, or very small intermittent or perennial streams.
2. Can eliminate gullies in or near the roadway upstream of the culvert.
3. Can provide a stable outlet for tile lines.
4. Reservoir spillway where the total drop is relatively low.
5. Elevation control of irrigation water.

Advantages

1. Relatively easy to construct and can be cast-in-place or precast. A county culvert crew should be able to easily tackle drops less than 6 feet.
2. Often, the most economical structure for controlling grade.
3. With the flow elevation dropping on the upstream side of the culvert, the flow has time to dissipate excess energy within the culvert before it emerges, limiting the scour potential and long-term maintenance on the downstream side of the culvert.
4. Useful when a culvert has limited available head upstream.
5. If using a reinforced concrete box (RCB) drop inlet, the crest of the box can be lengthened to create lower headwater depth and increase energy dissipation, even within a narrow waterway.
6. Can minimize the ROW required by raising the ditch grade.
7. Very stable with the likelihood of serious structural damage far less than for other types of structures.

Limitations

1. Sufficient storage must be present upstream of the roadway after drop inlet installation, such that the likelihood of the road overtopping is not increased.
2. Replacing an existing culvert with one set at a lower elevation in order to accommodate a drop inlet, especially for drops greater than 8 feet, may offset other savings due to increased dewatering expenses.
3. When the total drop exceeds 10-12 feet, it may be more costly than other types of structures, such as broken-back corrugated metal pipe (CMP) culverts.
4. Will not allow aquatic organism passage.

2.2.1 CMP drop inlet on a CMP culvert

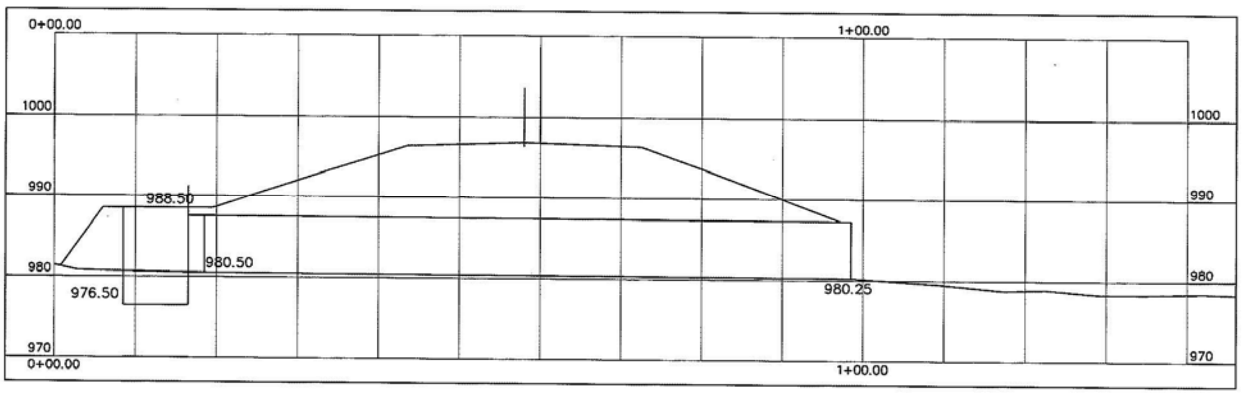
A corrugated metal pipe (CMP) drop inlet on a CMP culvert is the most basic, easiest to construct, and cheapest type of drop inlet. However, CMP drop inlets have a relatively limited range of use, with drainage area less than 0.5 mi^2 and grade controlled less than 12 feet.

Examples – The following four examples were chosen to show a range of different combinations of drainage area and situation: replacement of a failed culvert, a bridge replacement, a culvert replacement at a lower elevation, and a culvert extension with progressively smaller drainage areas. All four projects will help control gully erosion upstream.

1. County: Woodbury
HCA number: 11-3-F
Drainage area: 0.468 mi^2
Grade controlled: 8 feet
Total cost: $23,820
Grade control cost: $3,551
Contractor: Woodbury County
Completed: February 2011
Life expectancy: 30-50 years
Description: Failed CMP culvert replaced with an 84" CMP culvert and a 96" drop inlet to control gully erosion upstream.

Failed roadway before

Inlet looking upstream before



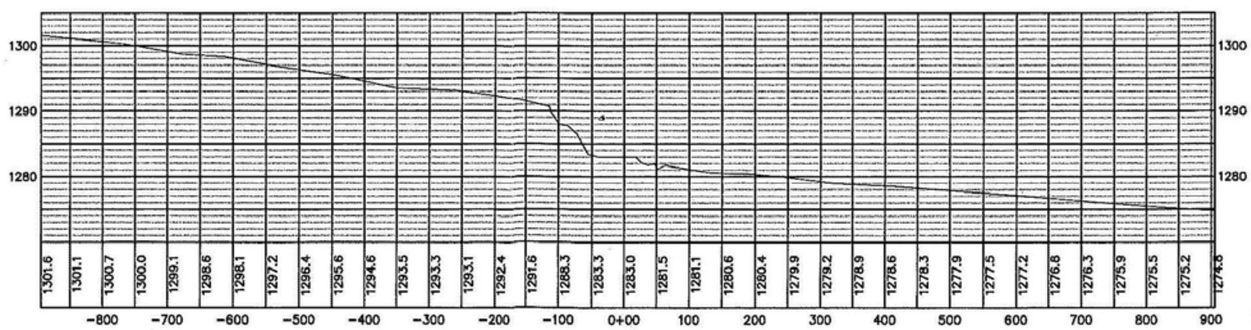
Drop inlet after

Into drop inlet after

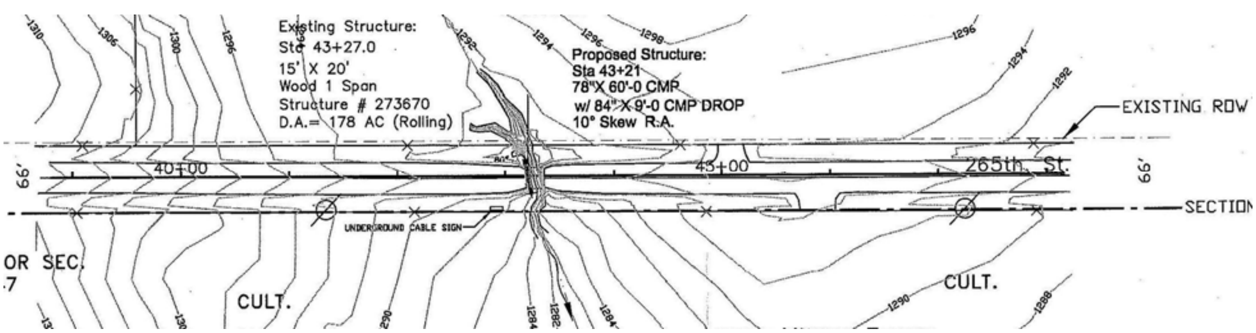
2. County: Plymouth
HCA number: 06-22-F
Drainage area: 0.28 mi^2
Grade controlled: 8.2 feet
Total cost: $20,423
Grade control cost: $7,250
Contractor: L.A. Carlson
Completed: June 2007
Life expectancy: 30-50 years
Description: Small bridge with a gully upstream replaced with a 78” CMP culvert and an 84” drop inlet (the stream profile is centered on the old bridge).

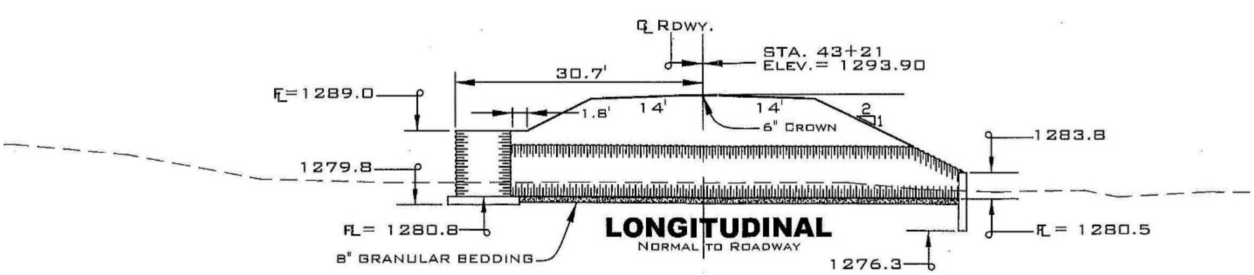
Looking upstream through bridge toward gully before

Looking upstream through culvert toward drop inlet after



STREAM PROFILE

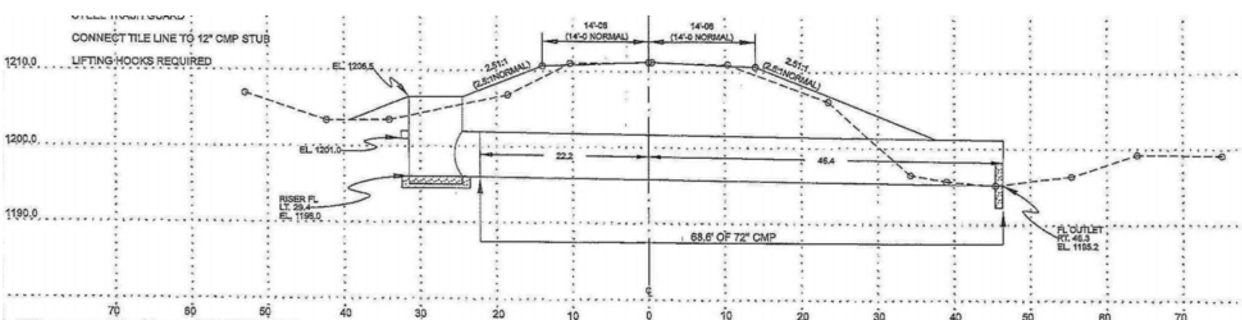




3. County: Crawford
HCA number: 17-7
Drainage area: 0.179 mi^2
Grade controlled: 10.5 feet
Total cost: $6,436
Grade control cost: $6,436
Contractor: Crawford County
Completed: November 2017
Life expectancy: 30-50 years
Description: CMP culvert with undercut outlet and small gully upstream replaced with a 72” CMP culvert set to a lower elevation and an 84” CMP drop inlet to control both grade issues.


Inlet before

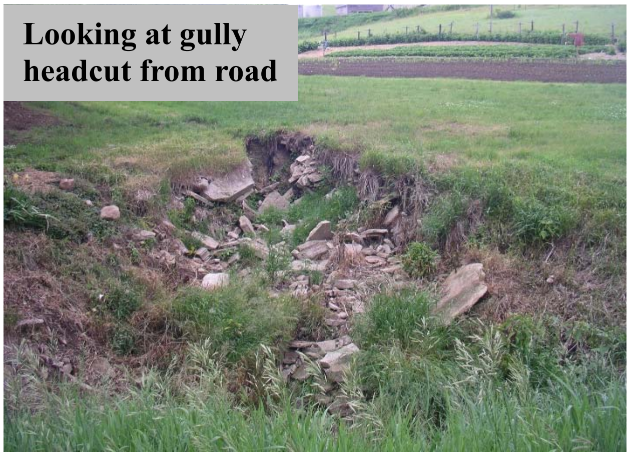

Undercut outlet before



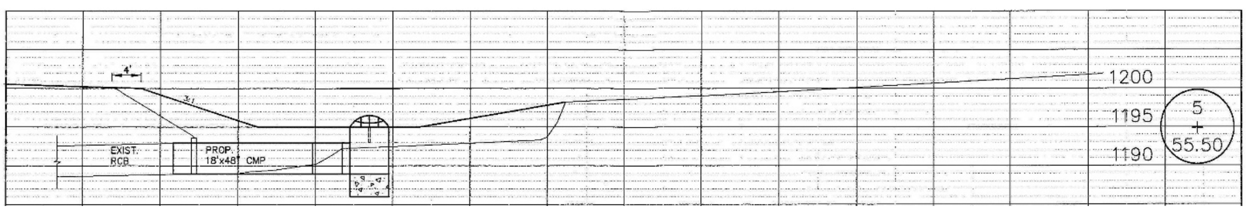

Drop inlet after

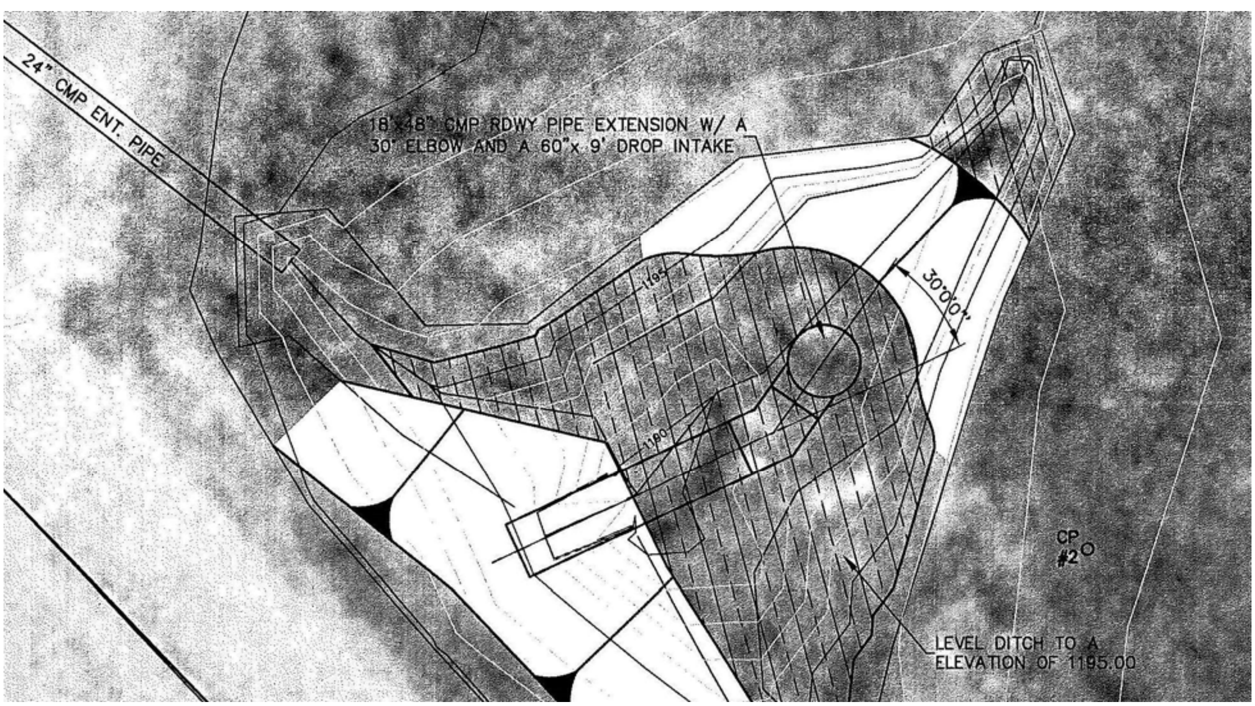

Outlet after

4. County: Woodbury
HCA number: 09-5
Drainage area: 0.094 mi^2
Grade controlled: 6 feet
Total cost: $8,533
Grade control cost: $8,533
Contractor: Woodbury County
Completed: January 2014
Life expectancy: 30-50 years
Description: Existing 48" RCB culvert extended with a 48" CMP culvert and a 60" drop inlet to control active gully upstream.



Materials: 18' of 48" CMP Culvert, 30 degree elbow (48"), 60" drop inlet 9' long with 48" stub, 62" ID drain cover (trash rack), 100 pounds of seed, 4 cubic yards of ballast (concrete or grout).





2.2.2 RCB drop inlet on a CMP culvert

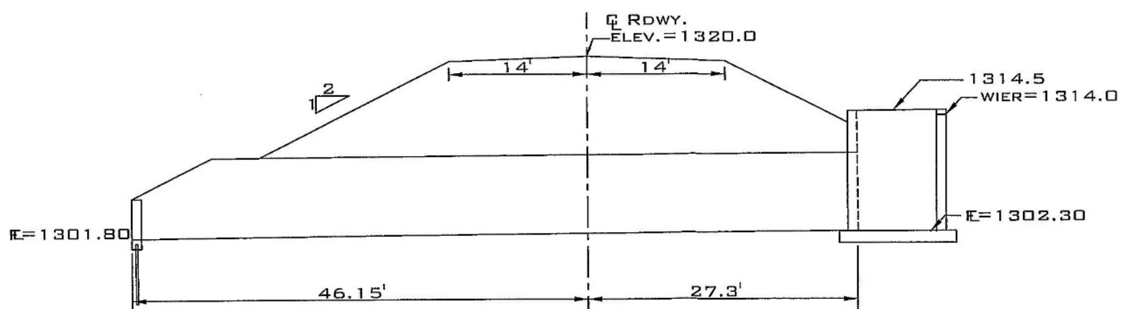
A reinforced concrete box (RCB) or pipe (RCP) drop inlet installed on a corrugated metal pipe (CMP) culvert is also a relatively basic, easy to construct, and cheap type of drop inlet. It can be cast-in-place or precast and easily attached to an existing or new culvert. However, RCB drop inlets added to CMP culverts also have a relatively limited range of use, with drainage area less than 1.0 mi^2 and grade controlled less than 12 feet.

<u>Examples</u> – The following three examples were selected to showcase the basic design, a range of drop height, and cast-in-place vs. precast.

1. County: Plymouth
HCA number: 15-2
Drainage area: 0.478 mi^2
Grade controlled: 11.7 feet
Total cost: $62,068
Grade control cost: $32,753
Contractor: Richards
Completed: December 2015
Life expectancy: 40-50 years
Description: Small bridge replaced with a 96” CMP culvert and a 10’ x 8’ RCB drop inlet to control gully erosion upstream.

Looking downstream over gully headcut and toward bridge before

Looking upstream through bridge toward gully headcut before



LONGITUDINAL SECTION

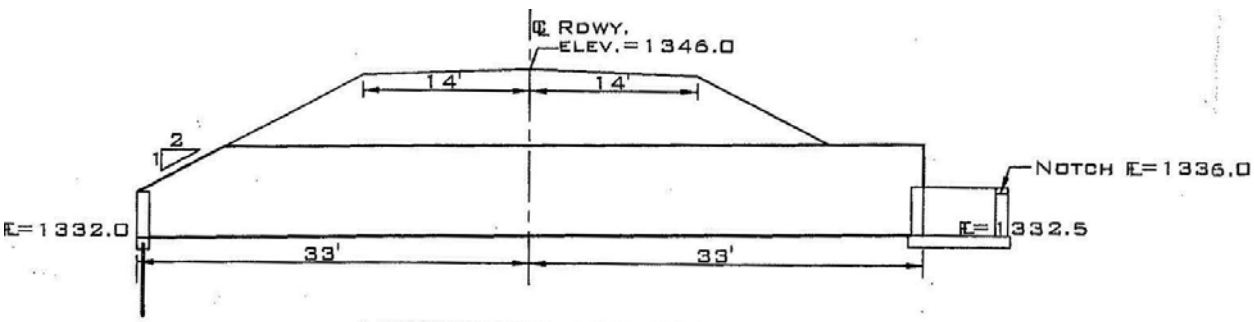
Drop inlet after

Into drop inlet after

2. County: Plymouth
HCA number: 06-23-F
Drainage area: 0.34 mi^2
Grade controlled: 3.5 feet
Total cost: $29,475
Grade control cost: $9,750
Contractor: Kooiker
Completed: June 2007
Life expectancy: 40-50 years
Description: Small bridge replaced with a 90” CMP culvert and a 10’ x 6’ RCB drop inlet to control gully erosion upstream.

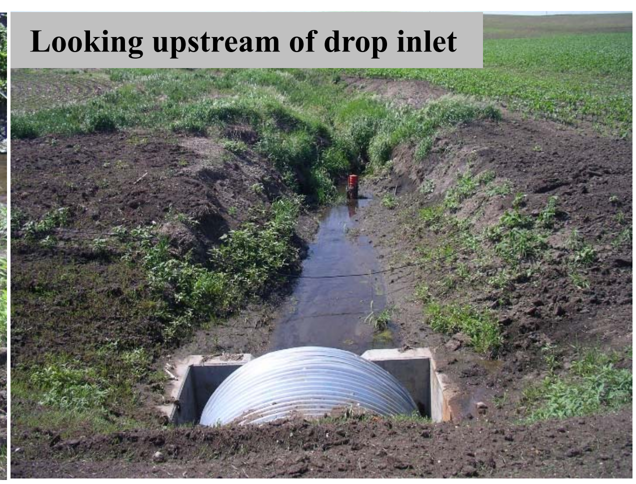

Looking upstream through bridge toward gully before


Looking upstream of bridge toward gully



LONGITUDINAL SECTION

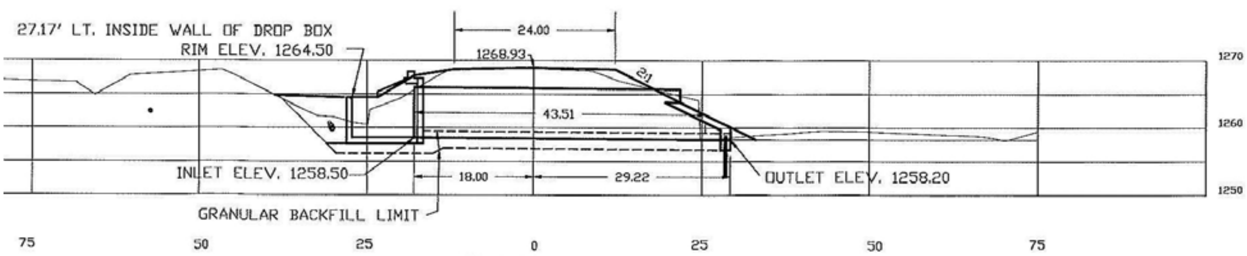

Drop inlet after


Looking upstream of drop inlet

3. County: Pottawattamie
HCA number: 12-3
Drainage area: 1.05 mi^2
Grade controlled: 6 feet
Total cost: $32,160
Grade control cost: $14,632
Contractor: Pottawattamie County
Completed: March 2013
Life expectancy: 40-50 years
Description: Existing CMP culvert replaced with a 90” CMP culvert and an 8’ x 6’ precast RCB drop inlet to control gully erosion upstream.


Looking at gully headcut from road


Failed road embankment at inlet as gully has grown



STA. 8+56.80, 0° Skew
DESIGN FOR 90" X 43.5' CMP WITH PRECAST DROP INLET

Drop inlet after


Looking upstream of drop inlet at filled gully after

2.2.3 RCB drop inlet on an RCB culvert

A reinforced concrete box (RCB) drop inlet installed on a reinforced concrete box (RCB) or pipe (RCP) culvert can be cast-in-place or precast and attached to an existing or new culvert. RCB drop inlets have more design flexibility than other drop inlets, and hence a greater range of construction difficulty. The simplest RCB drop inlet, one with less than 4 feet of grade control and less than 0.75 mi^2 drainage area, can be installed by a county culvert crew. On the other hand, an RCB drop inlet with more than 10 feet of grade control, more than 2.0 mi^2 drainage area, or replacing a flume bridge, also known as a Greenwood flume in western Iowa, will likely be much more difficult due to dewatering.

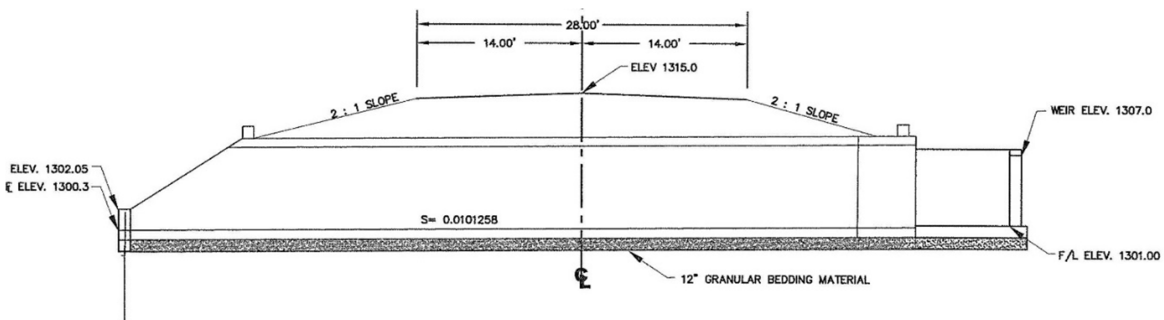
Examples – The following five examples were chosen to display the wide range of existing conditions that this type of design can accommodate: one small bridge replacement, one to control road ditch erosion, one to create a road dam/pond, one to replace a small flume outlet, and one to replace a large flume outlet.

1. County: Plymouth | HCA number: 16-6
Drainage area: 0.77 mi^2 | Grade controlled: 6 feet
Total cost: $101,698 | Grade control cost: $15,216
Contractor: Richards | Completed: September 2016
Life expectancy: 65+ years

Description: Small bridge with active gullies upstream replaced with a 12’ x 7’ RCB culvert and a 16’ x 8’ drop inlet.


Bridge and knickpoint upstream before


Side road ditch upstream of bridge eroding into road embankment



LONGITUDINAL


Drop inlet after

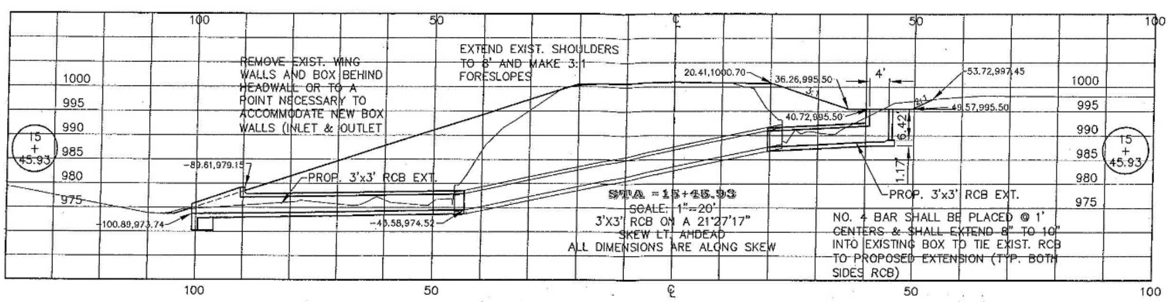

Into drop inlet after

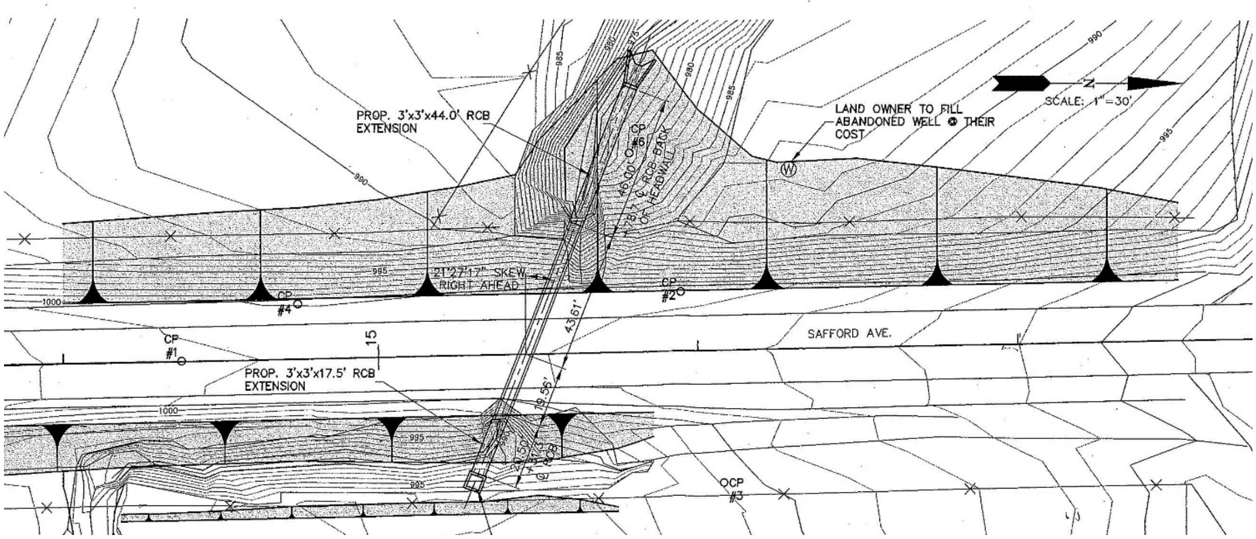
2. County: Woodbury
HCA number: 06-16
Drainage area: 0.188 mi^2
Grade controlled: 8 feet
Total cost: $64,605
Grade control cost: $32,776
Contractor: Dixon
Completed: June 2007
Life expectancy: 65+ years

Description: Extension of an existing 3' x 3' RCB culvert on both sides and use of a 4' x 4' RCB drop inlet to create less steep road embankments and to control a gully in the road ditch and adjacent field on the upstream side. The culvert effectively becomes a broken-back culvert with a drop inlet. Broken back culverts will be discussed in more detail in Section 2.4.


Looking upstream at gullied road ditch and failed road embankment near inlet as gully has grown

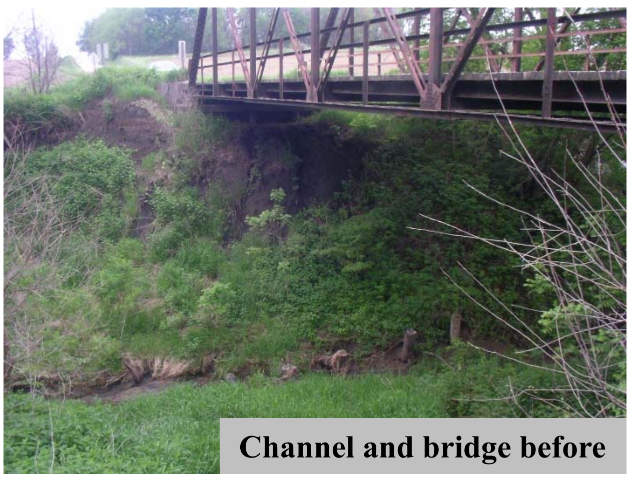

Looking upstream at drop inlet, less steep road slope, and filled gully after





3. County: Pottawattamie
HCA number: 14-11
Drainage area: 1.14 mi^2
Grade controlled: 15.4 feet
Total cost: $205,142
Grade control cost: $16,693
Contractor: Pottawattamie County
Completed: November 2015
Life expectancy: 65+ years
Description: A bridge with downcutting and widening channel replaced with a road dam created by a 6' x 6' RCB culvert and a 6' x 6' drop inlet.

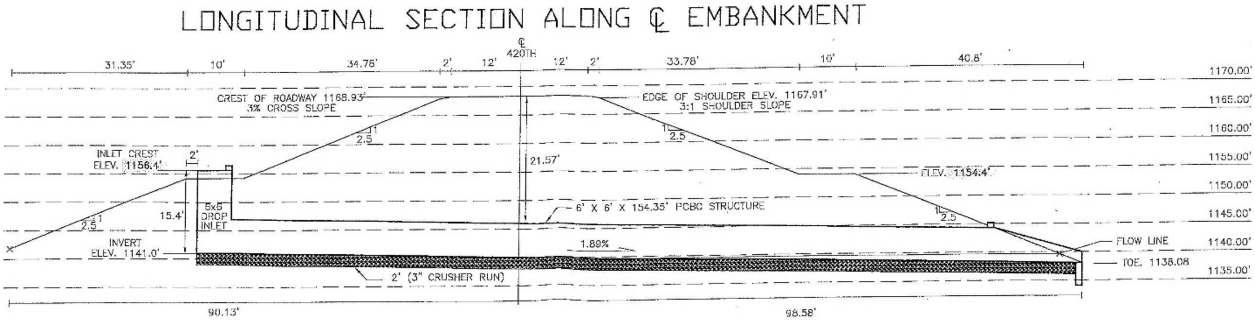
Note: Because the grade control was not "grandfathered in", this situation is likely to trigger compensatory mitigation during the U.S. Army Corps of Engineers permit process if the pool area inundates more than 300 linear feet of what was once stream corridor and/or it is considered a fish passage barrier.



Channel and bridge before

Looking upstream of road at drop inlet and pool after

LONGITUDINAL SECTION ALONG ℄ EMBANKMENT



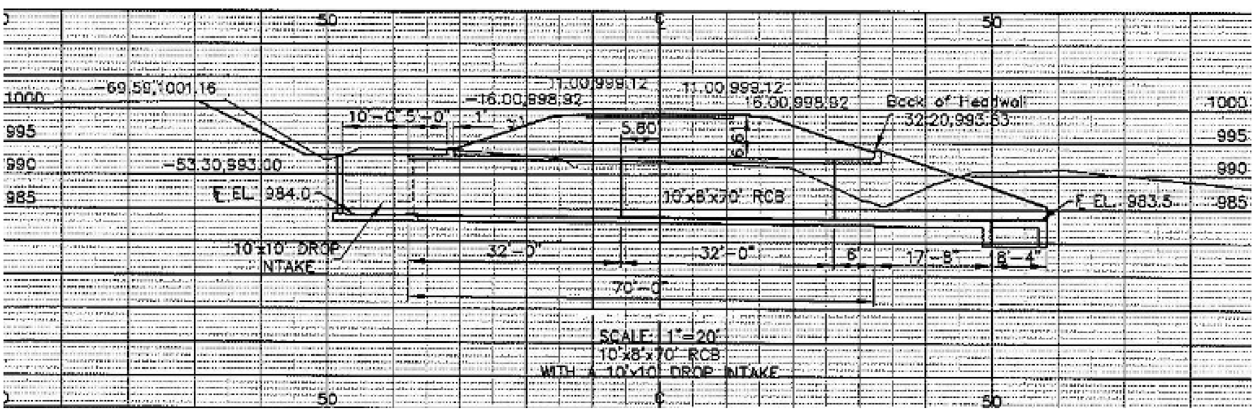
4. County: Woodbury
Drainage area: 0.65 mi^2
Total cost: $174,481
Contractor: L.A. Carlson
Life expectancy: 65+ years

HCA number: 08-16-F
Grade controlled: 9 feet
Grade control cost: $29,229
Completed: June 2009

Description: Bridge with concrete flume outlet replaced with a 10’ x 8’ precast RCB culvert and a 10’ x 10’ drop inlet.


Bridge with flume outlet before


Upstream of bridge before



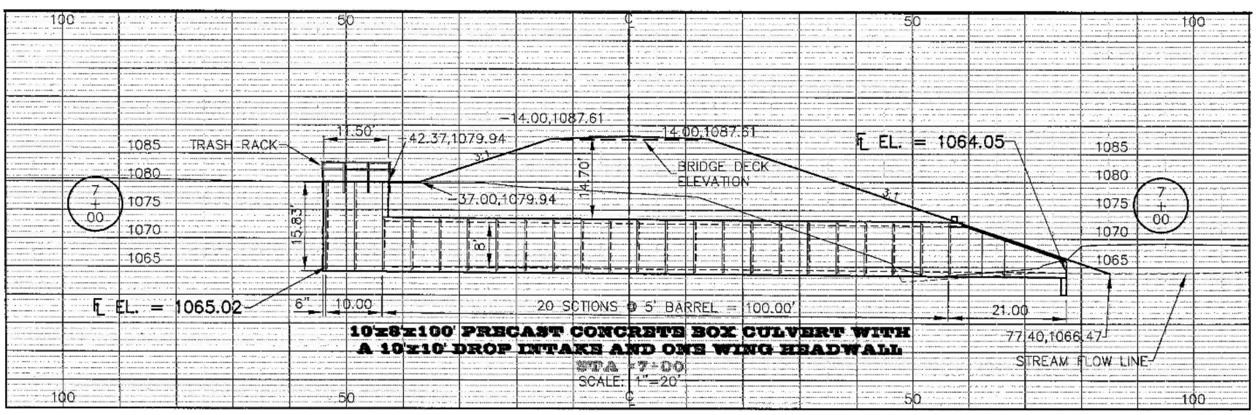

Looking upstream at drop inlet after

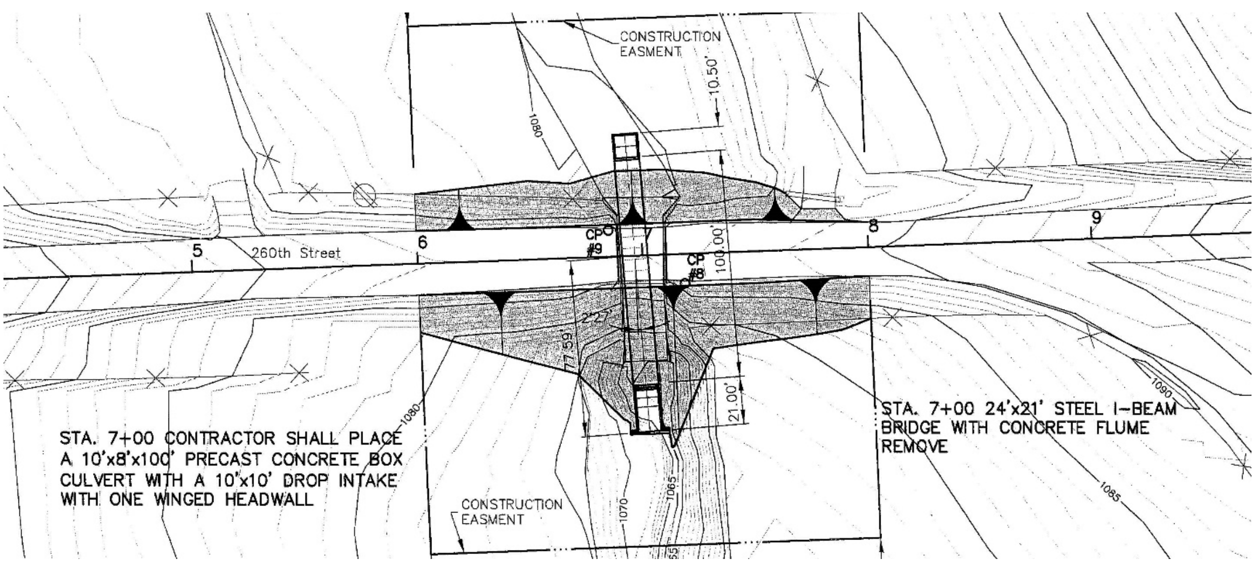

Looking upstream at outlet

5. County: Woodbury
HCA number: 14-7
Drainage area: 0.44 mi^2
Grade controlled: 15.83 feet
Total cost: \$200,491
Grade control cost: \$29,573
Contractor: L.A. Carlson
Completed: June 2016
Life expectancy: 65+ years
Description: Greenwood flume bridge replaced with a 10’ x 8’ precast RCB culvert and a 10’ x 10’ drop inlet.

Greenwood flume bridge before


Beginning RCB construction






RCB construction


RCB construction


Lifting skid steer


RCB construction

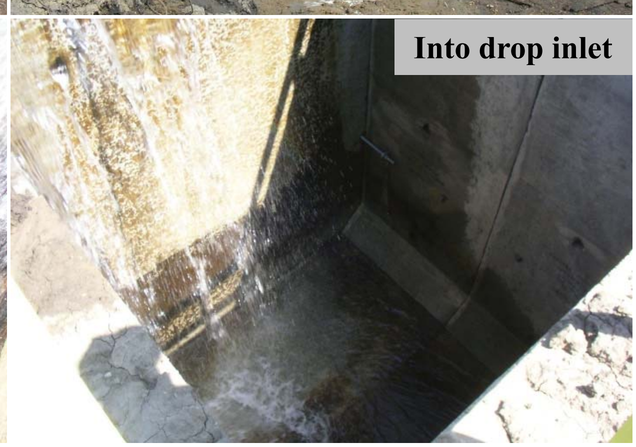

Drop inlet construction


Drop inlet construction


Drop inlet upstream


Outlet after


Into drop inlet


Into drop inlet

2.3 Reinforced concrete weir inlet on an RCB culvert

Description
A reinforced concrete weir inlet installed on the upstream end of a reinforced concrete box (RCB) culvert with tapered sidewalls is probably the most basic, easiest to construct, and cheapest type of culvert grade control. It can be installed as part of a new culvert or attached to an existing culvert but is usually cast-in-place.

Uses
1. Grade stabilization of small ephemeral streams, like grassed waterway outlets at the edge of fields, or very small intermittent or perennial streams.
2. Can eliminate gullies in or near the roadway.
3. Can provide a stable outlet for tile lines.
4. Elevation control of irrigation water.

Advantages
1. Very easy to construct and most often is cast-in-place.
2. Possibly the most cost-effective structure for controlling grade.
3. With the flow elevation dropping on the upstream side of the culvert, the flow has time to dissipate excess energy within the culvert before it emerges, limiting the scour potential and long-term maintenance on the downstream side of the culvert.
4. Arguably the most stable type of culvert grade control.

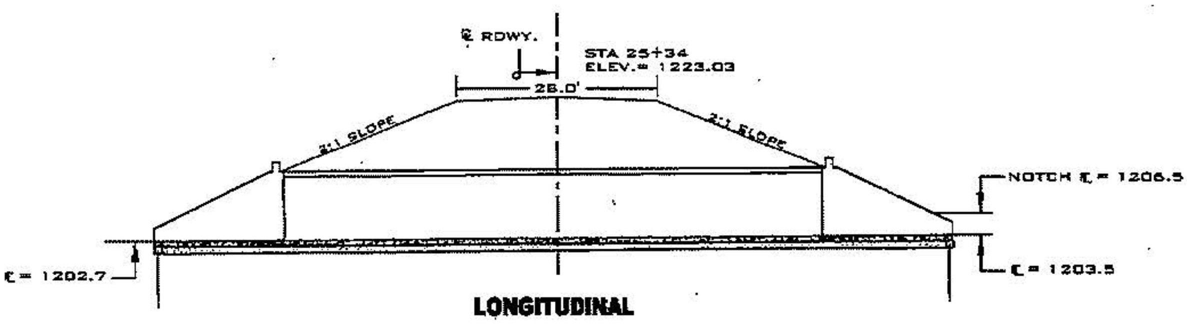
Limitations
1. Sufficient storage must be present upstream of the roadway after drop inlet installation, such that the likelihood of the road overtopping is not increased.
2. Typically, not suitable to control more than 4 feet of grade due to the height at the end of most flared headwalls and/or because of reduced inlet capacity.
3. Will not allow aquatic organism passage.

Examples – The following three examples were selected to exhibit the simplicity and flexibility of this type of grade control: one basic weir inlet, one including cattle steps, and one combined with other types of grade control.

1. County: Plymouth HCA number: 08-9-F
Drainage area: 2.11 mi^2 Grade controlled: 3 feet
Total cost: $106,791 Grade control cost: $7,175
Contractor: L.A. Carlson Completed: September 2008
Life expectancy: 65+ years
Description: Bridge replaced with a 14’ x 9’ precast RCB culvert with a 14’-wide concrete weir inlet.


Bridge downstream before


Channel upstream before



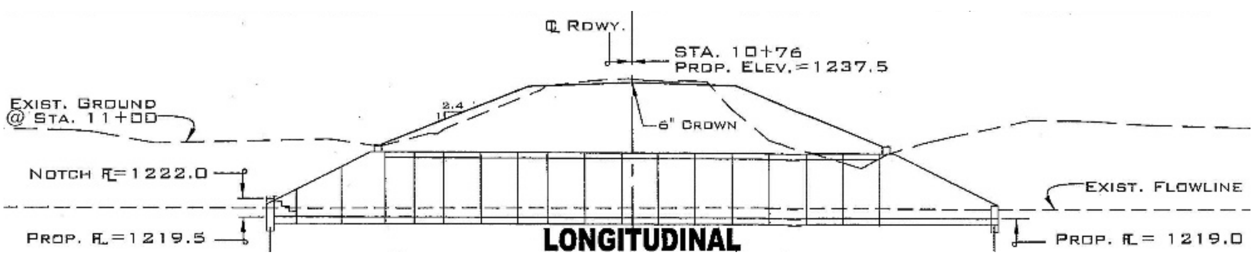

Looking upstream at weir inlet


Across weir inlet after

2. County: Plymouth
HCA number: 08-6
Drainage area: 1.24 mi^2
Grade controlled: 3 feet
Total cost: $89,900
Grade control cost: $7,000
Contractor: L.A. Carlson
Completed: December 2008
Life expectancy: 65+ years
Description: Bridge replaced with a 14’ x 8’ precast RCB culvert with a 14’-wide concrete weir inlet with cattle steps.


Bridge before


Bridge before




Looking upstream at weir inlet with cattle steps

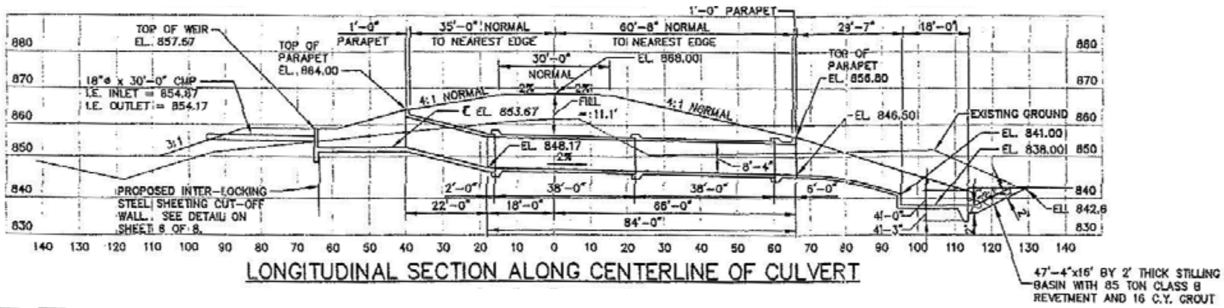

Looking across weir inlet with cattle steps

3. County: Woodbury
Drainage area: 1.29 mi^2
Total cost: $240,973
Contractor: Joy Dirt
Life expectancy: 65+ years

HCA number: 01-5
Grade controlled: 4 feet (total is 16.67)
Grade control cost: $36,200 (w/ taper and flume)
Completed: September 2001

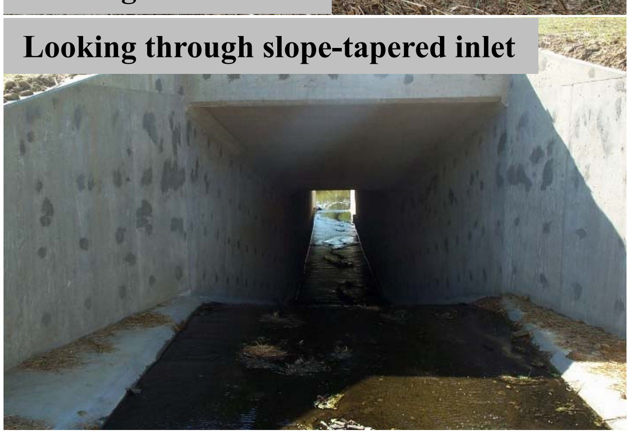
Description: Bridge replaced with an 8' x 8' RCB culvert with a 27'-6"-wide concrete weir inlet, 15' x 8' slope-tapered inlet, and a flume outlet. Slope-tapered inlets will be discussed in more detail in Section 2.5. Flume outlets will be discussed in more detail in Section 2.6. Culverts with sloped inlets and flume outlets will be discussed in more detail in Section 2.7.

Note: Because the grade control was not "grandfathered in", this situation is likely to trigger compensatory mitigation during the U.S. Army Corps of Engineers permit process if the pool area inundates more than 300 linear feet of what was once stream corridor and/or it is considered a fish passage barrier.




Looking at weir inlet


Looking over weir inlet into culvert


Looking through slope-tapered inlet


Looking upstream at flume outlet

2.4 Broken-back culvert

Description

A broken-back culvert, made from either corrugated metal pipe (CMP) or structural plate pipe (SPP), is a an alternative to installing only a steeply sloped culvert by breaking the slope into a steeper portion near the inlet followed by a horizontal runout section; a horizontal inlet section may also be included. Most broken-back culverts are built with the steep section underneath the roadway, but it can also be added to the outlet of an existing undercut culvert with the steep section placed on the downstream road embankment followed by an uncovered horizontal runout section.

Uses

1. Grade stabilization of small ephemeral streams, like grassed waterway outlets at the edge of fields, or very small intermittent or perennial streams.
2. Can be used to eliminate large gullies in or near the roadway.

Advantages

1. Often, the most economical structure for controlling large amounts of grade.
2. Flow has time to dissipate excess energy, potentially through a hydraulic jump, in the horizontal runout section within the culvert before it emerges, controlling outlet velocity, scour, and long-term maintenance on the downstream side of the culvert.
3. Adding a broken back extension is a good option to consider if the culvert is in good shape and not needing replacement.

Limitations

1. Has a shorter life expectancy than other types of structures due to the potential for corrosion and abrasion of the all-metal spillway.
2. The likelihood of serious structural damage is higher than for other types of structures due to the long potential road embankment slopes. The most likely failure mechanisms are 1) overtopping of the road and erosion of the downstream road embankment and 2) geotechnical failure of the road embankment under saturated slope conditions.
3. Due to the long steep slope of some structures, the structure may not entirely fit in the right-of-way, so a temporary construction easement may need to be acquired from the landowner.
4. May be difficult to reach the bottom of the channel downstream of the culvert if the channel has incised severely, potentially increasing construction cost.
5. Will not allow aquatic organism passage, unless the culvert has been embedded into the streambed or baffles specifically designed for fish passage have been built within the culvert.

2.4.1 Broken-back CMP culvert

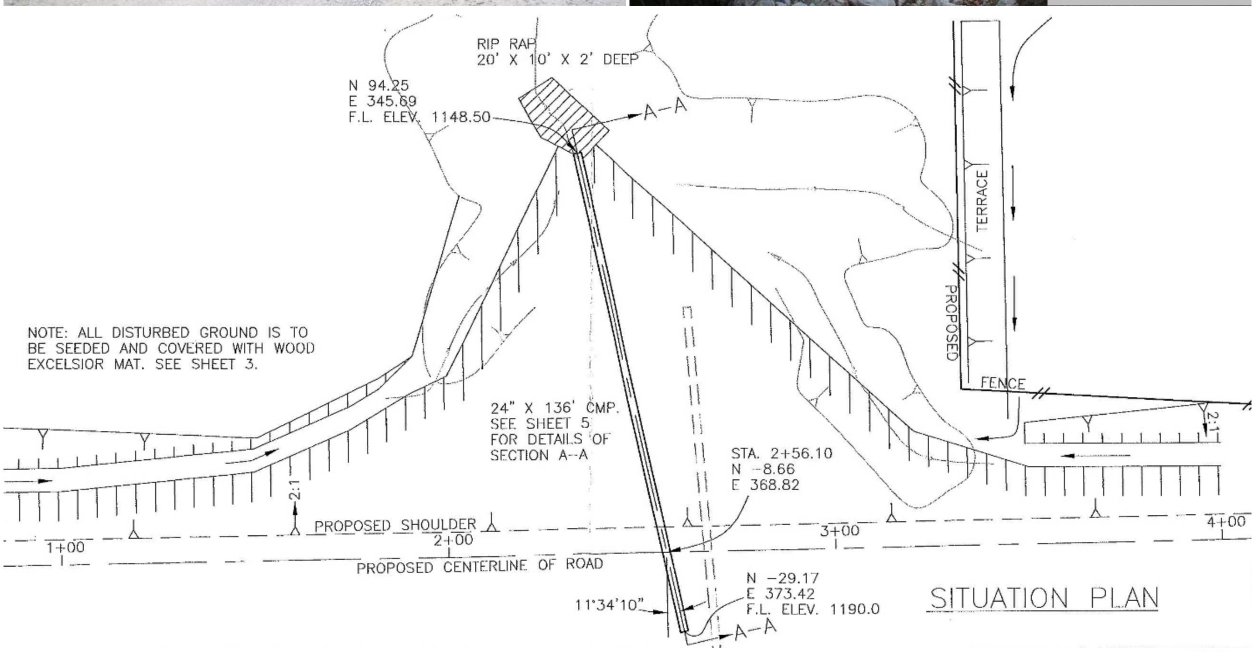
A broken-back, corrugated metal pipe (CMP) culvert is the most basic, potentially easiest to construct, and cheapest type of structure for sites requiring a large amount of grade control but having a small drainage area. The HCA has cost-shared on CMP broken-back culverts controlling up to 70 feet of grade, but unless multiple culverts are used, the drainage area has never been larger than 1.0 mi^2. This type of grade control is most often used where an existing culvert outlet has been undercut.

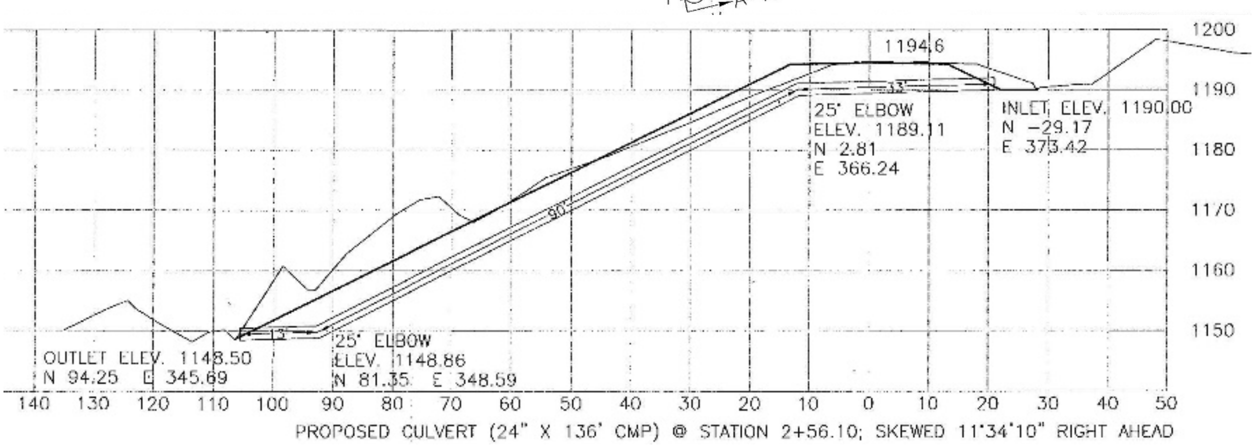
Examples – The following four examples are arranged from smallest drainage area to largest and were chosen to show a range of configurations and drop heights.

1. County: Pottawattamie
HCA number: 05-10-F
Drainage area: 0.0156 mi^2
Grade controlled: 41.5 feet
Total cost: $34,174
Grade control cost: $31,184
Contractor: Nelson & Rock
Completed: November 2005
Life expectancy: 30-50 years
Description: Undercut CMP culvert replaced with a 24” CMP broken-back culvert.

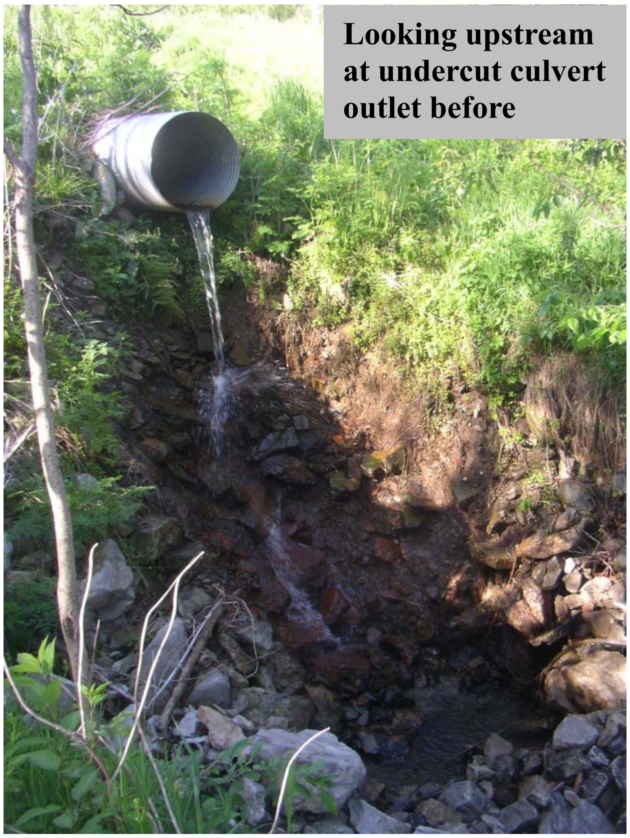

Gully eating into roadway before


Looking upstream at outlet and basin after



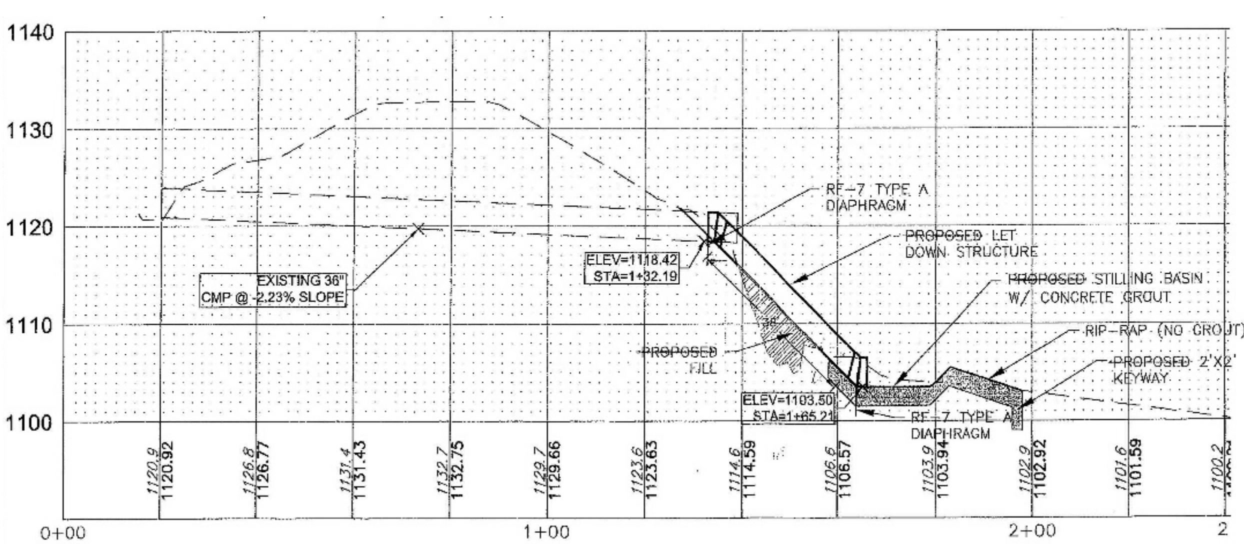


2. County: Montgomery
HCA number: 13-1
Drainage area: 0.058 mi^2
Grade controlled: 14.92 feet
Total cost: $31,842
Grade control cost: $31,842
Contractor: Empire
Completed: January 2014
Life expectancy: 30-50 years
Description: Existing undercut 36” CMP culvert extended with an angled 36” CMP letdown and grouted riprap stilling basin.


Looking upstream at undercut culvert outlet before


Looking upstream at outlet and basin after


Looking downstream from road at culvert outlet and basin after

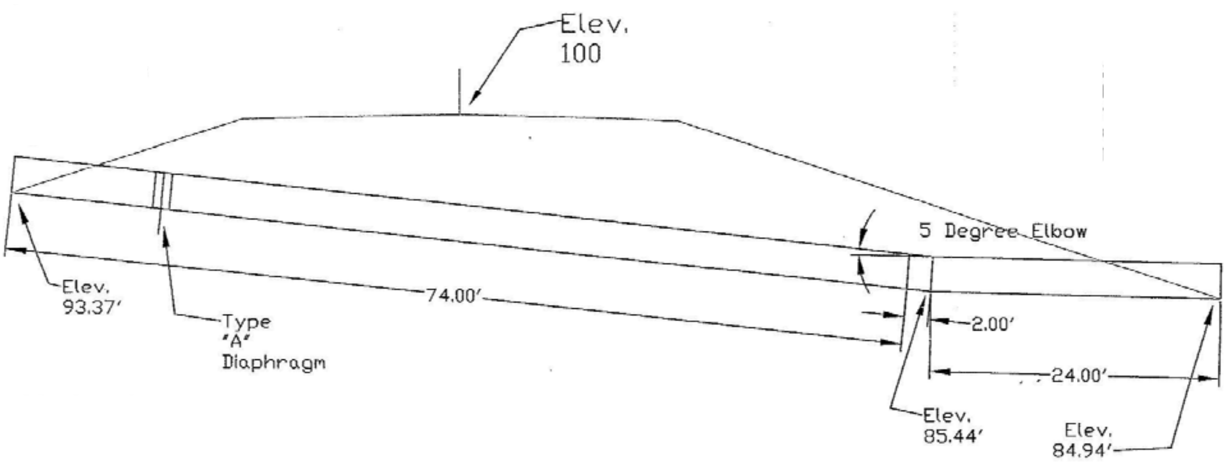


3. County: Taylor
HCA number: 05-27
Drainage area: 0.16 mi^2
Grade controlled: 8.43 feet
Total cost: $7,499
Grade control cost: $7,499
Contractor: Taylor County
Completed: November 2007
Life expectancy: 30-50 years

Description: Undercut and failed wooden box culvert replaced with a 36" CMP broken-back culvert.


Looking upstream through failed wooden box culvert before


Failed wooden box culvert before



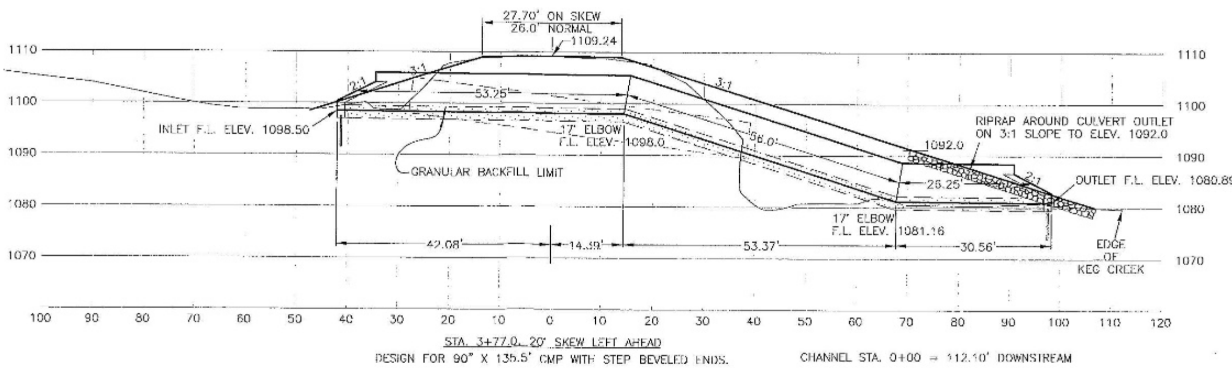

Looking from road at inlet after


Looking upstream at outlet after

4. County: Pottawattamie
HCA number: 06-6-F
Drainage area: 0.515 mi^2
Grade controlled: 17.61 feet
Total cost: $35,997
Grade control cost: $28,000
Contractor: Trevor Enterprise
Completed: August 2009
Life expectancy: 30-50 years
Description: Undercut CMP culvert replaced with a 90” CMP broken-back culvert.


Undercut outlet before


Undercut outlet before




Looking down on outlet after


Looking up into outlet after

2.4.2 Broken-back SPP culvert

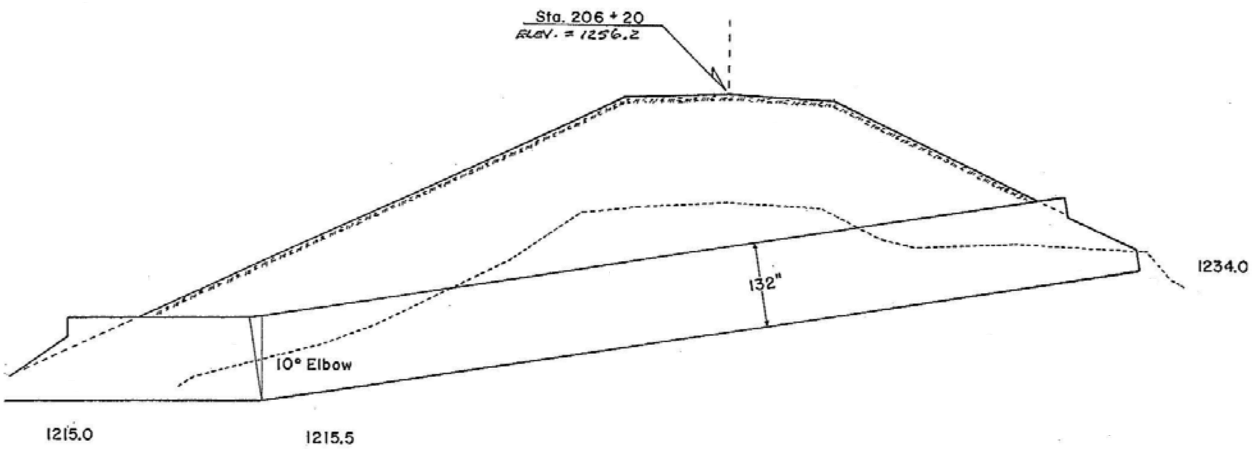
A broken-back structural plate pipe (SPP) culvert, made of either steel or aluminum, is often the most economical option for sites requiring moderate amounts of grade control, but having a drainage area larger than 1.0 mi^2. This type of culvert grade control is most often used when trying to replace existing grade control economically.

Examples – The following two examples were selected to display the usefulness of this design to replace other types of structures.

1. County: Monona
HCA number: 06-20-F
Drainage area: 1.34 mi^2
Grade controlled: 19 feet
Total cost: $201,853
Grade control cost: $74,368
Contractor: Joy Dirt
Completed: July 2007
Life expectancy: 30-50 years
Description: Greenwood flume bridge replaced with a 132” SPP broken-back culvert.


Looking downstream from road at flume outlet before


Looking downstream through culvert after

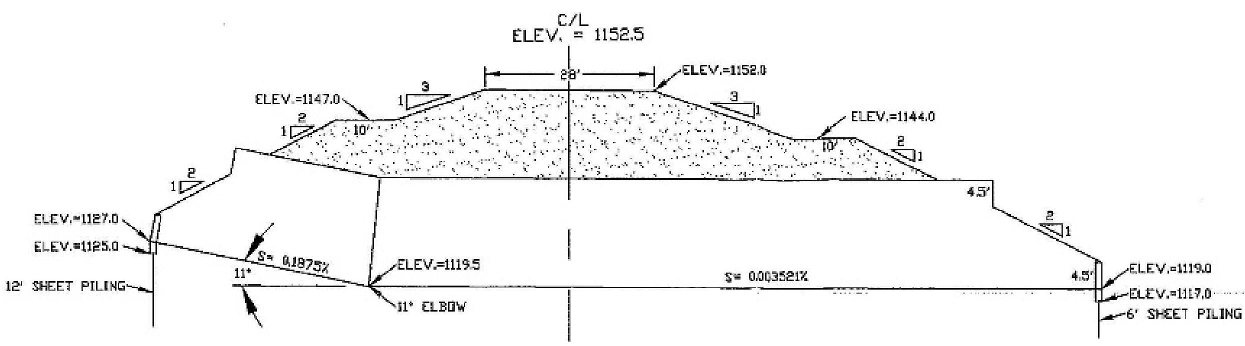


2. County: Plymouth
HCA number: 04-6-F
Drainage area: 4.1 mi^2
Grade controlled: 8 feet
Total cost: $164,122
Grade control cost: $48,000
Contractor: Nelson & Rock
Completed: September 2004
Life expectancy: 30-50 years
Description: Bridge on actively downcutting stream replaced with a 216" SPP broken-back culvert.

Note: Because the grade control was not "grandfathered in", this situation is likely to trigger compensatory mitigation during the U.S. Army Corps of Engineers permit process if the pool area inundates more than 300 linear feet of what was once stream corridor and/or it is considered a fish passage barrier.


Bridge before


Bridge and channel before




Looking downstream through culvert after


Looking upstream through culvert after

2.5 Sloped or slope-tapered inlet RCB or RCP culvert

Description

A sloped inlet on a reinforced concrete box (RCB) or reinforced concrete pipe (RCP) culvert has a steep slope to funnel water through the structure. Sloped inlets are often paired with tapered sidewalls to improve efficiency. A sloped or slope-tapered inlet can be cast-in-place or precast. To make construction simpler on a slope-tapered inlet, the inlet dimensions are tapered only in width, not in the height; for example, a 12' x 8' inlet may be tapered to an 8' x 8' barrel but not to an 8' x 6'. To use a slope-tapered inlet on a circular pipe culvert, a square to round transition is normally used to connect the rectangular slope-tapered inlet to the circular pipe.

Uses

1. Particularly useful when replacing a flume bridge, also known as a Greenwood flume in western Iowa, if less than 10 feet of grade is controlled.
2. A slope-tapered inlet should be considered if the increased costs are offset by the benefit in increased hydraulic performance, reduction in barrel size and cost, and desired grade control is achieved.
3. For sites needing less than 10 feet of grade control, a sloped or slope-tapered inlet can be used without energy dissipation downstream, but for sites needing more than 10 feet of grade control, a flume outlet section is also typically used (see section 2.7).

Advantages

1. A slope-tapered inlet can reduce construction costs by using a smaller barrel but still providing acceptable hydraulic capacity and upstream headwater.
2. High barrel velocities help keep the culvert clean of sediment deposition.
3. If flow velocity can be dissipated sufficiently within the culvert, the potential for scour and long-term maintenance downstream will be decreased.

Limitations

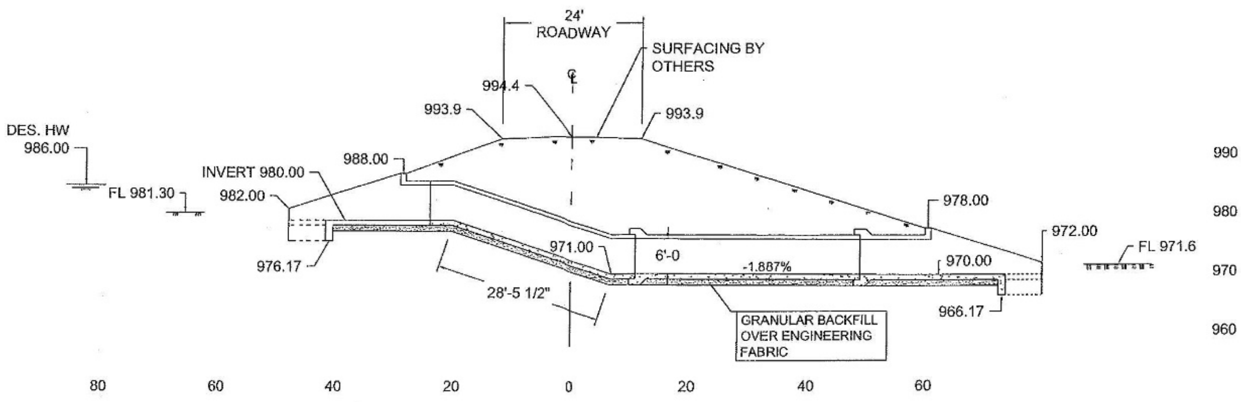
1. A slope-tapered inlet typically has higher design costs.
2. If outlet velocities are not dissipated sufficiently within the culvert, energy dissipation will likely be necessary, often in the form of a flume and basin for energy dissipation.
3. Will not allow aquatic organism passage.

Examples – The following three examples were chosen to exhibit a sloped inlet, a twin slope-tapered inlet to a single barrel culvert, and a twin slope-tapered inlet to a twin culvert.

1. County: Fremont
HCA number: 10-1-F
Drainage area: 0.593 mi^2
Grade controlled: 10 feet
Total cost: $164,237
Grade control cost: $47,860
Contractor: Christensen Bros.
Completed: April 2010
Life expectancy: 65+ years
Description: Failed 120” broken-back SPP culvert replaced with a 10’ x 6’ RCB culvert with a 10’ x 6’ sloped inlet.


Looking across failed roadway before


Looking downstream before



LONGITUDINAL SECTION
ALONG ℄ CULVERT

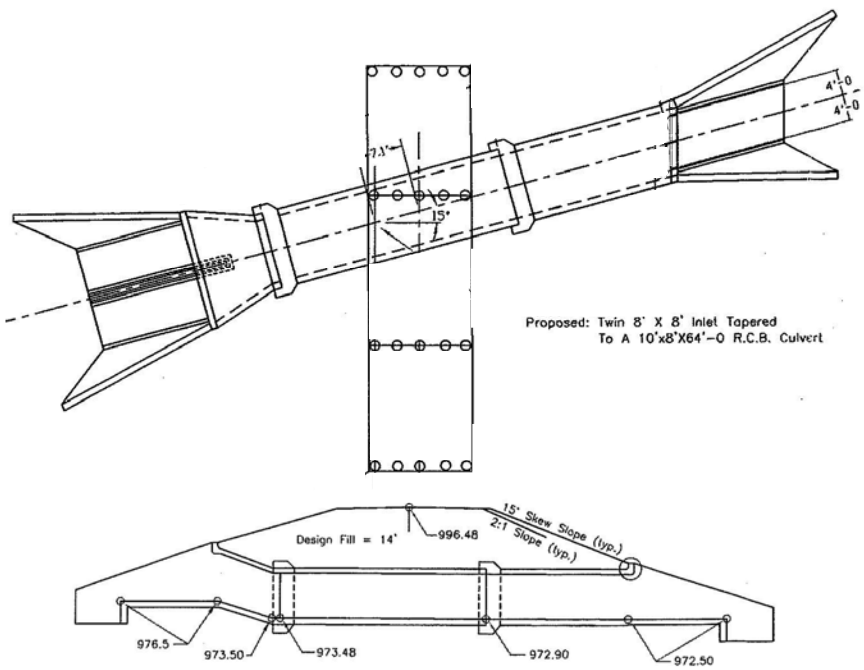

Looking into sloped inlet after


New outlet after

2. County: Page
HCA number: 02-10-F
Drainage area: 1.8 mi^2
Grade controlled: 3 feet
Total cost: $116,437
Grade control cost: $9,704
Contractor: Tracy Brothers
Completed: October 2003
Life expectancy: 65+ years
Description: Bridge replaced with a 10’ x 8’ RCB culvert with a twin 8’ x 8’ slope-tapered inlet.

Bridge before

Looking downstream at left side of slope-tapered inlet

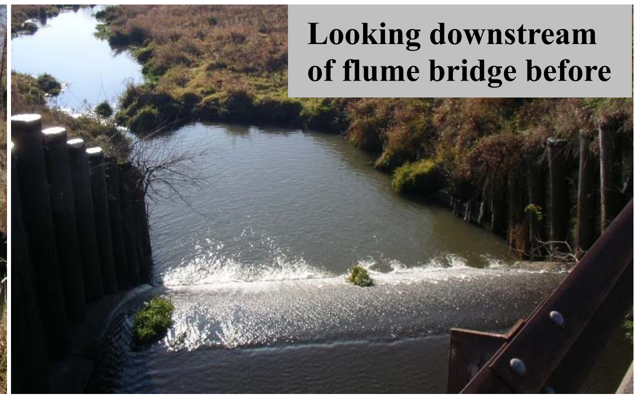


Slope-tapered inlet after

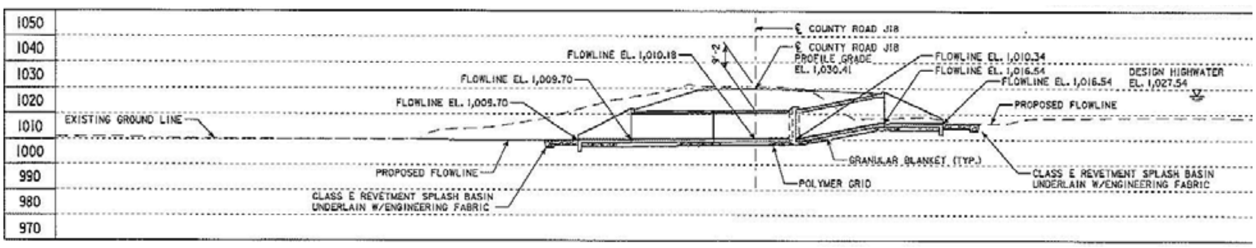
Looking upstream through culvert after

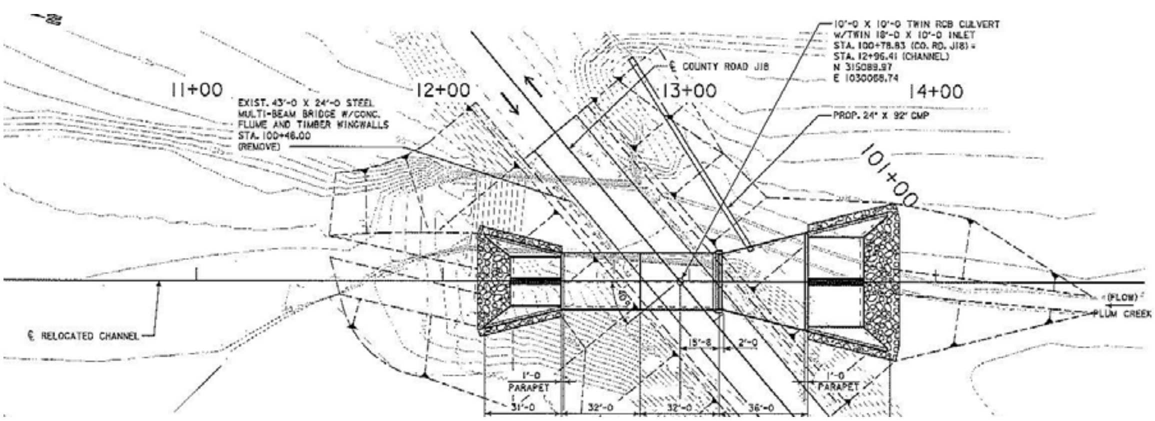
3. County: Fremont
HCA number: 17-3
Drainage area: 7.76 mi^2
Grade controlled: 6.84 feet
Total cost: $769,781
Grade control cost: $176,808
Contractor: Gus
Completed: March 2018
Life expectancy: 65+ years
Description: Greenwood flume bridge replaced with a 10’ x 10’ twin RCB culvert with a twin 18’ x 10’ slope-tapered inlet.

Greenwood flume bridge before



Looking downstream of flume bridge before





Looking downstream over slope-tapered inlet after

Looking upstream through culvert after

2.6 Flume outlet RCB or RCP culvert

Description

A flume outlet on a reinforced concrete box (RCB) or reinforced concrete pipe (RCP) culvert is an open channel at the outlet of the RCB or RCP culvert section with a steep, vertically curved section in which flow is carried at supercritical velocities. Typically, below the flume is a scour floor, which is a concrete extension of the apron at the bottom of the curtain wall elevation set at an elevation below the bed of the waterway. This allows for the natural development of a scour hole which helps dissipate energy above the natural basin and create a higher tail water elevation to contain the hydraulic jump. Adequate right of way should be purchased to encompass the scour hole, but riprap is generally not needed in the scour holes downstream from flumes. The flume and scour floor can be cast-in-place or precast.

Uses

1. Particularly useful when replacing a flume bridge, also known as a Greenwood flume. A flume bridge is similar in design and materials to an RCB flume except the RCB top is instead a bridge and the bridge abutments and flume walls are made of timber piles and wood panels.
2. Often used in spillways for pond creation, flood prevention, water conservation, and/or sediment collection.
3. Very useful for situations with more than 6 feet of grade control and drainage areas between 0.1 and 5 mi^2. Often used in lieu of a letdown structure when the pipe culvert is greater than 42 inches in diameter. For sites needing significant grade control (>12 ft) and having drainage areas greater than 0.75 mi^2, a flume outlet section is often used in conjunction with a slope-tapered inlet section (see section 2.7). On the other hand, if less than 3 feet of grade needs controlled at the outlet of a short RCB or RCP extension or if streambed degradation is anticipated on a culvert that is not already undercut, a scour floor alone could be considered.

Advantages

1. It usually is more economical than a drop inlet or broken-back structure when large capacities and large amounts of grade control are required.
2. If used in situations where temporary storage is available, the required flow capacity, and thus cost, can be reduced.
3. The combination of a scour floor and scour hole helps dissipate high outlet velocities and contain the hydraulic jump.

Limitations

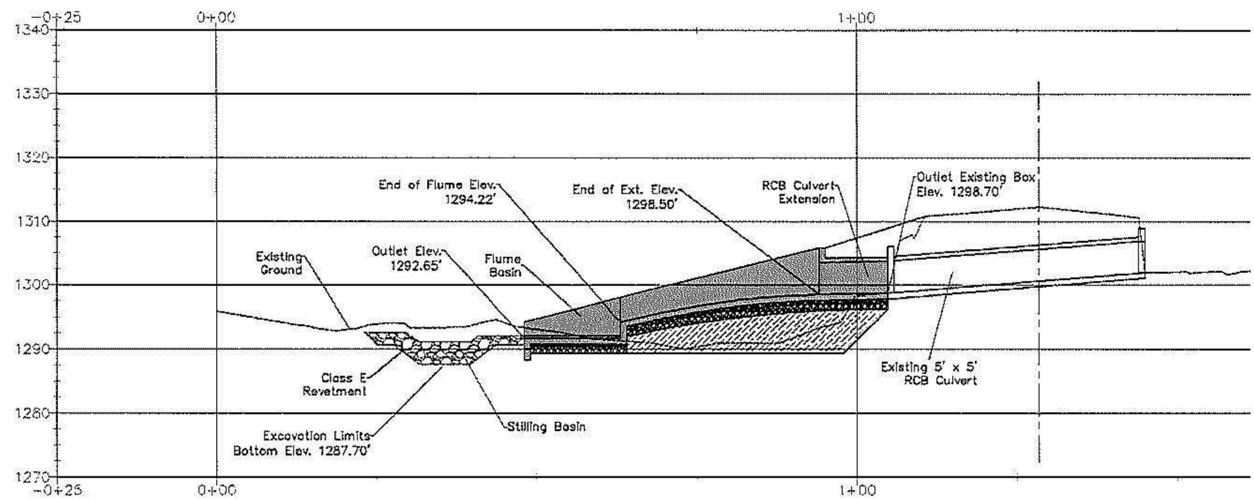
1. Even with the scour floor and scour hole dissipating high outlet velocities and containing the hydraulic jump, sometimes the scour hole can become larger than desired, especially if the streambanks around the scour hole become overly saturated, causing bank failures to occur.
2. In poorly drained locations, seepage may weaken the foundation.
3. Maximum flume lengths should be limited to approximately 60 feet, if possible, in order to reduce settlement problems and joint separations.
4. Will not allow aquatic organism passage.

Examples – The following four examples were selected to display two flume outlet extensions of existing RCB culverts and two new RCB culverts with flume outlets.

1. County: Adair
HCA number: 16-5
Drainage area: 0.47 mi^2
Grade controlled: 6.05 feet
Total cost: $66,634
Grade control cost: $57,209
Contractor: Gus
Completed: April 2017
Life expectancy: 65+ years
Description: Existing 5’ x 5’ RCB culvert extended with a 5’ x 5’ flume outlet extension and a loose riprap stilling basin downstream.

Undercut outlet before

Flume outlet after



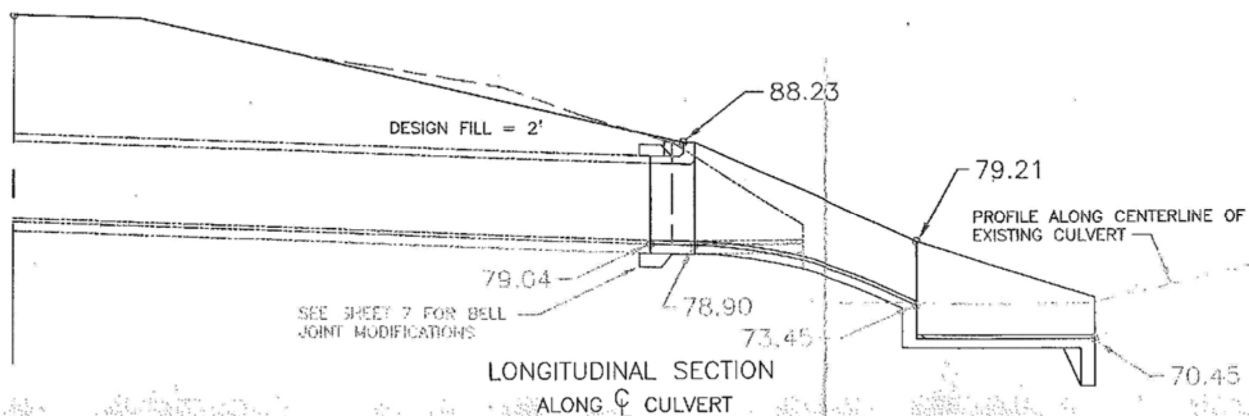
2. County: Page
Drainage area: 0.7 mi^2
Total cost: $48,049
Contractor: Gus
Life expectancy: 65+ years

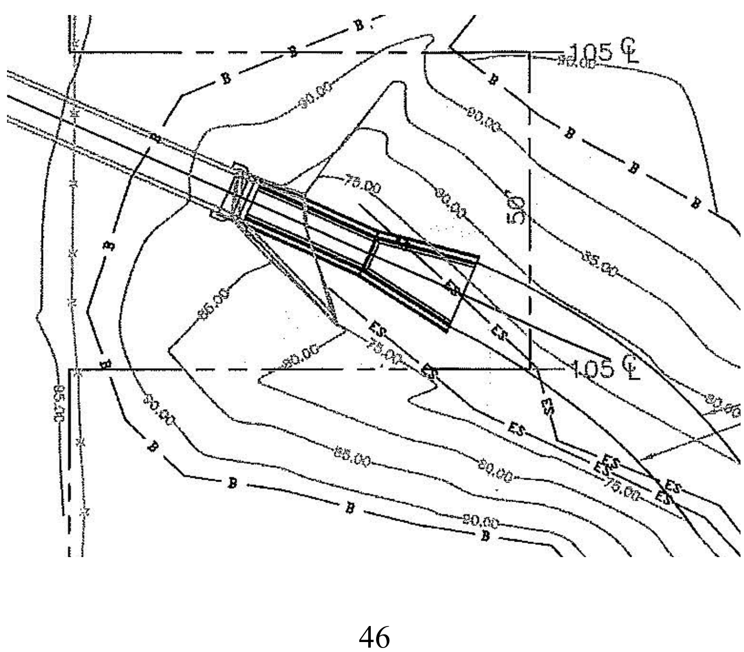
HCA number: 04-4-F
Grade controlled: 8.59 feet
Grade control cost: $42,336
Completed: September 2004

Description: Existing 6' x 7' RCB culvert extended with a 6' x 7' flume outlet extension and a loose riprap stilling basin downstream.


Undercut outlet before


Flume outlet after

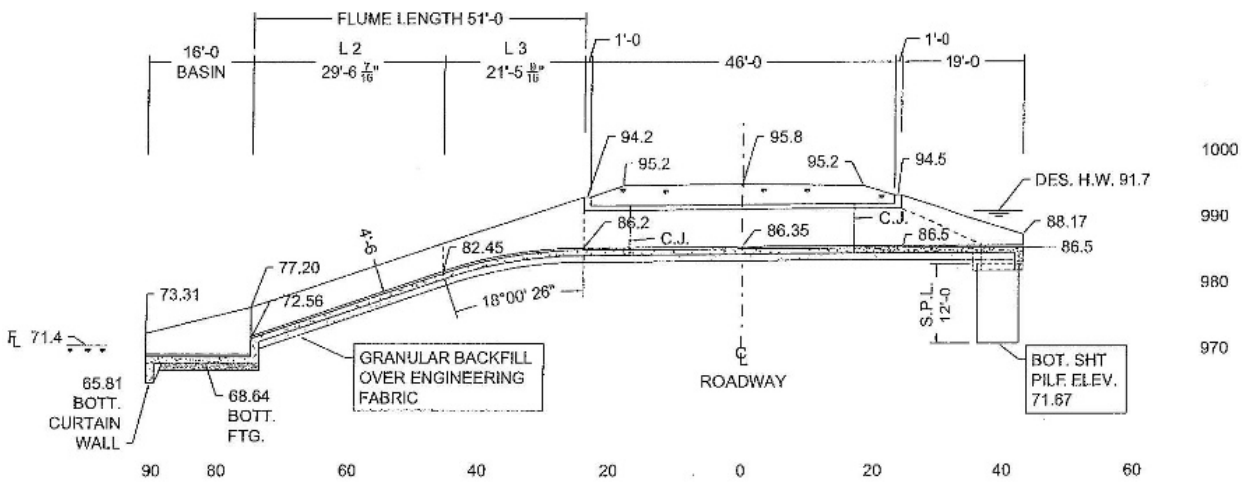




3. County: Fremont
HCA number: 09-2-F
Drainage area: 1.39 mi^2
Grade controlled: 16.7 feet
Total cost: $171,523
Grade control cost: $66,894
Contractor: Gus
Completed: August 2009
Life expectancy: 65+ years
Description: Greenwood flume bridge replaced with a 12’ x 6’ RCB culvert with a 12’ x 6’ flume outlet.

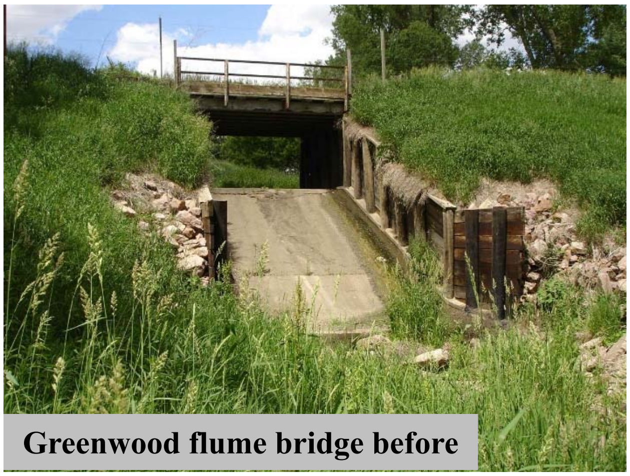

Greenwood flume bridge before


Flume outlet after

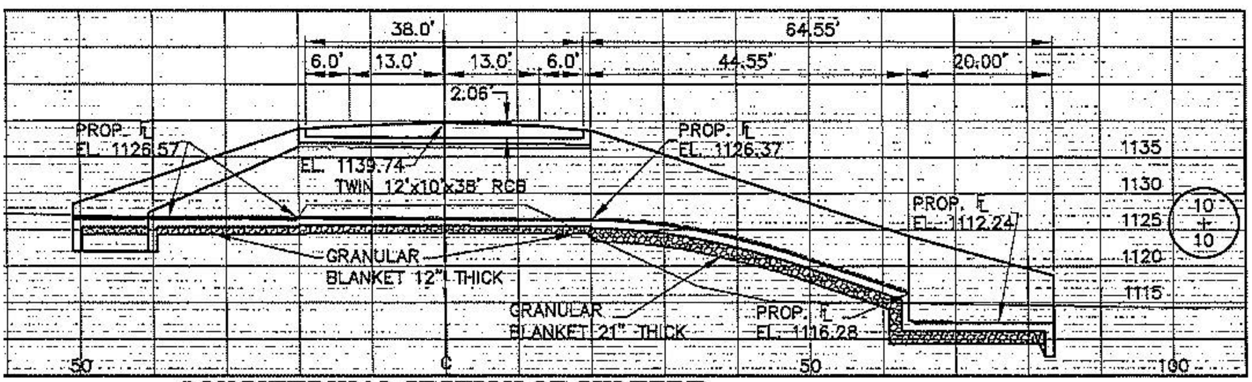


LONGITUDINAL SECTION
ALONG ℄ CULVERT

4. County: Woodbury
HCA number: 17-4
Drainage area: 2.61 mi^2
Grade controlled: 14.33 feet
Total cost: $342,806
Grade control cost: $134,768
Contractor: Graves
Completed: March 2019
Life expectancy: 65+ years
Description: Greenwood flume bridge replaced with a 12’ x 10’ twin RCB culvert with a 12’-9” x 10’ flume outlet.


Greenwood flume bridge before


Flume outlet after



LONGITUDINAL SECTION OF CULVERT
SCALE: 1"=20'
TWIN 12'x10' RCB WITH A 64.55' FLUME

2.7 Sloped or slope-tapered inlet and flume outlet RCB culvert

A sloped or slope-tapered inlet and flume outlet RCB culvert has both a sloped inlet and outlet. We have separated it out as its own section due to its widespread use for sites needing significant grade control (>10 ft) and having drainage areas greater than 0.75 mi^2. A sloped or slope-tapered inlet and flume outlet RCB culvert can be cast-in-place or precast. Particularly useful when replacing a flume bridge, also known as a Greenwood flume in western Iowa.

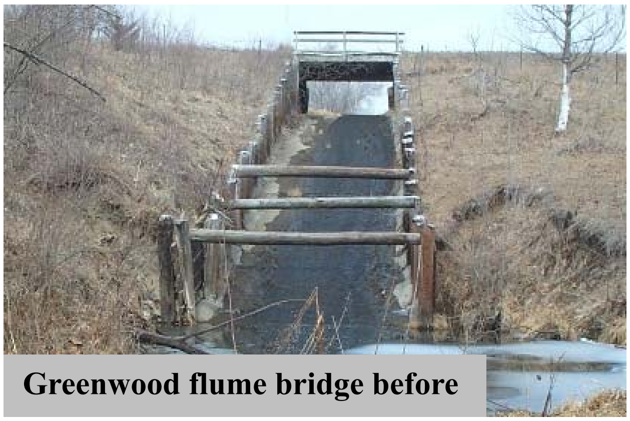
For more information regarding potential uses, advantages, and limitations see the previous two sections: sloped or slope-tapered inlets in section 2.5 and flume outlets in section 2.6.

Examples – The following three examples were selected to showcase a site with a large amount of grade control, a large drainage area, and a site requiring mitigation.

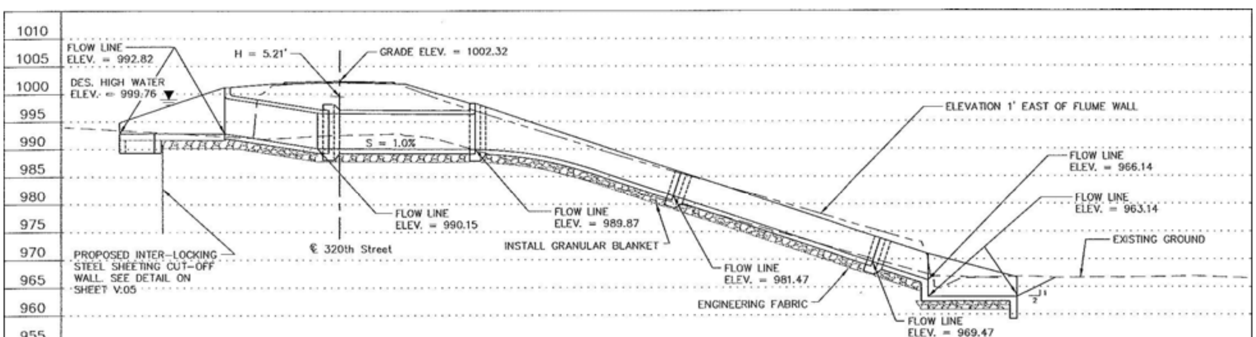
1. County: Fremont
Drainage area: 1.54 mi^2
Total cost: $157,814
Contractor: Gus
Life expectancy: 65+ years

HCA number: 03-4-F
Grade controlled: 29.7 feet
Grade control cost: $41,369
Completed: July 2006

Description: Greenwood flume bridge replaced with a 6' x 6' twin RCB culvert with a twin 10' x 6' slope-tapered inlet and 12'-9" x 6' flume outlet.


Greenwood flume bridge before


Pond upstream before



LONGITUDINAL SECTION ALONG ℄ CULVERT


Flume outlet after

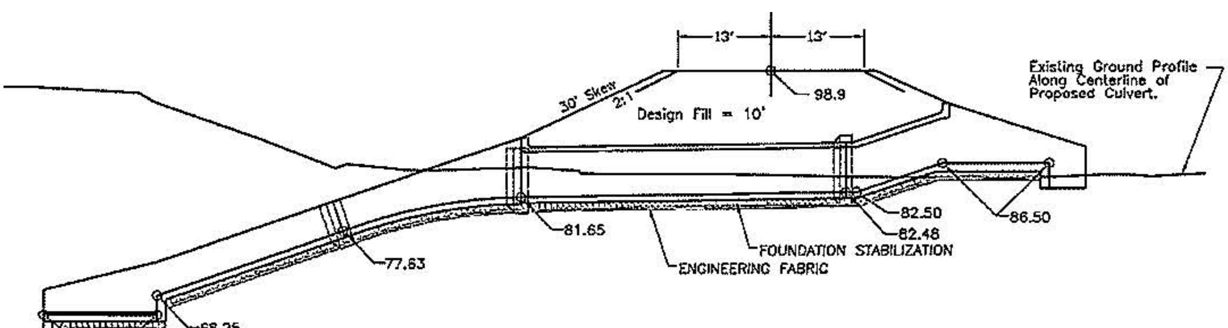

Slope-tapered inlet after

2. County: Page
HCA number: 08-11
Drainage area: 2.0 mi^2
Grade controlled: 21 feet
Total cost: $240,734
Grade control cost: $175,154
Contractor: Iowa Bridge & Culvert
Completed: December 2012
Life expectancy: 65+ years
Description: Bridge endangered by a knickpoint at least 8-foot high replaced with an 8’ x 6’ RCB culvert with a 12’ x 6’ slope-tapered inlet, 8’x 6’ flume outlet, and loose riprap stilling basin.

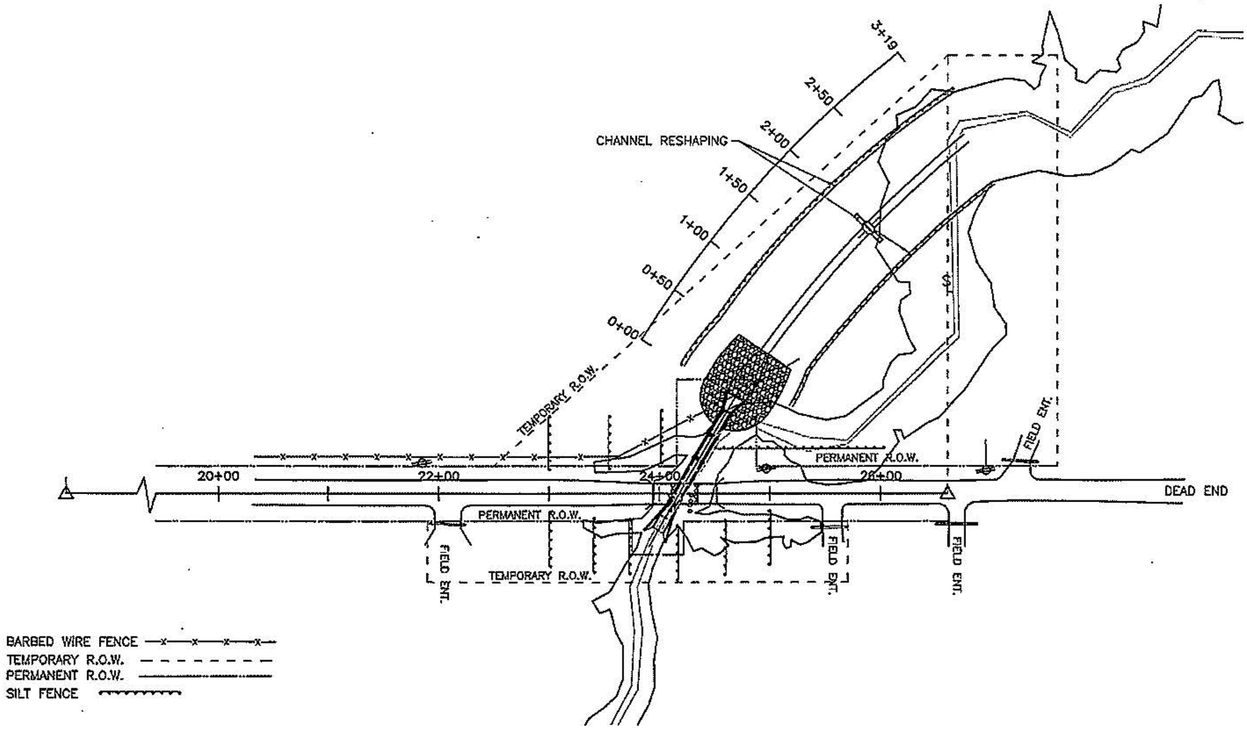
Note: Because the grade control was not “grandfathered in”, this situation triggered compensatory mitigation during the U.S. Army Corps of Engineers permit process because the pool area inundated more than 300 linear feet of what was once stream corridor and it is was considered a fish passage barrier. Mitigation was completed on-site through wetland creation.


Knickpoint downstream from bridge before


Channel after knickpoint passage downstream from bridge before



LONGITUDINAL SECTION
Along Centerline of Structure



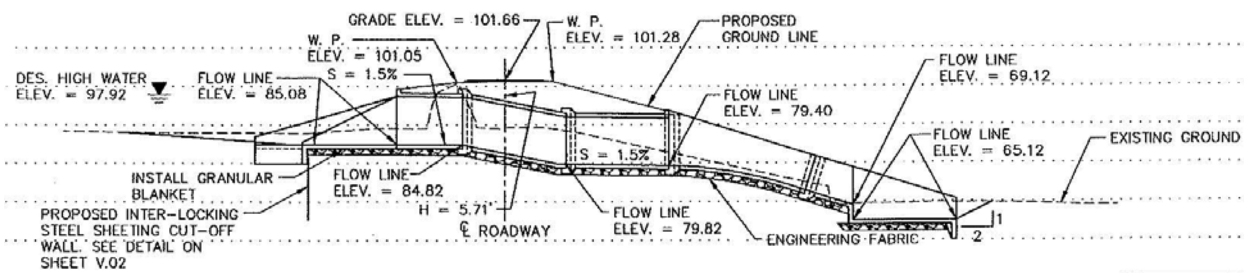
Slope-tapered inlet after

Flume outlet after

3. County: Fremont
HCA number: 03-5-F
Drainage area: 10.7 mi^2
Grade controlled: 20 feet
Total cost: $89,968
Grade control cost: $185,597
Contractor: Barton
Completed: October 2003
Life expectancy: 65+ years
Description: Greenwood flume bridge replaced with a 10' x 12' twin RCB culvert with a twin 16' x 12' slope-tapered inlet and 21' x 12' flume outlet.


Greenwood flume bridge before


Looking downstream through slope-tapered inlet after



LONGITUDINAL SECTION ALONG ℄ CULVERT


Slope-tapered inlet after


Flume outlet after

2.8 Armored sloped outlet and stilling basin

Description

An armored slope and stilling basin can be attached directly to the culvert outlet. Flow leaves the culvert and immediately cascades down the armored slope into a stilling basin where energy is dissipated before passing into the downstream channel. The slope and basin are created using riprap (either quarried rock or broken concrete) and often concrete grout. If the culvert outlet does not have a cutoff or curtain wall, sheet piling can be used to create one.

Uses

1. Most often used on an existing culvert that is structurally sound and not in need of replacement but has an uncontrolled drop at the outlet due to undercutting or scour.
2. Typically used on sites with less than 10 feet of grade control.

Advantages

1. Relatively easy to construct.
2. A good option to consider if the culvert is in good shape and not needing replacement.
3. Flow volume is limited only by what can pass through the culvert.
4. The stilling basin provides the culvert outlet with a stable backwater situation, drastically reducing the chance for scour around the culvert outlet.
5. If the grade controlled is less than 4 feet, it is very stable with the likelihood of serious structural damage far less than for other types of structures.
6. Can be designed for aquatic organism passage, but that will require a slope of at least 1:15.

Limitations

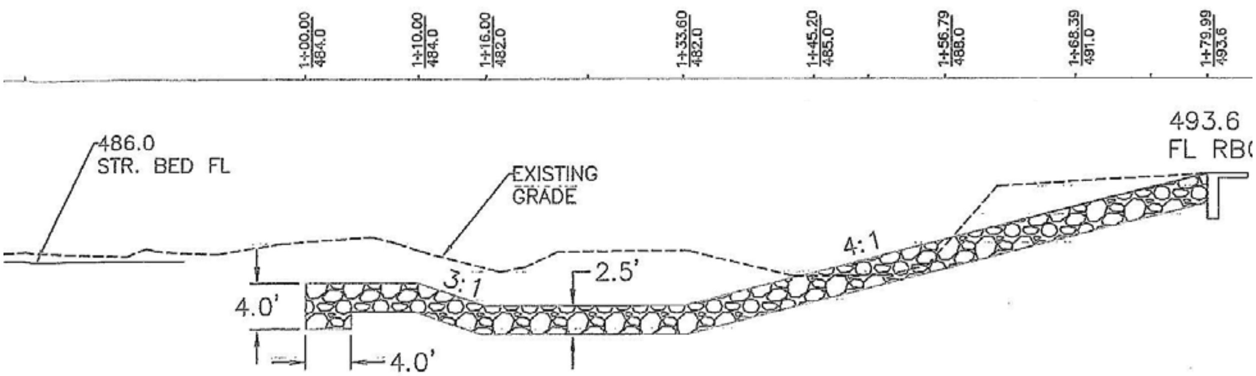
1. Tends to be more costly than other types of structures per foot of grade controlled for small drops but cost effective for big drops.
2. May be more costly than other types of structures if there is deep existing scour hole that will need to be filled and/or dewatered.

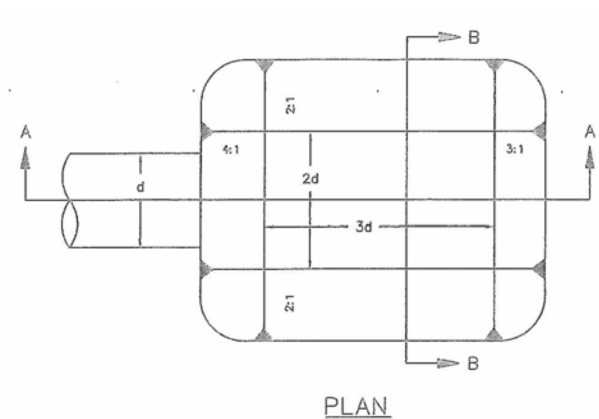
Examples – The following three examples were chosen to show armored sloped outlets being used as grade control at two undercut RCB culverts and as a Greenwood flume replacement.

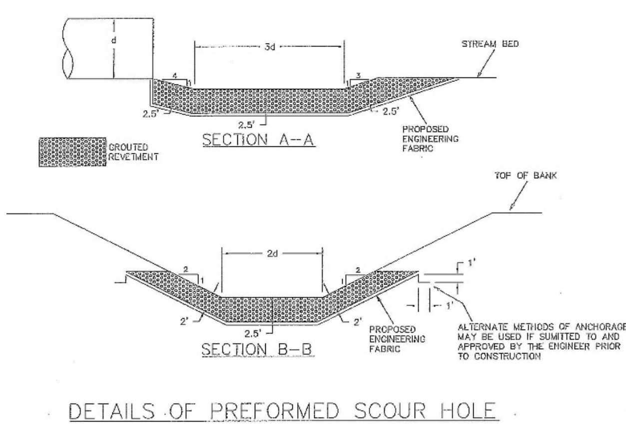
1. County: Ida
HCA number: 11-12
Drainage area: 3.5 mi^2
Grade controlled: 9.6 feet
Total cost: $64,712
Grade control cost: $64,712
Contractor: L.A. Carlson
Completed: August 2013
Life expectancy: 30-50 years
Description: Existing undercut RCB culvert outlet protected with a grouted riprap slope and stilling basin with a 27’-wide bottom.


Undercut outlet before


Armored outlet after



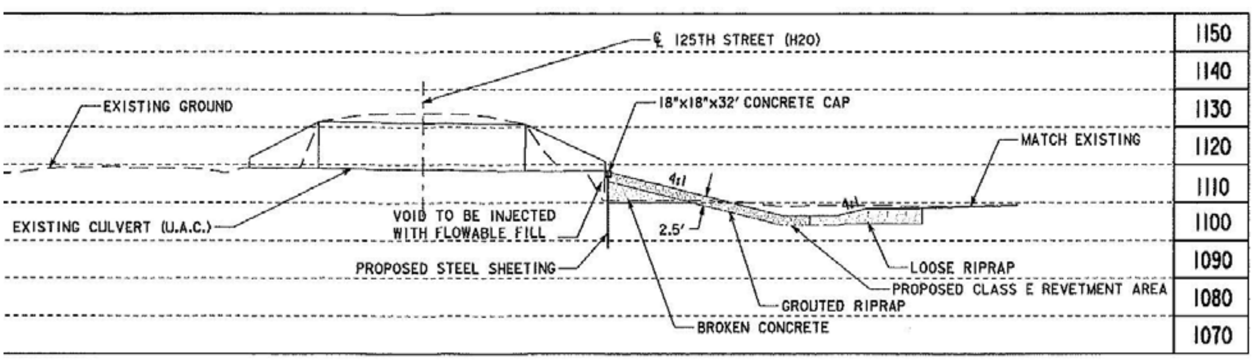




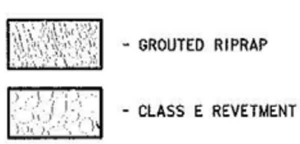
2. County: Adams
HCA number: 13-8
Drainage area: 3.45 mi^2
Grade controlled: 10 feet
Total cost: $127,199
Grade control cost: $127,199
Contractor: Nelson & Rock
Completed: June 2014
Life expectancy: 30-50 years
Description: Existing undercut RCB culvert outlet protected with a 32'-wide steel sheet pile weir, mudjacking under undercut outlet and behind weir, grouted riprap slope with a 20'-wide bottom, and loose riprap stilling basin.

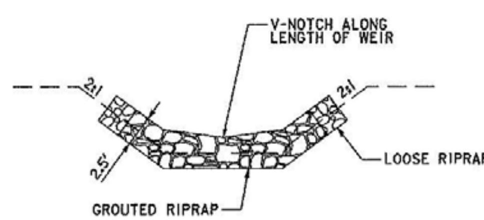

Undercut outlet before


Armored outlet after



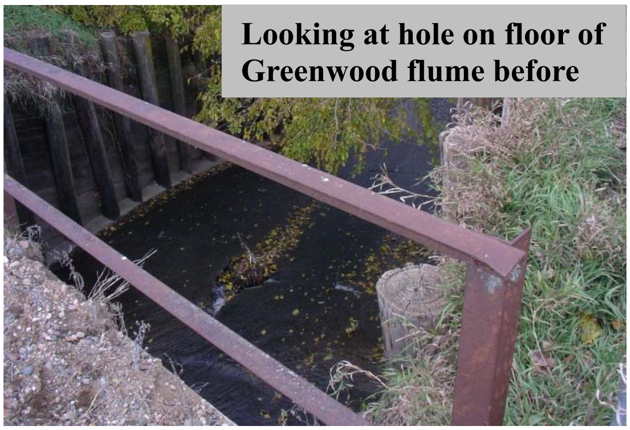
LONGITUDINAL SECTION ALONG CHANNEL ℄



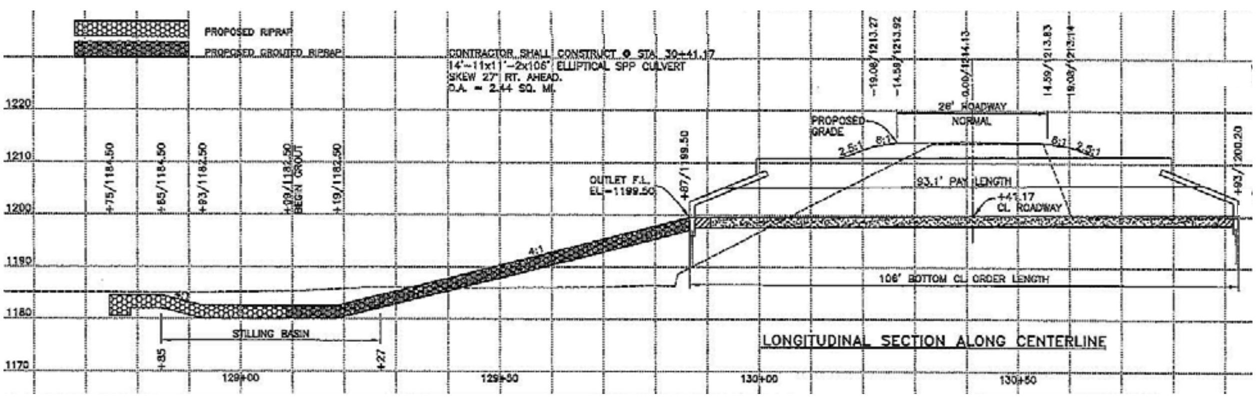


TYPICAL SECTION
THROUGH GROUTED WEIR SLOPE

3. County: Monona HCA number: 16-1
Drainage area: 2.44 mi^2
Grade controlled: 15 feet
Total cost: $314,556
Grade control cost: $64,489
Contractor: Clark / Monona County
Completed: August 2017
Life expectancy: 30-50 years
Description: Greenwood flume bridge replaced with a grouted riprap slope with an 8'-wide bottom and loose riprap stilling basin at the outlet of a new SSP culvert.


Looking at hole on floor of Greenwood flume before


Grouted riprap slope outlet after



2.8.1 General recommendations for armored slopes and weirs

The following are general recommendations when using weirs and armored slopes for grade control.

1. Make sure to not constrict the channel with armored slope or weir structure. Instead, make the structure at least as wide as the natural channel to reduce contraction scour.
2. Make sure an armored slope or weir structure is aligned with the channel to reduce scour. The whole stream reach should be considered, but downstream is most important. The transition from an armored channel section to an unaltered channel section downstream should occur in a straight stream reach if possible.
3. If using a sheet piling cut-off wall as part of a weir, extend the sheet piling wall well up and into the streambank to reduce the risk of flow going around the weir.
4. If using riprap, always try to use rock that can withstand freeze-thaw cycles long-term, such as quartzite, high-quality limestone or dolomite, or broken concrete that has been rounded and had the rebar cut off.
5. Concrete grout works well in preventing riprap movement in high energy environments, such as weir slopes. However, it is prone to mass failure if undercut, so it must be protected with flexible armoring that can adjust, such as loose riprap.
6. Never transition from inflexible armoring, such as grout or gabions, to a flexible armor, such as loose riprap or a flexible mat, on or near a slope. Doing so could cause movement of the flexible armoring and failure of the inflexible armor. Instead transition from material types in low-energy level or ponded areas.
7. Consider adding a stilling basin or a lengthened outlet to reduce scour downstream of an armored slope or weir structure.
8. If the stream has incised and it is unknown if incision has completed <u>or</u> if the watershed hydrology upstream may change to one of higher flow peaks, plan on future incision of the channel downstream of the outlet. Do not use inflexible armoring, such as grout or gabions at the outlet, because it cannot adjust without failure. Instead use something that can adjust to lowered elevations downstream, such as loose riprap or a flexible mat.
9. Before construction begins always verify the channel hasn't changed significantly since the initial survey used for design. Pay attention especially to changes in alignment and stream bed elevations.

2.9 Weir/drop spillway/chute downstream from culvert outlet

Description
A weir or drop spillway or chute can be constructed downstream from a culvert outlet. Flow leaves the culvert and enters a pool where excess energy is dissipated before eventually cascading or dropping over the weir or spillway or chute where energy is again dissipated before passing into the downstream channel. A weir typically is made of a grouted rock cascade, with or without a sheet pile cutoff wall, does not control more than 4-8 feet of grade, and tends to have a preformed stilling basin directly downstream. A drop spillway may be made of sheet pile (metal or vinyl), fabricated metal, timber, concrete blocks or reinforced concrete, does not control more than 4-8 feet of grade, and tends to have a level apron or splash pad. A chute typically is made of a grouted rock cascade, with or without a sheet pile cutoff wall, controls more than 8 feet of grade, and while it may have a preformed stilling basin directly downstream, it often discharges directly into a larger stream allowing backwater conditions to control scour.

Uses
1. Most often used on an existing culvert that is structurally sound and not in need of replacement but has an uncontrolled drop at the outlet due to undercutting or scour.
2. Prevention of a knickpoint eroding toward a culvert outlet before it reaches the culvert.

Advantages
1. Relatively easy to construct.
2. A good option to consider if the culvert is in good shape and not needing replacement.
3. If the drainage area entering the channel between the culvert and the weir/drop spillway is small, the flow volume is limited only by what can pass through the culvert.
4. Provides the culvert outlet with a stable backwater situation, drastically reducing the chance for scour around the culvert outlet.
5. Prevents channel downcutting from reaching the culvert outlet.
6. The long crest of the weir permits flows to pass over it with relatively low heads.
7. Very stable with the likelihood of serious structural damage far less than for other types of structures.
8. Can control more than one culvert outlet if the outlets are close enough that the backwater is beneficial for all.
9. Can be designed for aquatic organism passage, but that will require a slope of at least 1:15.

Limitations
1. May be difficult to reach the bottom of the channel downstream of the culvert if the channel has incised severely, potentially increasing construction cost.
2. Drops larger than 6-8 feet may require a series of weir/drop spillways, potentially increasing construction cost.
3. If built outside of the right-of-way, a temporary construction easement, and potentially a long-term access easement for maintenance, will need to be acquired from the landowner.

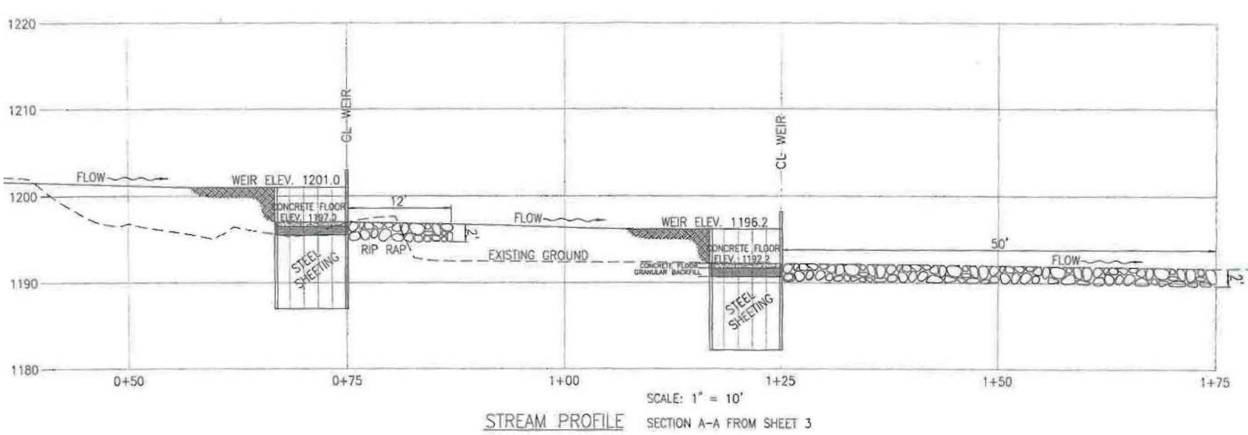
Examples – The following three sites were selected to exhibit an example of a weir, a drop spillway, and a chute.

1. County: Pottawattamie
HCA number: 06-24-F
Drainage area: 0.253 mi^2
Grade controlled: 8.8 feet
Total cost: $65,156
Grade control cost: $65,156
Contractor: Nelson & Rock
Completed: August 2009
Life expectancy: 30-50 years
Description: Three undercut culverts protected 70’ downstream with two 13’-wide straight-drop steel sheet pile weirs in series with a loose riprap outlet.

Undercut culvert before

Weirs looking upstream after

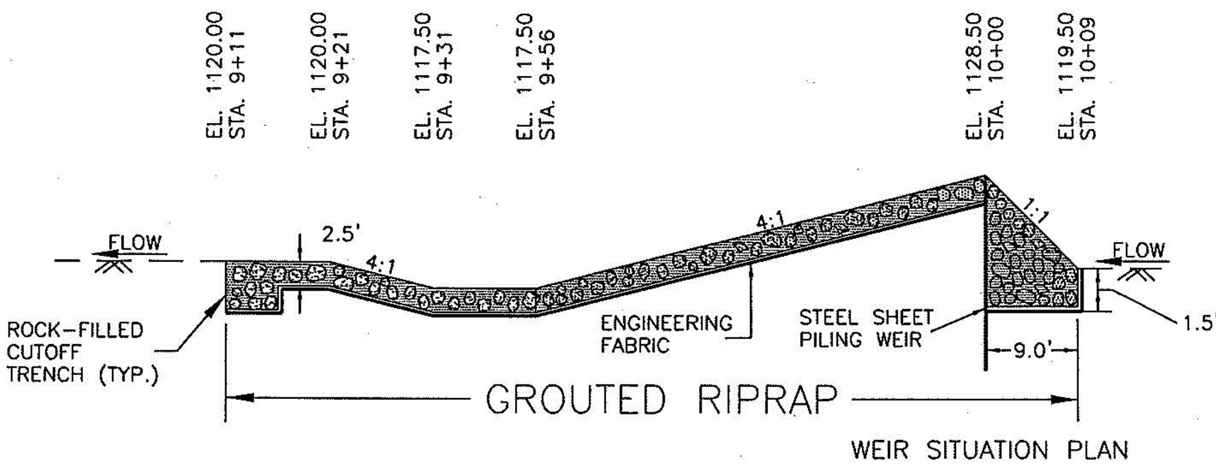
Weirs looking downstream after



2. County: Monona
HCA number: 05-6-F
Drainage area: 4.6 mi^2
Grade controlled: 8.5 feet
Total cost: $89,625
Grade control cost: $89,625
Contractor: Nelson & Rock
Completed: October 2005
Life expectancy: 30-50 years
Description: An undercut 162” multi-plate culvert protected 295’ downstream with a 35’-wide steel sheet pile weir with a grouted riprap slope and stilling basin.


Undercut culvert before

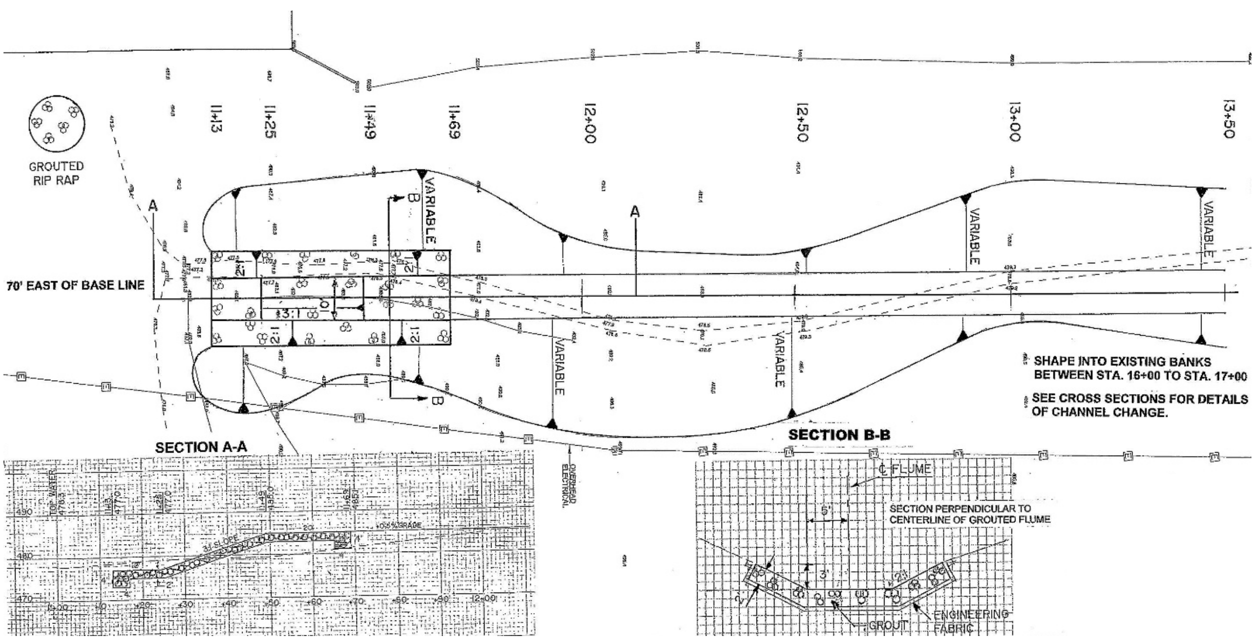

Weir looking upstream after



SECTION A–A
NOT TO SCALE

3. County: Crawford
HCA number: EWP-8311-4M
Drainage area: 1.05 mi^2
Grade controlled: 8.1 feet
Total cost: $52,854
Grade control cost: $52,854
Contractor: Nelson & Rock
Completed: October 2009
Life expectancy: 30-50 years
Description: An undercut culvert and incised road ditch protected 900' downstream with a grouted riprap chute with a 10'-wide bottom.


Rock chute and road ditch after



2.10 Low-water crossing with culvert(s)

Description

A low-water crossing is designed to provide safe passage during low flows but will overtop at high flows and therefore be closed to traffic. The culvert(s) underneath the crossing will convey all flows up to the low-flow design discharge. The crossing will act as a broad-crested weir combined with culvert flow for greater discharges. The major design consideration is protection of the crossing roadway and embankment, typically riprap along or paving of the embankment, from erosion and scour on the downstream side of the roadway due to the drop in water surface elevation and acceleration of flow during overtopping. Grade control can be accomplished at a low-water crossing by sloping the culvert barrel through the roadway or by incorporating an armored slope at the culvert outlet.

Uses

1. Low-cost bridge replacement and grade control option, especially for flume bridge replacement, on low-traffic roadways.
2. Typically used on sites with less than 8 feet of grade control.

Advantages

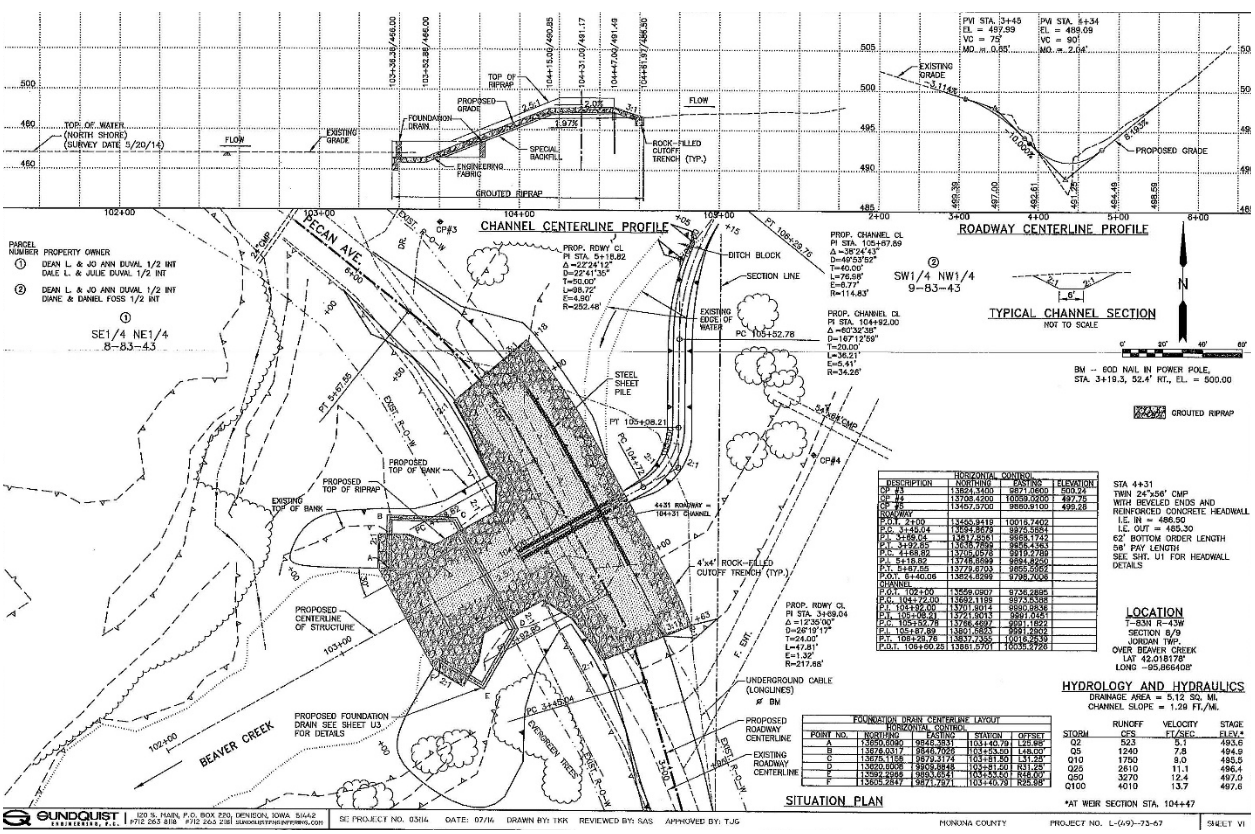
1. Cheaper than building a sloped inlet and/or flume outlet RCB culvert.
2. Can control more grade than structural plate culverts.
3. Due to the open top crossing, it can accommodate drainage areas much larger than any other type of culvert.

Limitations

1. Will be dangerous to motorists when the road is overtopped or flooded.
2. The likelihood of serious structural damage is far greater than for other types of structures due to the frequent overtopping. The three most likely failure mechanisms are 1) erosion of the road approach to the side of the armored slope, 2) erosion of the roadway or armored slope on the downstream side from scour, and 3) channel incision downstream undercutting the armored slope. The likelihood of serious structural damage increases as the amount of grade control increases.
3. Signs warning of the dangers associated with high water must be posted.
4. Maintenance is often needed following high-flow events after debris and ice can become lodged in the culvert(s) or is deposited on the road or slopes. Uncleared roadway debris and ice chunks can be a major hazard for motorists. It might be best to consider other options if the watershed, and especially the stream corridor, is heavily wooded. The cost of long-term maintenance to clear debris should be considered before choosing this option.
5. Will not allow aquatic organism passage.

Examples – The following three examples were chosen to display low-water crossings with a range of grade control and drainage area.

1. County: Monona
HCA number: 14-12
Drainage area: 5.12 mi^2
Grade controlled: 20.5 feet
Total cost: $458,247
Grade control cost: $214,800
Contractor: Nelson & Rock
Completed: May 2015
Life expectancy: 30-50 years
Description: Failed Greenwood flume bridge replaced with a low-water crossing with a grouted riprap flume with a 38'-wide bottom and two 24" CMP culverts for low flow conditions.




Grouted flume after


Low-flow culvert inlets after


High flow in March 2019


Road overtopped in March 2019

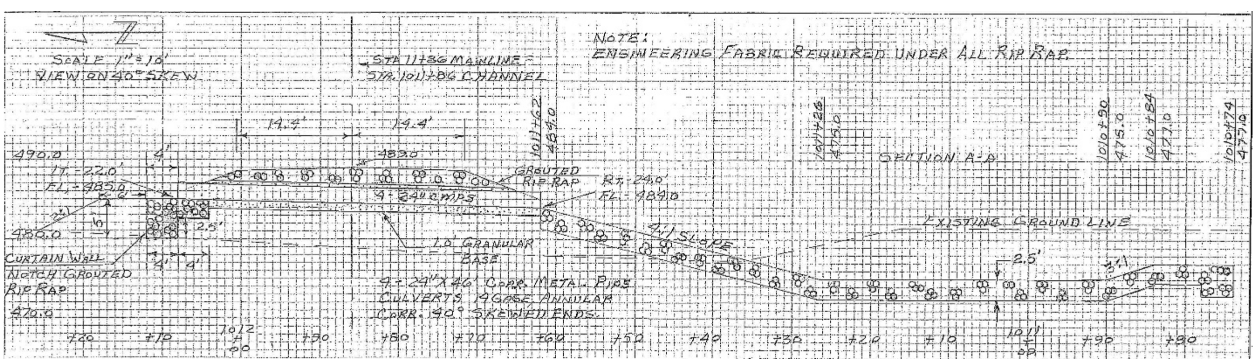
2. County: Crawford
HCA number: 11-11-F
Drainage area: 10.4 mi^2
Grade controlled: 8 feet
Total cost: $121,504
Grade control cost: $159,086
Contractor: Ten Point
Completed: December 2011
Life expectancy: 30-50 years

Description: Bridge replaced with a low-water crossing with a grouted riprap slope and stilling basin with a 16'-wide bottom and four 24" CMP culverts for low flow conditions.

Note: Because the grade control was not "grandfathered in", this situation is likely to trigger compensatory mitigation during the U.S. Army Corps of Engineers permit process if the pool area inundates more than 300 linear feet of what was once stream corridor and/or it is considered a fish passage barrier.

Bridge before

Low-water crossing after



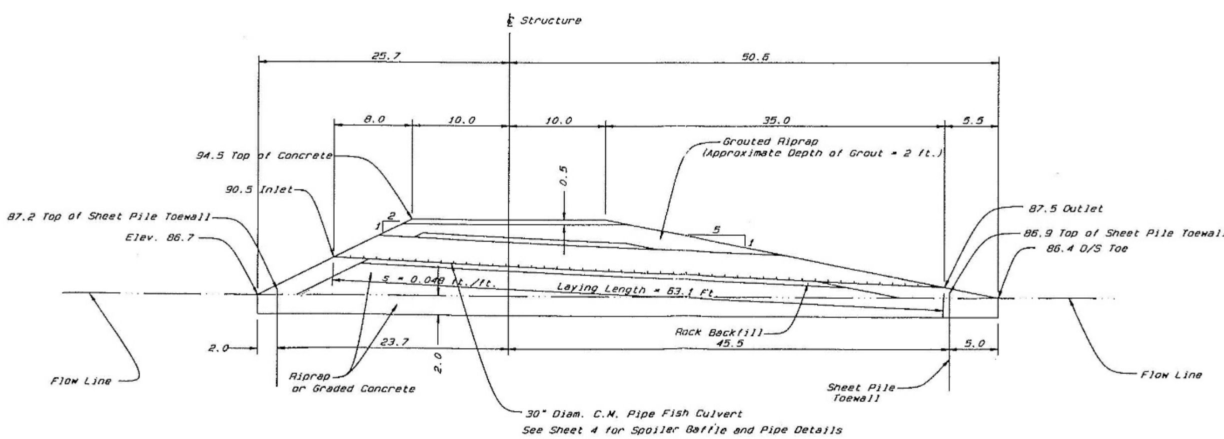
3. County: Harrison
HCA number: 00-13 Mike Schomers
Drainage area: 30.4 mi^2
Grade controlled: 4.1 feet
Total cost: $38,156
Grade control cost: $38,156
Contractor: Earl Dick Jr.
Completed: September 2002
Life expectancy: 30-50 years

Description: New low-water crossing for landowner with a grouted riprap slope and two 30" angled CMPs, one having fish baffles, for low flow conditions.

Note: Despite one culvert having baffles for fish passage, this situation could still trigger compensatory mitigation during the U.S. Army Corps of Engineers permit process if the pool area inundates more than 300 linear feet of what was once stream corridor.


Low-water crossing after


Fish baffle culvert on left



3. RECOMMENDATIONS

We recommend that an attempt be made to create an easy-to-use spreadsheet-based decision-matrix tool, along with any associated graphs/charts/other tools, to help engineers select the most cost-effective and constructible type of culvert grade control that also provides the longest-term performance with the least amount of ongoing maintenance. Some variables that should be represented in the decision-matrix tool are: type of culvert grade control, grade control needed, discharge (drainage area), site conditions, constructability, material costs, total project costs, anticipated structure life expectancy, anticipated long-term maintenance, replacement vs. adding on to existing structure, roadway type, and ADT.

We also recommend that this document be updated every five years to keep the information in it as current and useful as possible.

4. REFERENCES

Iowa DOT. 2018. *Bridge and Culvert Design Manual*. Chapter 4 - Preliminary Design of Culverts. https://iowadot.gov/bridge/policy/LRFDBridgeDesignManual.pdf

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