Design Guidelines for Bridge Size Culverts

Bridge Engineering Section
Technical Standards Branch
Alberta Transportation

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Foreword

These guidelines cover many aspects of design of bridge size culverts, and are complemented by other guidelines such as the Bridge Conceptual Design Guidelines and the Bridge Structures Design Criteria. These guidelines apply to all Alberta Transportation projects involving bridge size culverts.

Although this document is intended to be thorough, certain cases may arise where specific guidance is not provided or not applicable. Consultants working for Alberta Transportation must exercise good engineering judgment, which is technically sound and well justified, in the application of these guidelines. The design standard/practice exception process may need to be triggered on some projects.

Any project specific questions relating to these guidelines should be directed to the project administrator.

Any feedback or technical clarification requests relating to this document should be directed to the Director, Bridge Engineering Section, Technical Standards Branch, Alberta Transportation.

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TABLE OF CONTENTS

1 INTRODUCTION

The Design Guidelines for Bridge Size Culverts have been developed by Alberta Transportation (AT), and are based on International & National Codes of Practice, Manuals, Technical Books and Papers, etc. A 'best practice' approach has been used to incorporate practical design and construction experience that has been developed by Alberta Transportation and their consultants over the years. It is anticipated that the use of these Guidelines will result in the uniform design and construction of culverts throughout the province of Alberta. It should be noted that subsequent guidelines/design bulletins/best practice guidelines may be published, which would superseded the information presented in this guideline.

Most design topics are presented in three parts:

1) Background: to serve as an introduction to the issue, to review current practices, and to identify any concerns that have been identified.

2) Considerations: a brief summary of the engineering concerns that were reviewed prior to making recommendations are outlined. It is recognized that site specific factors additional to those identified may exist that could affect design recommendations.

3) Recommendations: typically these should be considered a minimum desirable standard. However, it is recognized that for some situations, it may be desirable to reduce (or enhance) a standard.

Definitions

- Bridge Size culvert crossing – crossing with buried structure(s) with equivalent diameter (based on sum of end areas of all structures at crossing) of greater than or equal to 1500 mm.

- Standard bridge culverts are structures at a bridge size culvert crossing that do not require site specific structural design, other than material thickness. This currently includes Corrugated Steel Pipe (CSP) structures, Structural Plate Corrugated Steel Pipe (SPCSP) structures up to 4.5m in diameter, Welded Steel Pipe (WSP) structures up to 3m in diameter, and precast concrete box structures up to 3m in maximum dimension.

- Major bridge culverts are structures at a bridge size culvert crossing that require site specific structural design. This includes all buried structures not listed under standard bridge culverts.

Tunneling options can become quite varied with limited experience and competition in the industry for structures greater than 3m in diameter. Therefore, 3m is set as the upper limit for WSP pipes currently being considered as standard bridge culverts. At the time of publication, 3.0m is the maximum dimension available for precast concrete structures, and therefore this has been set as the upper limit for inclusion in the standard bridge culvert category.

Note standard drawing S-1418, "Installation of Large Steel Pipes" is not applicable to flexible bridge culverts of greater than 3000mm diameter or to non-flexible bridge culverts. Scaling of backfill envelope dimensions is allowed for pipes up to 4.5m in diameter (see section 10).

2 CONSTRUCTION (OR 'P') DRAWINGS

Background:

Historically, culverts were installed by in-house Bridge Crews using Culvert Authorizations, with design information being provided in the form of sketches, written instructions, or site specific 'P' drawings. A substantial amount of supplementary design information was also provided on the standard drawing S-1418, "Installation of Large Steel Pipes". Since AT currently outsources culvert design and construction, it is appropriate that the process for handling the design and installation be reviewed.

Considerations:

- Site specific drawings provide an accurate representation of actual conditions (channel slope, geometry, geotechnical conditions, etc.), and can emphasize the size and/or complexity of a structure when required.
- Drawings substantially reduce ambiguities that cannot be clarified easily through written instructions.
- Culverts may be installed by an inexperienced workforce.
- "As constructed" details provide useful records for future maintenance and design.
- Innovations in culvert material types or construction techniques, including the use of precast concrete or PVC culverts and tunnelling.

Recommendations:

- In addition to the current version of standard drawing S-1418 'Installation of Large Metal Pipes', a site specific 'P' drawing(s) should be produced for all bridge size culverts.
- Drawing S1418 is not applicable to flexible bridge culverts of greater than 3000mm diameter or to non-flexible bridge culverts.
- All details shown on the 'P' drawing should be to scale.
- Drafting standards and standard details shall be in accordance with section 2 of the "*Engineering Drafting Guidelines for Highway and Bridge Projects*".

3 RIGHT-OF-WAY AND EASEMENTS

Background:

The department can be held responsible for problems whose cause can be attributed to, or associated with, the structure. Construction or maintenance at a culvert site generally results in disturbance of stream banks and/or streambed. As such, there is a tendency for erosion to occur adjacent to a structure. Streams, in general, are considered active features which evolve in time, often time independently of any manmade infrastructure. Such processes include lateral stream mobility, degradation, and bed sediment transport.

Considerations:

- Ensure structure(s) and associated protection works are not on private property.
- Ensure right of way for construction entry and maintenance.
- During design, allow for natural process, such as lateral movement of the watercourse.
- Shape of the right of way should be convenient for surveying and tying-in.
- Future maintenance or construction such as road widening, or slope improvement.

Recommendations:

- Right of way or easement should be acquired for the structure, associated protection works, and future maintenance. This should be shown on site specific 'P' drawings and/or stated in the written instructions.
- In general, an allowance of approximately 5.0 m should be taken beyond the limits of protection work when establishing the right of way area. The shape of the area should be kept simple and defined by limits that can be conveniently tied into the survey.
- Temporary field access agreements with land owners may be a cost effective option during construction or major rehabilitation works.

4 HYDROTECHNICAL DESIGN PARAMETERS

Background:

In order to properly size a bridge culvert, it is necessary to determine the design flow or range of flows that the culvert is expected to operate under.

Considerations:

- Drainage Area
- Channel Geometry
- Historical Information
- Topographic Survey Information

- Basin runoff Potential
- Channel Capacity

Recommendations:

The design flow for bridge size culverts is to be estimated as per Section 2.2 of the current version of the AT "*Bridge Conceptual Design Guidelines*". This document outlines the use of three techniques: Channel Capacity, Historic Highwater Observations, and Basin Runoff Potential in determining hydrotechnical design parameters, namely flow depth (Y), mean channel velocity (V) and flow (Q).

5 CULVERT SIZING

Background:

Sizing of bridge size culverts based on hydrotechnical design parameters requires consideration of the expected performance, cost, and associated risks of various culvert options under design flow conditions. Fixed rules such as specified amounts of freeboard or degrees of constriction can be easily applied to determine a culvert size but do not necessarily optimize the crossing dimensions or take all of the site specific factors into account.

Considerations:

- Hydrotechnical design parameters
- Cost
- Potential flooding impacts (land use, AADT)
- Fish passage
- End protection works
- Geotechnical conditions (uplift, slope stability)
- Barrel opening blockage (drift, beaver dams, icing)
- Future maintenance/rehabilitation (lining for high traffic roads/high fills)
- Size/shape availability from suppliers

Recommendations:

Guidance on sizing of culverts can be found in section 2.3 of the current version of the AT "*Bridge Conceptual Design Guidelines*".

6 FISH PASSAGE

Background:

The department supports the initiative that culverts on fish bearing streams should be designed to allow for the movement of fish.

Considerations:

- Provincial *Water Act*
- Federal *Fisheries Act* (DFO requirements)
- Minimizing environmental impact
- QAES assessment
- Culvert velocities
- Culvert embedment (burial depth)

Recommendations:

Guidance on assessment of fish passage at culverts can be found in section 2.3.4 of the current version of the AT "*Bridge Conceptual Design Guidelines*".

For sites where substrate and holders are considered to reduce velocities, the following parameters are recommended:

- *Substrate holder should be made of steel and conform to the shape of the pipe up to the desired height.*
- *Height of substrate holder should be 0.3m (0.2m if pipe diameter < 3m)*
- *Spacing of holders should be in the range of height divided by slope of pipe (minimum spacing = 7m)*
- *Substrate should be Class 1M or Class 1 rock, with an average thickness matching the height of the holder.*
- *Substrate and holders are only required for portions of the pipe where the mean velocity exceeds the mean channel velocity (typically the upstream portion of the pipe).*
- *Materials shall conform to most recent version of the "Standard Specifications for Bridge Construction"*

7 BURIAL DEPTH

Background:

Historically, culverts were installed to match the existing streambed elevation, oftentimes with little or no end protection works. With many Alberta streams being classified as "geologically young", the bed of these streams naturally degrade as the stream matures. As well, culvert installation can result in locally increased velocities at the culvert outlet. The combination of these factors has, in the past, led to scour holes, bank erosion and 'hanging' or perched outlets developing, resulting in a permanent barrier to upstream fish passage.

Considerations:

- Natural stream maturation (degradation)
- Perched outlets or piping
- Velocities at the culvert outlet

- Hydraulic efficiency of culvert
- Costs

Recommendations:

Culvert inverts should be buried one quarter of the rise (D/4) below the average natural streambed up to a maximum depth of 1 m. Exceptions to the recommended burial depth may be considered when site specific features require special attention. This may include reducing the burial depth if competent bedrock is encountered or increasing upstream burial depth as a result of historical stream degradation.

8 SCOUR/EROSION PROTECTION

Background:

At some culvert sites (particularly older ones), erosion protection is not in place resulting in scour and/or erosion issues. These issues can lead to such problems as impeded fish passage, scour holes, piping, and slope failure. Unless remedial measures are taken, the culvert's structural integrity may be compromised, potentially leading to failure.

Considerations:

- Design hydrotechnical parameters
- Culvert velocities
- Streambed material and susceptibility to scour/erosion
- Embankment slopes
- Fish Passage

Recommendations:

Guidelines for river protection works at culvert ends can be found in section 2.4 of the current version of the AT "*Bridge Conceptual Design Guidelines*". Specifications for rock riprap and geotextile can be found in Chapter 10 of the "*Standard Specifications for Bridge Construction*". The current version of standard drawing S-1418 should be used as a guideline for minimum requirements and typical layout.

9 BACKFILL MATERIAL FOR FLEXIBLE CULVERTS

Background:

Structural integrity of flexible culverts comes from the backfill material placed around the structure and the manner in which it is placed. Structural issues arising in culverts are often the result of unsuitable backfill material (unacceptable gradation, plasticity, moisture content, etc.), poor compaction, or the use of frozen material, all experienced during the construction phase. Structural integrity can also be compromised by such instances as freeze/thaw cycles, piping, and inlet/outlet scour. When selecting a backfill material, it should be recognized that granular material has higher shear strength, compacts more readily, and requires less control or effort to place than clay material.

Considerations:

- Compaction and moisture content
- Shear strength
- Bearing strength, settlement, and consolidation
- Drainage
- Potential for frost heave (soil plasticity)
- Temperature during installation

Recommendations:

Approved granular backfill should be placed around the barrel of all flexible culverts to form a structural backfill envelope along with an approved clay material to form seals. Refer to the current version of the "*Standard Specifications for Bridge Construction*", Section 2 'Backfill' and/or the current version of standard drawing S-1418, for the required gradation and quality control for backfill materials.

The use of only crushed aggregate material for the backfill envelop may be considered if any of the following conditions exist:

- Little or no difference in price between pit run gravel and crushed aggregate,
- Quality of locally available pit run is known to be of poor quality,
- High cover and/or weak foundation material,
- Presence of natural springs in the material above the culvert (can be problematic during freeze/thaw cycles).
- Corrosive environment

10 STRUCTURAL BACKFILL ENVELOPE

Background:

In addition to using compacted granular fill on a firm foundation, the shape and size of the backfill envelope is a critical factor in ensuring structural integrity of a flexible culvert. The shape shown on the current version of standard drawing S-1418 has performed well under "normal" conditions. Special consideration to the structural envelope must be taken with large diameter (greater than 3.0 m) culverts and/or adverse geotechnical conditions exist.

Considerations:

- Size of backfill envelope
- Practical installation procedures
- Culvert material
- Bearing capacity of foundation

- Economics vs. structural performance

Recommendations:

- In general, the backfill envelope shape shown on the current version of standard drawing S-1418 should be used for flexible culverts.
- For structures with an equivalent diameter of 3000 mm or less, the shape and dimensions shown on drawing S-1418 should be used.
- For structures with an equivalent diameter between 3000 mm and 4500 mm, a similar, but structurally enhanced envelope should be used and specified on site specific drawings. Enhancements could include increased width and/or depth of excavation and/or increased thickness of granular material above the crown.
- For major culvert structures (as defined in Section 1), a site specific backfill shape should be designed.
- For non steel structures, a site specific backfill shape should be designed.
- When soft foundations exist, the use of a woven geotextile filter fabric at the base of the excavation between the clay seals, as shown on the current version of standard drawing S-1418 is recommended. Woven geotextile filter fabric specifications are listed in section 18 of the "*Standard Specifications for Bridge Construction*".

11 CLAY SEALS

Background:

From a strength perspective, it is desirable to have compacted granular material placed around a flexible culvert structure especially beneath roadway travel lanes. Clay seals are typically provided at the ends of culverts to impede seepage around the exterior walls of the culvert and prevent piping. However, on large diameter culverts, especially those with low to medium cover, clay seals may extend beneath the roadway a significant amount.

Considerations:

- Potential for piping to occur
- Competency of granular backfill
- Potential for frost heave
- Attainability of suitable clay material

Recommendations:

- At natural streams, where cover is greater than span/2.25, clay seals should be constructed as per the current version of standard drawing S-1418.
- At sites where cover is less than or equal to span/2.25, or where suitable clay material is unattainable, clay seals as per standard drawing S-1418 with a modified

slope interface should be installed. The slope interface between the clay and the granular backfill material should be placed at 1H: 2V.

12 ROAD GEOMETRICS

Background:

Oftentimes, the design of a culvert also includes the design of the approach roadway over the culvert. The road geometric parameters should be optimized to consider AADT, road use, costs, location, etc.

Considerations:

- Current and potential traffic volumes
- Initial and future construction (detours, culvert extensions, etc.)
- Costs
- User safety
- Future roadway classification or plans

Recommendations:

Guidelines for the optimization of roadway design related to a culvert crossing can be found in the current version of the AT "*Bridge Conceptual Design Guidelines*".

13 ROADWAY WIDTH

Background:

In general, the design width for roads is based on roadway design life of 15 to 20 years whereas culvert structures are based on a design life of 50 years or more. Extending the length of an existing metal culvert due to road widening has resulted in structural and fish passage issues, oftentimes developing from the original culvert installation. If a barrier system is proposed for a culvert crossing, the roadway width should be adjusted to account for it.

Considerations:

- Provision of additional width for future widening,
- Land impacts/Right of Way needs
- Safety
- Design speed/AADT
- Desirable clearzone/barrier warrants
- Fill height (construction costs/accessibility)
- Shy distance if guardrail installed,
- Economics of installing a longer culvert now versus lengthening in the future

Recommendations:

- Provide additional length if future widening has been identified.
- If a barrier system is proposed, the roadway width should be adjusted to account for shy offset to the barrier, barrier dimensions, and lateral support and/or deflection distance behind the barrier.

14 SIDESLOPES

Background:

For economic reasons, older culverts were often constructed with sideslopes steeper than 3:1. Problems such as slumping and crushed bevel ends have been identified at older culvert sites. This is often associated with poor foundations and/or unstable sideslopes.

Considerations:

- Safety of the travelling public and roadside obstacles
- Slope stability and/or structural integrity
- Land impacts/RoW needs
- Economy, (guardrail protection versus clear zone limits),
- AADT/road classification
- Aesthetics
- Access path above structure (wildlife, pedestrians, etc.)
- Construction practices

Recommendations:

A minimum sideslope of 3:1 is to be used for culvert sideslopes. A 4:1 sideslope (recoverable) with no guardrail should be evaluated. In some cases, a 4:1 slope through the clear zone, followed by 3:1 outside the clear zone may be optimal (no guardrail). The minimum horizontal distance between the edge of the shoulder and the end of the barrel is 4.0 m.

Steeper sideslopes may be considered during construction (particularly during tunnelling installations to minimize the extent of tunnelling required), on the basis of geotechnical recommendations. At all times, an acceptable factor of safety must be maintained.

15 LENGTH OF STRUCTURES

Background:

Structure length calculations are based on subgrade width and elevation, sideslopes, berms, bevel ends, invert elevations, slope, skew, and other site specific details, as applicable.

Considerations:

- Roadway width
- Future roadway upgrades including overlays
- Roadway geometrics
- Sideslope stability
- Bevel ends
- Burial depth
- Fill height
- Site specific details
- RoW

Recommendations:

- Use the recommendations concerning sideslopes, berms, bevel ends and burial depth given elsewhere in this Guideline. Refer to the current version of Section C 'Cross-Section Elements' of the Highway Geometric Design Guide for guidance on the appropriate roadway subgrade width

16 MINIMUM COVER REQUIREMENTS FOR STEEL CULVERTS

Background:

Various codes (AASHTO, CSA, SCI) have proposed a range of minimum cover requirements for soil steel structures.

Considerations:

- Live load impact effect on structures with cover less than 600 mm,
- Questionable shear strength of shallow depth of soil over crown (particularly on horizontal ellipse culverts),
- Potentially reduced cover due to rutting,
- Top plate bending, and not ring compression, may develop in long span culverts as defined by AASHTO Clause 12.6,
- Minimum cover for construction equipment,
- Alberta Transportation has adopted the provisions of Canadian Highway Bridge Design Code (CHBDC) "CSA-S6-14" for the design of culverts: Unless noted otherwise the design live load is CL 800 plus Dynamic Load Allowance.

Recommendations:

- Minimum cover provided shall be in accordance with the requirements of the current version of the CHBDC or 600mm, whichever is the greater. The minimum cover should be taken as the least dimension between the crown of the culvert and the edge of the shoulders.

- If the highway is to be paved within the same construction season that the culvert is installed, then pavement structure depth may be considered as cover provided that a factor of safety of 1.5 is maintained during paving operations.
- For strength requirements during construction, refer to Clause 7.6.3.3.1 of the CHBDC. Where the above criteria cannot be met, special considerations to mitigate the lack of cover (such as a concrete distribution slab) may be required. These recommendations do not apply to concrete structures.

17 BEVEL ENDS

Background:

Bevel ends retain the sideslopes and transition slopes at the ends of a culvert, and are designed to enhance hydraulic performance by minimizing entrance and exit losses. They also provide an aesthetically pleasing termination to a structure.

Considerations:

- Stability of sideslopes, transition slopes and protection works
- Aesthetics and serviceability
- Termination of fences
- Difficulty in pouring concrete
- Temporary support for large diameter CSPs
- Material type
- Connection details, including fish passage

Recommendations:

- Bevel slopes should be no steeper than 2:1 for stream culverts.
- Depending on site specific geometry, or fencing requirements, use square ends, 1:1 or 2:1 for terminating cattlepass culverts.
- All bevels are to be cut perpendicular to the longitudinal axis (i.e. do not cut top arc on a skew).

18 GEOTECHNICAL

Background:

Geotechnical issues can affect the efficiency and safety of culvert installation and operation during the life cycle.

Considerations:

- Culvert construction delays, scope changes, costs due to encountering soft soils and seepage
- Potential for failure of backslopes during excavation

- Settlement/consolidation of the culvert resulting in invert curvature and ponding within the structure
- Site specific geotechnical information
- Fill height
- Backfill material

Recommendations:

A desktop geotechnical study (as per Engineering Consultant Guidelines (ECG) Vol. 1, section 7) should be completed for all bridge size culvert crossings. Results of this study should include

- Comment on the risk of encountering soft soils and seepage issues, potential for backslope failures, and settlement (camber) issues.
- Guidance on the anticipated depth of any recommended test holes.
- Comment on the suitability of retaining/removing an existing bridge headslope due to potential settlement.

Ideally, this desktop study will be completed at the project scoping stage. If this has not been done, the desktop study should be included in the engineering design assignment, and further geotechnical investigation and analysis included as a deletable item, with the decision to include it depending the results of the desktop study.

Based on the results of the desktop study, the feasibility of a buried structure option may be called into question and this should be considered in selection of optimal crossing solution (see Bridge Conceptual Design Guidelines).

Additional geotechnical investigation and analysis (as per ECG Vol. 1 Section 7) shall be obtained in the following cases:

- Embankment height above the existing ground is greater than 6 metres and the foundation material has not been previously pre-consolidated.
- Foundation and/or embankment material is known or suspected to be poor
- Significant issues were identified by the desktop study.
- The crossing is a major bridge culvert (see section 1)
- A life expectancy in excess of 50 years is highly desirable (high AADT, high fills, strategic crossings, long detours, etc.)
- Tunnelling techniques are the anticipated construction method.

In these cases, recommendations on construction issues and techniques, backslope configuration, and camber to address potential settlement should be updated based on this analysis. Camber requirements should be defined by calculating the required amount for at least five stations along the stream bed.

19 BED PRESHAPING

Background:

Prior to placing the bottom plates, a layer of loose, fine granular material matching the curvature of the bottom plates is usually placed between the inside faces of the clay seals. Bed preshaping reduces pipe deflections during assembly, minimizes pipe rotation during backfilling, and helps ensure uniform contact between the bottom surface of the pipe and the bed.

Considerations:

- Flexibility during assembly
- Difficulty in placing and compacting
- Rotation during backfilling
- Improved uniform contact between bed material and pipe

Recommendations:

- A preshaped bed should be designed and used for the installation of round culverts with a diameter greater than 3.0 m, horizontally ellipse culverts, and shapes with flat radius bottom plates.
- Prior to placing the bottom plates, a layer of loose, fine granular material (200 mm thick) should be placed above the granular portion of the bed to match the curvature of the plates over the preshaped bed. Clay seals at culvert ends should be shaped similarly before bottom plate placement.
- It should be ensured that granular material does not penetrate through the clay seals.

20 CONCRETE END TREATMENT

Background:

Uplift forces from hydrostatic pressures have in the past resulted in culvert failure due to bending as well as 'hanging outlets'. Contributors to this issue include dead load reductions at culvert ends (amount of fill), structurally inferior ends, scour/erosion issues, and construction issues. Pipe ends have also known to become damaged/deformed from maintenance activities such as grass cutting.

Considerations:

- Potential for piping
- Potential for uplift
- Slope stability
- Icing and/or drift problems
- Reduction of hydraulic losses

- End stiffening
- Aesthetics

Recommendations:

The following table should be used as guidance. The equivalent diameter (D) is to be based on the total pipe area (A); $D = \sqrt{\frac{4A}{\pi}}$

Equivalent Pipe Diameter (m)		
< 3.0	3.0 to 4.5	> 4.5
Should consider concrete end treatment if: (a) Sideslopes and/or transition slopes prone to sliding, (b) Heavy ice or ice jams are likely, (c) Potential for ponding to occur, (d) Drift problems likely. (e) Steep culvert slope.	Typically provide concrete end treatment at the upstream end only. Provide concrete end treatment at both ends under the following conditions: (a) If velocities are greater than 2.0 x average stream velocity under design conditions (b) For aesthetic reasons.	Provide concrete end treatment at both ends.

Concrete end treatment is to be constructed in accordance with the current version of standard drawings S-1444 and S-1445.

21 SPACING OF MULTIPLE CULVERTS

Background:

Multiple culvert installation can be an appropriate and acceptable engineering solution in low cover situations, for wide channels, or in culvert icing situations. Minimizing culvert spacing to reduce the amount of granular and clay material needed while still maintaining structural integrity is desirable.

Considerations:

- Gradeline (low cover, unbalanced loads)
- Channel Geometry
- Cost

- Passage of drift
- Icing
- Fish passage
- Construction
- Skewed and/or staggered culverts
- Material type

Recommendations:

- Multiple culverts should be a good fit to the natural channel (i.e. equivalent bed width created should be similar to that of the natural channel bed). Flow expansion should be avoided.
- Overflow culverts outside of the natural channel (typically placed at a higher elevation or lateral distance away) should be considered when icing concerns are noted.
- Horizontal spacing between adjacent culverts should be at least 1.0 m or span/3 of the larger span, whichever is the greater.
- Placement and compaction of crushed granular material (Des. 2, Class 40) between pipes should be in accordance with drawings and specifications.
- Site specific backfill design details are required for sites with multiple pipes.

22 SITE INSPECTIONS DURING INSTALLATION

Background:

Historically, culverts were designed by the Department, and installed by Road Authorities using their own forces, contractors, or bridge crews. Currently, the design, tender, and construction of all Provincial bridge structures are performed by Consultants.

Metal culverts are complex structures that rely heavily on the surrounding backfill for structural integrity. Under loading, the flexible metal pipe deflects slightly, and through this movement transmits radial forces to the surrounding backfill. This interaction results in the development of ring compression in the pipe, leading to a state of static equilibrium. The soil component of this 'system' provides the majority of the load carrying capacity. As long as the integrity of the surrounding backfill remains, the culvert will perform satisfactorily.

Poor installation practices have led to foundation and backfill failures, resulting in excessive bending, deflection, or ultimate structural failure of the pipe. Typically these problems result in remedial action, and/or premature replacement of the structure. There are several factors which contribute to a poor installation including an inexperienced workforce, unstable or weak foundation material, poor bed preparation, inappropriate or frozen backfill material, poor compaction, incorrect assembly of plates etc. Past experience has shown that one of the most effective methods of combating the likelihood of these problems is to ensure that an appropriate level of inspection is carried out at all stages of the culvert installation.

Considerations:

- Quality control
- Cost
- Performance and structural integrity
- Future maintenance
- Construction technique (open cut vs tunnelling)
- Geotechnical conditions

Recommendations:

The Consultant shall provide bridge construction services as outlined in the *Engineering Consultant Guidelines Vol. 2* and as per the current version of the *Bridge Construction Inspection Manual*.

Additional construction inspection requirements should be considered when difficult geotechnical conditions are anticipated and on tunnelling projects.

23 WATERPROOFING CONCRETE ELEMENTS

Background:

Protecting structures from the corrosive effects of de-icing salt is an ongoing issue. Measures currently being taken to protect concrete structures include waterproofing systems, protective sealers, extra cover for reinforcement and epoxy coated reinforcement. Exterior surfaces of buried concrete structures typically receive a protective sealer which has been considered adequate to date. Concern has been expressed that over time buried concrete structures under low fill situations may be adversely affected by salt to the same degree as concrete decks.

Considerations:

- Future maintenance
- Inability to inspect buried concrete surfaces or those covered by structural plates

Recommendations:

- Apply an approved Type 1C sealer (see *Alberta Transportation Products List)* to all surfaces that may be in contact with de-icing salts. The sealer shall be applied in accordance with section 4 of the *Standard Specifications for Bridge Construction*. All elements requiring a sealer should be identified in a contract special provision.
- Consider the use of corrosion resistant reinforcement or increased cover for exposed concrete elements (headwalls, curbs, etc.) where de-icing salts are likely to be used.

24 EXTENSIONS

Background:

Placement of additional fill over an existing culvert can lead to problems such as further settlement of the embankment and/or foundation. The resulting redistribution of loads can cause the pipe to become distressed, resulting in cracked seams or barrel deformation. Once in contact with soil, a culvert will start to lose its galvanic protective coating, with the amount and rate depending on the culvert age and soil corrosion potential. When a culvert extension is placed, dissimilar metals (with different degrees of galvanic protection) come into contact. This can result in a corrosion cell, causing more rapid corrosion in the area of contact between the original culvert and the extension.

Considerations:

- Structural adequacy
- Condition of existing culvert (deformations, cracked seams, corrosion)
- Hydraulic adequacy
- Fish Passage
- Cost (extension, replacement, detours)
- Existing soil conditions (moisture content, corrosion potential)
- Geotechnical conditions (differential settlement)

Recommendations:

A detailed engineering assessment including life cycle costing should be performed prior to extending any culvert. In general, metal culverts should not be extended if any of the following criteria apply:

- The BIM general rating for the barrel is 4 or less,
- The culvert is structurally or hydraulically inadequate,
- The proposed grade raise exceeds 2.0 m,
- The resulting culvert length is greater than deemed acceptable for fish passage.

Note *Further information on culvert management strategies can be found within the 'Bridge Management Strategy Guideline'*

25 LOW LEVEL CROSSINGS

Background:

Under rare conditions, it may be considered appropriate to install a low level crossing. Typically, this would be on extremely low volume traffic local roads where loss of roadway use for a short period of time would not be a major inconvenience, or where it is considered uneconomical to replace a bridge for occasional traffic such as land access or seasonal farm equipment.

Considerations:

- Acceptable level of inconvenience
- Safety
- Hydrotechnical design parameters
- Cost
- Risk
- Potential for drift and ice
- Environmental concerns, including fish passage

Recommendations:

- When feasible for low AADT and non-critical routes, the use of a low level crossing may be considered. Typically land access and temporary crossing situations would fall into this category.

26 CATTLE PASSES

Background:

The provision of a cattlepass, (which may sometimes also include accommodation for small vehicles and/or pedestrians), can be part of right-of-way negotiations and agreement. To reach an equitable solution, several factors are considered (size, costs, land severance implications, land values, etc.). Based on the outcome of these considerations and discussions with the landowner, a recommendation as to whether to offer the owner a cattlepass, other benefits, or a cash payout is made by the right of way buyer.

Considerations:

- Traffic volume
- Animal volume
- Frequency of crossing
- Land severance
- Right-of-way acquisition
- Costs
- Stormwater management and highway drainage

Recommendations:

- Minimum rise of cattlepass structures should be 2200 mm.
- A concrete floor, to a minimum depth of 150 mm, with a rough textured surface or a compacted granular floor should be considered.
- Length should be determined such that sideslopes terminate at the top of the floor level when no bevel is used.

- Surface water should not pond inside the structure. This could be achieved by setting the inverts slightly above adjacent ground, by longitudinally sloping or crowning the inverts, or by employing ditch drainage when necessary.

27 OPENING MARKERS

Background:

Pedestrians or others travelling along the right-of-way may be at risk if the inlet/outlet of a bridge size culvert is concealed by vegetation or snow.

The Attorney General's office has recommended that, to minimize liability, some type of guardrail or fence system be installed when it is known that people will frequently be in the vicinity of a culvert and possibly suffer a serious injury from a fall.

Considerations:

- Safety
- Proximity to residential or recreational areas
- Height of cover
- Liability

Recommendations:

- Consider installing a marker system and/or warning signs at all culvert sites located within or near residential or recreational areas.
- Provide railings for all pedestrian walkways located immediately adjacent to culvert ends.

28 CORROSION SURVEY AND SERVICE LIFE PREDICTION

Background:

Corrosion is a natural process that breaks steel down into its constituent components, and can govern the effective service life of steel culverts. A corrosion survey and analysis can be used to identify appropriate material type, thickness, and coating to reach the minimum service life of 50 years.

Considerations:

- Soil resistivity and pH values in the area
- Existing (and nearby) structure’s performance, if applicable
- Potential for future lining – AADT, height of cover
- Lifecycle costs

Recommendations:

A corrosion survey should be completed for sites where a bridge-size metal culvert is a likely solution. Corrosion survey and design life estimation shall be carried out by a qualified Corrosion Specialist, at sites known or suspected to have a corrosive environment, with moderate to high traffic volumes and/or a considerable height of cover.

Resistivity and pH values of the soil should be taken on the road sideslopes (each side) and from the upstream and downstream banks. Resistivity and pH values of the water should be taken upstream and downstream of the site. If the existing structure is a metal culvert, static potential reading should be carried out at 3, 6, 9, and 12 o'clock positions at the upstream and downstream ends.

These values can be used with prediction tools to assess the ability of a range of culvert configurations (material type, thickness, and coating) to obtain the expected minimum service life of 50 years. The predicted service life will be the lesser of time to first perforation based on soil side (based on average of soil pH and resistivity values) and water side (based on average of water pH and resistivity values) corrosion. For analysis, a 50 year life may be assumed for metal culverts and a 75 year life for concrete culverts. Note that an oversized steel pipe with lining between years 40 and 50 is an additional life cycle strategy that can be considered in high traffic volume/high fill cases.

Tools that can be used to estimate service life for various steel culvert configurations are available in the current version of the CSPI *"Handbook of Steel Drainage & Highway Construction Products – Canadian Version"* and associated online Technical Bulletins

*A*dditional information can be found in the AT document *"Best Practice Selection of Culvert Types"*. If static potential readings are available for the existing pipe, they can be used to estimate the rate at which the existing galvanizing is being consumed, and confirm the predicted life values from these tools.

Guidance on available culvert types and materials can be found in the *AT Products List* and Section 18 of the Standard Specifications for Bridge Construction. Selection of the optimal culvert configuration that meets the required service life should be based on life cycle economic analysis. Oversizing to allow for future lining may be a cost effective strategy at sites where open-cut replacement would be expensive or require extensive traffic accommodation (high fills, high traffic volume). Cathodic protection systems are not endorsed by the department as service life extension strategies, as they have historically proven to be difficult and costly to maintain/operate.

29 CULVERT DESIGN PROCESS

See Section 10 and Appendix "J1" of the current version of the "*Engineering Consultant Guidelines for Highway and Bridge Projects – Volume 1*" for requirements.

30 SITE SURVEY REQUIREMENTS

The site survey data is used to assess the water flow characteristics of the existing channel and to determine the location and dimensions of the existing and/or proposed crossing or improvement works. It is necessary that all the survey information gathered be accurate in order to optimize the bridge design. Sufficient information should be collected to enable conceptual design (see Section 3.1 of the *Bridge Conceptual Design Guidelines*) and contract drawings (see *Engineering Drafting Guidelines for Highway and Bridge Projects*).

31 FREQUENTLY USED STANDARD DRAWINGS

Current standard drawings for bridge size culverts are listed at on the *Bridge Engineering web page.*

32 TUNNELLED CULVERTS

Background:

Tunnelled culverts may be an alternative to open-cut culvert installation for some sites and certain size ranges. The main benefits of this approach are less interference with traffic during construction, less grading work, and the potential for an accelerated schedule.

In most cases, this will involve a thick wall welded steel pipe (WSP) and a combination of jacking (advancing the WSP into the fill by ramming), and boring (removing the fill from within the WSP).

An automated approach utilizing special equipment has proven to be cost competitive for pipe sizes up to 1.8m in diameter. This technique may be feasible for sizes up to 2.5m in diameter, but costs may be affected by availability of experienced contractors and equipment. For larger sizes (WSP pipe is available up to 3.6m in diameter), fill removal by modified bobcat within the advanced WSP may be feasible.

Other techniques that do not involve jacking WSPs may be available, such as tunnel boring machines (used for light rail transit and storm drains in larger cities) and tunnel liner plates.

Considerations:

- Traffic impact of open-cut excavation
- Risk of failure to advance - length of tunnel, geotechnical conditions

- Risk of not achieving horizontal/vertical alignments
- Cost of tunnelling vs open-cut
- Availability of contractors
- Future maintenance (unexpected settlement, seepage, debris)
- Schedule
- Equipment limitations (length limits, diameter limits)
- Impact of smooth wall pipe on velocities for fish passage
- Potential need to realign the channel for new pipe
- Availability of construction area to set up ramming equipment
- Connection details between bevel ends if different materials are used (potential corrosivity differential, debris accumulation, fish passage, inspection, costs)

Recommendations:

- Consider jack and drill WSP options if pipe size is relatively small (<3m), fill height is significant (>5m), or traffic volumes are significant (>2000vpd).
- Undertake a cost analysis of options and consider risks. A moderate increase in initial cost over an open-cut option may be optimal if savings in user costs are significant.
- Undertake geotechnical drilling to confirm soil suitability and assess sideslope stability during construction.
- Consider tunnelling in the winter to minimize dewatering issues.
- Consider partial removal of sideslopes (i.e. partial open cut replacement) to minimize tunnelling distances while maintaining live traffic.
- WSP thickness should be sufficient to meet the 50 year design life for corrosion or the jacking forces, whichever is greater.
- Thinner/different materials (e.g. SP) may be considered suitable for culvert ends (where jacking through fill is not required). Cost savings should be confirmed as multiple types of construction will result.

33 RCP AND PBC STRUCTURES

Background:

Historically, reinforced concrete pipe (RCP) and precast box culvert (PBC) bridge sized culvert structures have only represented a small portion of Alberta Transportation's inventory, mainly due to higher capital costs and limited industry supply capacity in comparison to flexible steel structures. More recently, RCP and PBC structures have become more competitive and have been found to be the optimal solution for some sites.

Considerations:

- Cost (initial capital and lifecycle)
- Impact on traffic (longer life, quicker construction)

- Desirable lifespan
- Availability of suppliers
- Abrasion
- Capacity of contractors
- Construction schedule
- Geotechnical conditions
- Backfill requirements may differ from flexible structures
- Impact of smooth structures on velocities for fish passage
- Height of cover
- Soil and water corrosion potential

Recommendations:

- Consider RCP or PBC structures if height of cover is minimal, and upgrading the roadway geometry is undesirable.
- Consider RCP or PBC structures if high sediment bed loads are expected (abrasion) or corrosion is a major concern.
- Consider RCP or PBC structures if traffic volumes are high and significant user impact would result from future open cut replacement.
- Undertake a lifecycle cost analysis of options, considering risks, and site optimization. When comparing to steel culverts, consider the option of initially oversizing the steel culvert to allow for a liner to be installed when it is approaching the end of its life.
- Refer to Section 28 for service life prediction/life cycle analysis parameters
- Refer to CHBDC, Section 7.8 and section 26 of the most recent version of the Standard Specifications for Bridge Construction for requirements for detailed design, materials, connection details, installation, etc.
- Refer to supplier specifications for guidance on backfill requirements, specific cover requirements, and product availability/sizes.
- Develop site specific drawings.
- Consider tendering multiple options if steel and concrete options are similar.