3.0 CONSTRUCTION MATERIALS

3.1 General

Materials typically employed in the construction of water control structures include earth and rock materials; cast-in-place concrete; steel and specialty metals; wood; and various products fabricated from precast concrete, metal, and plastics as discussed below.

3.2 Earth And Rock Materials

3.2.1 Impervious Materials

Impervious fill is normally used to provide a relatively impermeable barrier to reduce seepage.

Generally, impervious fill should consist of low to medium plasticity clay as classified by the PFRA modified Unified Soils Classification system with a minimum of 50% passing the 80 μm sieve size and a maximum particle size of 150 mm. Immediately next to structures or other works such as instruments, a maximum particle size of 80 mm or less may be required. Non-plastic material should be avoided because it is vulnerable to piping.

In cases where high plasticity clay with a liquid limit greater than 50% is to be used as impervious fill, special care will be required during compaction to prevent the build up of excessive lateral earth pressures on the structure.

3.2.2 Filter and Drainage Materials

Filter and drainage materials are often used beneath and adjacent to water control structures to prevent piping and minimize the development of excess porewater pressures.

Filter and drainage requirements will primarily depend on the site condition, and also on the type, purpose, and size of the structure. For example, for a structure located on an impermeable foundation where little seepage flow is expected, the use of one layer of filter material may be all that is required. However, where higher seepage flows are anticipated beneath a large structure or due to a more pervious foundation, a two-zone arrangement, consisting of one layer of filter material and one layer of drainage material, may be needed. Under this arrangement, the filter material is placed between the insitu foundation material or impervious fill material and the drainage material.

Filter material consisting of clean, durable sand, is normally used to prevent the migration of insitu or fill materials which could lead to piping failure or the plugging of drainage systems. Drainage material, consisting of durable, clean gravel, is usually provided in cases where increased seepage capacity is required. Durability testing of filter material normally includes soundness testing using a magnesium sulphate solution in accordance with CAN/CSA-A23.2-9A-00.

The gradation of the filter and drainage materials is normally established using accepted filter design criteria as discussed in Section 6.4.

The use of a natural sand material is preferred over a crushed sand product since the former is less susceptible to particle breakdown during handling, transport, and compaction. Compaction requirements should be carefully chosen so that the appropriate densities can be attained without causing a reduction in permeability due to excessive particle breakdown. For major projects that require large quantities of filter materials or in instances where the source has been specified, field trials may be carried out to establish the amount of breakdown that will occur due to handling and transporting, the compactive effort required to achieve the required densities, and the breakdown due to compaction.

On small projects where it would be costly to produce a small quantity of job specific materials, consideration should be given to using gradations for commonly produced materials such as concrete (fine and coarse) aggregates. In particular, concrete sand, with a gradation that falls completely within the envelope defined by the gradation requirements of ASTM C33-01, has been used as filter sand.

The placement and compaction of filter and drainage materials should be closely monitored in the field to verify that over compaction, adverse particle breakdown, and segregation do not occur.

In addition to filter materials, geotextile fabrics can also be used to limit the migration of soil particles into coarser materials or to prevent soil materials from infiltrating into drainpipes or through pipe joints. As noted in Section 3.10, the Province does not use geotextiles in critical areas where its failure could have catastrophic consequences.

3.2.3 Riprap and Bedding Materials

Riprap is used to prevent erosion due to high flow velocities or wave action.

The riprap protection consists of at least one riprap layer, and one bedding layer; however in cases where the D_{50} of the riprap layer exceeds about 300 mm, a secondary bedding layer may be required.

Riprap should consist of clean, hard, dense, durable, sound fieldstone or quarried rock particles. Durability testing of riprap particles is currently based on the Durability Index and Durability Absorption Ratio as developed by the State of California Division of Highways. As part of this test, the apparent specific gravity of the rock material must exceed 2.5. Ideally, riprap should be obtained from proven sources.

Rocks that are laminated, fractured, porous, or otherwise physically weak are usually unsuitable for use as riprap. In cold climates, where sandstone, shale, weak metamorphic rocks, and some types of bedded sedimentary limestone are used as riprap, rock breakdown can occur, Matheson (1988). However, sandstone has been used in some instances where substantial volumes of such materials were readily available from required excavations, and therefore provided a significant cost advantage over imported materials. Under this scenario, a much greater thickness of sandstone was placed to account for the less durable nature of the material.

Bedding should consist of clean, durable, and sound cobble, gravel, and sand particles. Tests for soundness are performed in accordance with CAN/CSA-A23.2-9A-00 using a magnesium sulphate solution.

Typical riprap gradations developed and used by TRANS are provided in Table 3-1. The sizes shown in the table represent equivalent spherical diameters. Factors incorporated in the development of these gradations included providing a reasonable number of nominal sizes (D_{50}) of riprap at appropriate increments to satisfy most design requirements, consideration of filter criteria, and establishing a gradation envelope that facilitates production (i.e. avoids narrow bands that make production of the material excessively onerous). In cases where larger nominal size riprap than shown in Table 3-1 is needed, the designer should determine the appropriate gradation.

Table 3-1
Typical Riprap Gradations

Description	Rock Mass and Size	Percent Passing by Mass
Riprap with D_{50} = 175 mm	40 kg or 300 mm	100
	10 kg or 200 mm	30 to 70
	7 kg or 175mm	20 to 50
	3 kg or 125 mm	0
Riprap with D_{50} = 300 mm	200 kg or 500 mm	100
	90 kg or 400 mm	50 to 90
	40 kg or 300 mm	20 to 50
	10 kg or 200 mm	5 to 20
	5 kg or 150 mm	0
Riprap with D_{50} = 500 mm	700 kg or 800 mm	100
	300 kg or 600 mm	40 to 80
	200 kg or 500 mm	20 to 50
	90 kg or 400 mm	5 to 30
	40 kg or 300 mm	0

Guidelines for determining the gradation and thickness of the riprap and bedding materials that are needed to resist high flow velocities or wave action are provided in Section 11.0.

3.2.4 Nomenclature for Earthwork Materials

TRANS has developed a nomenclature system for use in designating and specifying earthwork materials on drawings and specifications as shown in Table 3-2. For projects where more material types are required, additional designations can be developed based on the type of material, its gradation, and permeability.

Table 3-2
Nomenclature for Earthwork Materials

Increasing Size and/or Permeability

Material Type	Drawing and Specification Designation
Impervious Fill	Impervious Zone 1A
Random Fill	Random Zone 2A Random Zone 2B
Filter Material	Fine Filter Zone 3A Coarse Filter Zone 3B
Gravel Material	Drainage Gravel Zone 4A Road Gravel Zone 4B Pitrun Gravel Zone 4C
Bedding Material	Fine Bedding Zone 5A Coarse Bedding Zone 5B Granular Armour Zone 5C
Riprap	Riprap Zone 6A Riprap Zone 6B Riprap Zone 6C

3.3 Concrete

3.3.1 Mix Ingredients

Mix ingredients for concrete include cement, supplementary cementing materials, fine aggregate, coarse aggregate, water, and admixtures.

In general, cement and supplementary cementing materials should conform to CAN/CSA-A3000-03, while the other mix ingredients should conform to the requirements of CAN/CSA-A23.1-00 and A23.2-00.

As noted in CAN/CSA-A23.1-00, Appendix B for Alberta, evidence of alkali-silica reactivity has been found in bridges, dams, and water management structures; virtually all gravels in the Province are at least moderately reactive based on the concrete prism test; and, chert, greywacke, carbonate cemented cherty sandstone, and quartzite were identified as the responsible aggregates.

Alkali aggregate reactivity (AAR) testing conducted by the Province of Alberta in cooperation with CANMET, has determined that aggregates, primarily in central and southern Alberta, should be considered potentially reactive, Roy and Morrison (2000).

As a result, unless conclusive AAR testing has been performed, the current approach being used by the Province is that all aggregates should be considered potentially reactive, and that preventative measures to mitigate AAR should be employed. These measures include:

- Limiting the total alkali content (Na_2O equivalent) of the cement to a maximum of 0.65%. Cement produced in the prairies generally has a total alkali content of between 0.55% and 0.65%, Roy and Morrison (2000).

- Limiting the amount of alkali (Na_2O equivalent) contributed by the cement to the concrete as outlined in CAN/CSA-A23.1-00, Appendix B, and CAN/CSA-A23.2-00, Standard Practice 27A.

- Using a sufficient amount of fly ash as outlined in CAN/CSA-A23.1-00, Appendix B, and CAN/CSA-A23.2-00, Standard Practice 27A.

- Minimizing the early design strength requirements to accommodate a lower cement content and a greater fly ash content in the mix.

3.3.2 Concrete Mix Design

In general, the preference is to design the concrete mix without overusing cement, and to employ fly ash as a substitute for cement. This approach will minimize temperature and shrinkage effects and the potential for AAR, and thereby improve the durability of the concrete.

3.3.3 Foundation Concrete

A layer of unreinforced foundation concrete (also sometimes referred to as lean concrete or mud slab concrete) may be used in advance of placing structural concrete to:

- Prevent weathering or disturbance of the underlying foundation materials.

- Protect any underlying drainage materials from contamination and displacement due to surface runoff or construction activities.

- Provide a good, clean working surface for placing concrete reinforcement and erecting formwork, particularly for large pours when there may be an extended delay between foundation preparation and concrete placement.

- Infill voids in order to level rock foundation areas. Foundation bedrock should be cleaned of loose material prior to placement of foundation concrete where a concrete structure is to be placed directly on the foundation.

A minimum compressive strength of 15 MPa at 28 days is generally used for foundation concrete, and a thickness of between 50 mm and 100 mm is ordinarily provided depending on the extent and type of construction work that will occur upon it. The surface of the foundation concrete should be levelled after placement to provide a reasonably even surface, free of excessive depressions or indentations that could trap dirt, debris, or water/snow/ice.

3.3.4 Structural Concrete

In general, the minimum compressive strength at 28 days, maximum water/cement ratio, and air content for structural concrete should be chosen based on the class of exposure for the concrete as defined in CAN/CSA-A23.1-00.

However for water control structures, the minimum compressive strength should not be less than 30 MPa at 28 days except for large, thick structures or elements thereof where thermal effects are a concern and the early design strengths (28 days) are not required. In such cases, a minimum compressive strength of 30 MPa at 90 days or longer period may be used.

In areas where high bearing stresses (e.g. post-tension anchorage zones), other strength considerations (i.e. areas of potential cavitation), or durability are a concern, strengths greater than 30 MPa at 28 days may be required.

3.3.5 Mass Concrete

Special measures should be considered for massive structures or elements thereof in order to reduce the temperature of the concrete during hydration, and thereby reduce the attendant volume changes which cause cracking.

At the Oldman River Dam Spillway (1992) and the St. Mary Dam Spillway (1998) projects, mass concrete was used within the interior sections of large, thick elements such as the piers, walls, and base slabs at the headworks (minimum 25 MPa at 90 days), and massive structures such as the gravity flip bucket (minimum 20 MPa at 90 days). A skin of reinforced structural concrete (minimum 500 mm thick) encases the mass concrete and provides durability.

For these projects, mass concreting measures have included:

- Minimizing the amount of cementitious material required in the concrete mix by not requiring the specified concrete compressive strength to be reached until 90 days, and by incorporating 80 mm coarse aggregate.

- Replacing a portion of the cement with fly ash.

- Limiting placement temperatures to between 5°C and 10°C, largely through the use of liquid nitrogen to pre-cool the mix. The injection of liquid nitrogen directly into the central mixer has proven to be an efficient and effective method of pre-cooling the concrete to the required placing temperatures.

- Limiting the height of pour, and the wait time between adjacent pours.

- Extending the curing period to a minimum of 14 consecutive days.

- Limiting the temperature rise during concrete hydration to a maximum of 22°C. Adiabatic testing was performed during the trial mix program to determine the temperature rise.

For mass concrete containing 80 mm coarse aggregate, it is preferred that a central mixer be provided at the batch plant in order to produce concrete that is thoroughly mixed to a uniform mass.

3.3.6 Roller Compacted Concrete

Since 1980, roller compacted concrete (RCC) has been used in the construction and rehabilitation of concrete gravity dams as well as to provide overtopping protection and added spillway capacity for embankment dams. It has been successfully used on many projects in the Unites States, and is becoming more widely accepted in Canada. Design information for RCC can be obtained from USACE EM 1110-2-2006 (2000), ACI (2000), and PCA (2000).

Durability concerns for RCC are primarily related to its resistance to freezing and thawing and to erosion due to high velocity flow as discussed in USACE EM 1110-2-2006 (2000). For freeze/thaw exposure conditions and in areas that will be subjected to high velocity flows on a frequent basis, measures such as employing a minimum design compressive strength of 20 MPa, using an air-entraining admixture in the mix to increase its air content, and/or providing an outer protective layer of conventional air-entrained concrete should be considered to improve durability.

For large, thick sections, where heat generation and cracking is a concern, a number of the mass concreting measures described in Section 3.3.5 can be employed.

3.3.7 Precast Concrete

Precast concrete manholes, pipes, and bridge girders are often incorporated in the design of water control structures.

Precast concrete manholes are normally designed and manufactured in accordance with ASTM C478-03 using concrete with a minimum compressive strength of 30 MPa. For deep installations or where higher lateral earth pressures may occur, a special design may be required. For the base of the manhole, a monolithic base manhole unit is preferred.

Precast concrete pipes are discussed in Section 3.5.2.

Precast prestressed concrete bridge girders are commonly manufactured using concrete with a minimum compressive strength of 35 MPa at 28 days. Prestressing is generally not performed until the concrete has attained a minimum compressive strength of 28 MPa.

3.3.8 Concrete Reinforcement

Concrete reinforcement should usually consist of Grade 400 deformed bars conforming to CAN/CSA-G30.18-92.

The use of epoxy coated reinforcement conforming to ASTM A775-04a may be considered where the concrete will be exposed to deicing chemicals or chlorides, such as on bridge decks and curbs, or at other locations where added corrosion protection is required. However, examples of unsatisfactory corrosion protection performance of epoxy coated reinforcement have been reported.

3.4 Metals

3.4.1 Structural Steel

Structural steel should normally conform to CSA-G40.21-92, Grade 300W or 350W, which is the standard, weldable steel used where notch toughness at low temperatures is not a design requirement.

Hollow steel sections should normally conform to CSA-G40.21-92, Grade 350W.

3.4.2 Specialty Metals

In general, specialty metals consist primarily of stainless steel and aluminium members.

Stainless steel bars and shapes should ordinarily conform to ASTM A276-04.

Aluminium components should conform to CAN3-S157-83. Alloy 6063-T54 is ordinarily used for semi-structural applications (ladders, stair treads) whereas alloy 6351 or 6061 is usually used for structural applications. In cases where aluminium components will be embedded in cast-in-place concrete, contact surfaces (between aluminium and concrete) must be coated with bituminous paint or other appropriate material to avoid a chemical reaction between the two materials.

3.4.3 Bolted and Welded Connections

In general, bolted and welded connections should conform to the requirements of CAN/CSA-S16.1-94.

To minimize the potential for corrosion, stainless steel or galvanized bolts are typically used. It is noted that some cases of galling of the threads have occurred with the use of stainless steel bolts and nuts. As a result, consideration should be given to using galvanized steel or bronze nuts with stainless steel bolts, particularly where they connect items that will require routine removal for maintenance purposes.

In addition to strength requirements, the design of welded connections for members subjected to immersion should consider the requirements noted in Section 3.4.6 for proper corrosion protection.

3.4.4 Wire Ropes

Galvanized steel wire ropes have good corrosion resistance, and are typically stronger, more resistant to abrasive wear, and far less expensive than stainless steel wire ropes. Therefore, galvanized steel wire ropes are normally used. For installations where access for inspection and replacement is difficult and corrosion is a concern, the use of stainless steel wire ropes may be considered. Pertinent information on selecting wire ropes is provided in USACE EM 1110-2-3200 (1998).

3.4.5 Sheet Piles

Steel used in the fabrication of sheet piles usually conforms to CSA-G40.21-92. Various grades of steel are employed, and the sheet piles are also fabricated in a variety of profiles.

3.4.6 Corrosion Protection

Depending on exposure conditions, corrosion protection of steel components generally consists of hot dip galvanizing or painting.

In general, miscellaneous metal work items such as handrails, guardrails, ladders, cover plates, embedded angles, armour plates, and bolts are hot dip galvanized.

For fabricated assemblies that will be galvanized, guidelines for minimizing distortion, warping and corrosion, as outlined in ASTM A384-02, CAN/CSA-G164-81, and applicable AHDGA publications, should be incorporated. Also, since the viscosity of zinc prevents it from entering any space tighter than 2.4 mm, narrow gaps between plates, overlapping surfaces, and back-to-back angles and channels should be avoided. Where overlapping or contacting surfaces cannot be avoided, all edges should be seal welded. In addition, vent/drain holes required for galvanizing should preferably be located so that they are out of sight. Galvanized surfaces should not be in direct contact with, or exposed to, runoff water from brass or copper articles, since such exposure can result in rapid deterioration of the zinc coating.

Larger elements, such as structural frames for buildings, hoist towers and vertical lift or radial gates, are normally painted. It is preferred that surface preparation and painting occur in the shop under the appropriate controlled conditions, and that field applications be limited to minor touch ups.

The Province does not have a specific standard for paint systems that should be used for a particular installation. On past projects by the Province, a coal tar epoxy system has generally been used to protect steel elements subjected to immersion; however, this paint system is no longer being used primarily because of the difficulties associated with its reapplication particularly under moist/wet conditions.

More recently, a single component moisture-cured urethane paint system was applied on the radial gates and stop logs for the St. Mary Dam spillway (1998) and the radial gates at the South Heart Dam spillway (1999), based on field performance information obtained from the USBR. The USBR is using a moisture-cured urethane paint system instead of other paint systems, including coal tar epoxies, because of its field performance with respect to corrosion protection, wide range of applications including as an overcoat on other paint systems, ease of application, and ease of repair particularly under moist conditions. As a result, the use of the single component moisture-cured urethane paint is currently preferred for large elements subjected to immersion; however, its ongoing field performance on existing elements should be reviewed. It is also noted that the cost of the moisture-cured urethane paint is substantially more than the coal tar epoxy paint.

For smaller gates, a two part, self-priming, surface tolerant epoxy (i.e. not coal tar) paint for marine applications is currently being used; however, its ongoing field performance should be reviewed.

For steel elements subjected to immersion service, the design should incorporate the following requirements derived from NACE RP0178 (1995) and USACE EM 1110-2-2702 (2000), where appropriate.

- Structural members should be properly detailed such that all exposed portions of the structure can be properly prepared and painted.
- Drain holes should be provided to prevent entrapment of water.
- Pockets or crevices that will not drain, and that cannot be properly abrasive blasted and coated, should be avoided.
- Sharp edges and fillets should be ground to a smooth radius of at least 3 mm; however, 6 mm is preferred.
- Lap joints should be avoided, but where used, the joint should be seal welded.
- Welds should be continuous and smooth with no porosity, holes, high spots, lumps or pockets.
- Where dissimilar materials are in contact, an electric insulator should be provided between the two metals. Large cathode-to-anode area ratios should be avoided.
- Where possible, welded connections should be used in lieu of bolts since small amounts of water can be trapped under fasteners or between plies.
- Weld ends, slag, splatter or any other deposits should be ground from the steel.

The preparation of steel surfaces to be painted should ordinarily conform to the appropriate standards produced by the SSPC. In cases where the structure will be subjected to immersion service, a “white metal” blast cleaned surface conforming to SSPC SP-5 is typically required for most paints.

For projects where large gates or similar equipment are required, the preference is to have the surface preparation of receiving surfaces and the shop application of the specified paint system inspected by a NACE certified inspector, representing TRANS.

In certain cases, depending on the exposure conditions, importance, and weight, specialty metals may be required instead of galvanized or painted steel. Examples include using stainless steel anchor bolts for immersed conditions, and aluminium hatches to facilitate access.

Where various types of metals (steel, stainless steel, aluminium, brass, etc.) or metallic coatings (i.e. zinc) are proposed for use within the same structure or facility, and will be in contact with water or soil, the potential for galvanic corrosion to occur should be reviewed.

3.5 Wood

The use of timber in water control structures is no longer as prevalent as it once was, however it is still utilized for items such as stop logs and flashboards.

In general, wood components are designed in accordance with CAN/CSA-O86.1-01. Preservative treatment, conforming to CAN/CSA-O80, is normally used to provide protection against decay and wood-destroying insects. Since CAN/CSA-O80-97 includes a number of preservatives, the type of treatment required for a particular installation should be clearly specified. During installation, all cut ends, drill holes, etc. must be field treated with an appropriate preservative.

3.6 Conduits and Pipes

3.6.1 General

Conduits are closed channels used to convey water, and typically are circular, elliptical, inverted horseshoe, inverted pear, oblong, rectangular, or square in shape. A circular conduit is also referred to herein as a pipe.

In general, conduits are manufactured using cast-in-place concrete, precast concrete, steel, corrugated steel, poly vinyl chloride (PVC), and polyethylene.

Concrete conduits are designed as rigid conduits, while steel, corrugated steel, PVC, and polyethylene conduits are designed as flexible conduits.

A rigid conduit is designed to resist the applied loads by internal forces (bending moments, hoop thrust, and shear) with very little deflection. For a buried rigid conduit, the applied earth load could be more or less than the weight of the soil prism above the conduit depending on the installation condition (trench condition or projection condition) plus any equipment surcharge.

A flexible conduit relies on lateral soil support to limit its deflection to within an allowable value so that the applied loads are resisted primarily as hoop thrust forces. For a buried flexible conduit, the applied earth load acting on it will not exceed the weight of the soil prism above the conduit plus equipment surcharge.

3.6.2 Rigid Conduits and Pipes

In general, precast concrete pipes are designed, fabricated, and tested in accordance with ASTM and AWWA standards. Applicable ASTM standards include C76-03 and C655-02 which applies to culverts, sewer pipes, and storm drains, and C361-03 for low pressure pipe installations. Applicable AWWA standards include C300-04, C301-99, and C302-04 which cover reinforced or prestressed concrete, cylinder or non-cylinder, pressure pipes. Information on the design of rigid concrete conduits and pipes can be found in USACE EM 1110-2-2902 (1998), USBR (1987), and applicable ASTM and AWWA standards.

Depending on the standard, precast concrete pipe is either chosen from design tables or specially designed to suit a particular installation. Careful review of the pipe standard is required, and the need to specify a special design and provide specific design parameters, including installation condition, bedding condition, depth of earth cover including soil unit weights, live loads due to vehicles or construction equipment, external hydrostatic pressure, and internal hydrostatic pressure including any surge pressure, should be considered.

The joints for precast concrete pipes should normally consist of a bell and spigot configuration with a rubber gasket.

Precast concrete pipe dimensions, including the joint details and dimensions, should be carefully reviewed as part of the design process, and verified during the shop drawing review phase. Joint details, such as the shear capacity of the bell and spigot sections, installation gap width, rotation capability, longitudinal movement (spreading) capability if anticipated, and maximum gap width, should be considered. Since a uniform pipe wall thickness (i.e. without oversized bell) is normally provided for pipes with an inside diameter of 1.2 m or greater, the implications of the resulting lower shear capacity at the joint, due to the thinner wall at the bell and spigot, should be considered.

Where the pipe will be subjected to large vertical loads or located at the structure interface the need to provide cast-in-place concrete pipe bedding (cradles) to increase the shear capacity and improve the side support should be considered. Keyed joints in the concrete bedding, which are aligned with the pipe joints, are normally installed to maintain some rotation capability (in flexure, but not shear) to accommodate differential movements.

In dams, high canal embankments, or similar installations, only precast reinforced concrete pipes or cast-in-place reinforced concrete conduits designed for pressure applications should be considered. Caution should be exercised when using precast concrete pipe where the depth of earth cover will exceed about 8 m, particularly with respect to the increased shear, rotation, and spreading that may occur at the joints. Further review of the shear capacity of the bell and spigot, and the specifying of special design measures (i.e. higher concrete compressive strength or additional joint reinforcement) may be warranted. Inspections of the pipe during their manufacture should also be performed. As an added performance measure, the outside perimeter of the precast concrete pipe joint should be wrapped with geotextile to prevent possible infiltration.

Significant cost factors when considering the use of large precast concrete pipe include the local availability of a suitable crane, total pipe length, need to provide cast-in-place concrete bedding, volume of other cast-in-place concrete, schedule requirements, and life cycle considerations.

Cast-in-place reinforced concrete conduits are used where the design flow capacity, loading, foundation conditions, and potential deformations warrant a specific design. It is also generally preferred due to its robustness in cases where it is equally or more cost effective than precast concrete pipe.

For projects where it is not possible to clearly determine whether a precast concrete pipe or cast-in-place concrete conduit is the more cost effective solution, consideration may be given to designing and including both alternatives in the construction contract documents. This approach should be reviewed beforehand with TRANS.

3.6.3 Flexible Conduits and Pipes

Flexible conduits should not be used in dams, high canal embankments, or other similar situations because of the concern that voids may form between the backfill material and the deflected pipe. In addition, steel pipes, corrugated steel conduits, and structural plate corrugated steel conduits are highly susceptible to corrosion, and the strength properties of PVC and polyethylene pipes may diminish over time as discussed in USACE EM 1110-2-2902 (1998).

Typically, steel pipe is fabricated and tested in accordance with a number of ASTM and AWWA standards.

Corrugated steel and structural plate corrugated steel conduits are typically manufactured in accordance with CSA-G401-01. Corrugated steel conduits include pipe and pipe-arch shapes. The pipe-arch shape can be considered for installations that have limited headroom; however, careful attention must be paid to the high corner bearing pressures that will develop. For improved watertightness (i.e. to reduce leakage that would occur), a gasketed joint, typically consisting of an annular coupler and rubber gasket, is normally required. The ends of the helical corrugated steel unit are re-corrugated to accommodate the coupler. Proper pipe alignment and installation is required to ensure that a good joint, with an evenly compressed gasket that will not be displaced by hydrostatic pressure, is obtained. The joints may be wrapped with geotextile for installations where infiltration is a concern. Structural plate corrugated steel conduits include a variety of shapes including pipe, pipe-arch, horizontal ellipse, vertical ellipse, and inverted pear. The pipe, pipe-arch, horizontal ellipse shapes generally represent the most prevalent conduit types used. For the pipe-arch and horizontal ellipse shapes, particular attention must be paid to zones with high bearing pressures.

PVC pipes for gravity applications are typically manufactured in accordance with CSA-B182.2-02 and ASTM D3034-04, and in accordance with CSA-B137.3-99 for pressure applications. The pipe joints should normally consist of a bell and spigot configuration with a rubber gasket.

Polyethylene pipe is typically manufactured in accordance with ASTM F714-03, D3035-03a, and D3350-02a.

3.7 Structure Joint Materials

3.7.1 Waterstops

Waterstops are typically manufactured from PVC, rubber, polyethylene, or stainless steel. PVC and rubber waterstops are used in most cases, therefore the following discussion deals mainly with PVC and rubber waterstops.

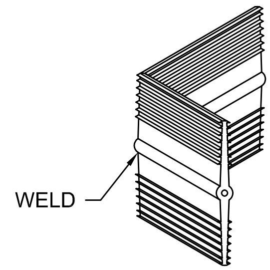
In general, PVC waterstops are less elastic, slower in recovery, and more susceptible to oils and some chemicals than rubber waterstops. However, PVC waterstops are readily available in many more types and profiles, are less costly, and have been the most widely used material by the Province for water control structure applications.

The shape and size of the waterstop should be chosen based on the joint type, expected joint movements, hydrostatic head, exposure and installation conditions, and availability. Typically, waterstops that have a ribbed profile provide better sealing characteristics than those that have a dumbbell profile. In addition, the use of a waterstop designed for a minimum hydrostatic head of 373 KPa should be considered since this will result in a thicker, stiffer waterstop section that will be less susceptible to deformation during concreting.

To maintain watertightness, a flat shape is ordinarily used within non-moving joints (construction joints) whereas a centre bulb or a tear web shape is normally employed within moving joints (contraction and expansion joints). It is preferred that the widths of the flat shaped and centre bulb shaped waterstops be not less than 150 mm and 225 mm, respectively, in order to provide adequate embedment. In addition, external base seal type waterstops may be used as a dirt stop at joints as noted in Section 3.7.7.

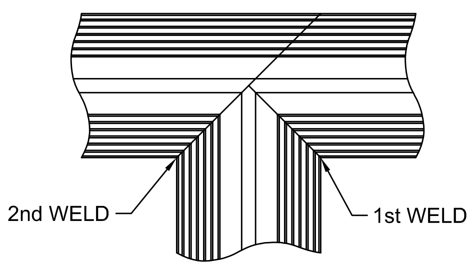
Heat welding is normally used to splice PVC waterstops in the field. These splices represent potential weak points or points of discontinuity in the waterstop, and therefore the design should minimize the number of splices that are required. Where splices are needed, field joints constructed as shown on Figure 3-1 can be used. The use of the field joints will minimize the total number of splices required when compared to the use of factory fittings. In cases where it would be difficult to construct the joint using field welds, the use of factory-made joints or fittings, that only require straight butt welds in the field, should be considered.

FLAT "L"

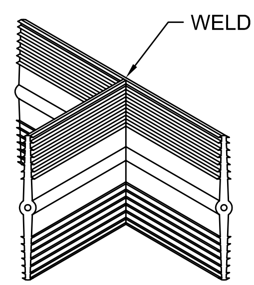


VERTICAL "L"

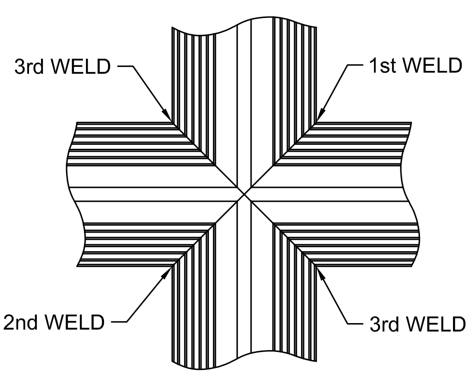
BENDING IS PREFERRED TO
WELDING THIS FITTING



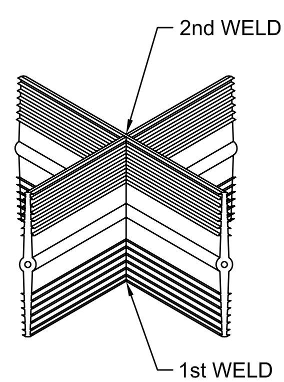
FLAT "T"



VERTICAL "T"



FLAT CROSS



VERTICAL CROSS

ALBERTA TRANSPORTATION CIVIL PROJECTS BRANCH **ALBERTA ENVIRONMENT** WATER MANAGEMENT OPERATIONS	**WATER CONTROL STRUCTURES - SELECTED DESIGN GUIDELINES** **TYPICAL JOINTS FOR PVC WATERSTOP** DATE: November 2004 · CAD FILE: 99008A3-1.dwg · FIGURE No.: 3-1

3-1 Jan 07'2005 - 10:34am Jesse Llorca

To protect the overall integrity of the primary waterstop particularly in moving joints, the number of splices required in the primary waterstop should be minimized. For example, where the waterstop in an expansion joint (i.e. primary waterstop for this example) intersects a waterstop in a contraction joint or a construction joint (i.e. secondary waterstop for this example), the continuity of the primary waterstop is maintained and the butt end of the secondary waterstop is spliced to the edges of the primary waterstop as illustrated on Figure 3-2. Similarly, where the waterstop in a contraction joint (i.e. primary waterstop for this example) intersects a waterstop in a construction joint (i.e. secondary waterstop for this example), the continuity of the primary waterstop is maintained and the butt end of the secondary waterstop is spliced to the edges of the primary waterstop.

It is noted that some evidence of embrittlement damage (loss of plasticizer) to PVC waterstops (installed between 1965 and 1967) has been observed by PFRA during the 1985 repairs of the structure joints on the Gardiner Dam spillway. The loss of plasticizer was attributable to the high compressive stresses at the joint and/or due to solvents from the adjacent asphalt impregnated fibreboard material which served as joint filler. As a result, PFRA recommended that where high compressive stresses are likely to occur at a joint neither the PVC waterstop nor the asphalt-impregnated fibreboard be used.

Within structure joints that incorporate shear keys, the position of the PVC or rubber waterstop relative to the shear key should be carefully considered to ensure that the more compressible waterstop does not affect the shear capacity of the concrete key.

3.7.2 Joint Filler

A compressible joint filler material is ordinarily used at an expansion joint to provide the required separation between two structure components.

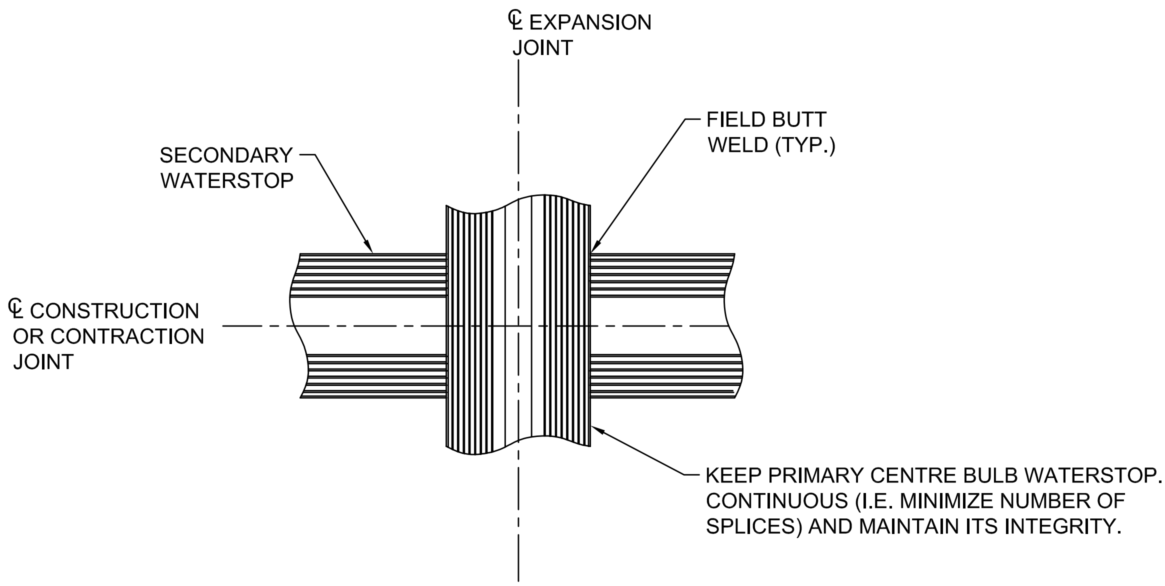
In general, closed-cell PVC foam and asphalt-impregnated fibre boards have been used as joint filler. PVC foam boards are preferred because they have better compressibility and recovery performance characteristics, and are compatible with joint sealant materials and PVC waterstops.

Generally, PVC foam boards can be manufactured with different compressive resistance and recovery performance characteristics, therefore they can provide additional design flexibility.

Asphalt-impregnated fibreboard requires more pressure to compress it, and its recovery is less than that for PVC foam boards. Under compression, the asphalt material is displaced and the board begins to break down. As noted in Section 3.7.1, the asphalt-impregnated fibreboard may not be compatible with PVC. In addition, its compatibility with the proposed joint sealant material should be confirmed.

3.7.3 Joint Sealant

Joint sealant is primarily provided to prevent unwanted particles from entering the joint and thereby



CONFIGURATION OF FIELD SPLICE FOR WATERSTOPS

ALBERTA TRANSPORTATION CIVIL PROJECTS BRANCH **ALBERTA ENVIRONMENT** WATER MANAGEMENT OPERATIONS	**WATER CONTROL STRUCTURES - SELECTED DESIGN GUIDELINES** **WATERSTOP CONTINUITY BETWEEN JOINTS**		
	DATE: November 2004	CAD FILE: 99008A3-2.dwg	FIGURE No.: 3-2

3-2 Jan 07'2005 - 10:34am Jesse Llorca

causing excessive compressive forces during expansion (joint closing).

In general, the joint sealant consists of an elastomeric material. It is preferred that a polyurethane based product be used.

Proper design, installation, and curing are important factors in the long-term performance of the joint sealant.

The required width of the sealant should be determined based on the amount of movement expected. The depth of the sealant is normally limited to about 13 mm, and the depth to width ratio within 1:1 to 1:2.

Historically, joint sealant installations have had a poor performance record. This has largely been attributable to improper surface preparation and installation. Therefore proper surface preparation, including removing laitance, applying a compatible primer to concrete surfaces, and installing a bond breaker (polythene tape or a compressible closed-cell polyethylene foam backer rod) between the joint filler and sealant, must be provided.

3.7.4 Prefabricated Joint Systems

Prefabricated joint systems consist of manufactured expansion joint assemblies that are typically used in bridges. The expansion joint assembly generally consists of an angle and anchor bolts that are embedded in the concrete at either side of the joint, a neoprene seal, clamping bars, and cover plates. The steel components are generally galvanized except for the bolts which are of stainless steel. Common trade names include Honel, Elastometal, and D. S. Brown.

3.7.5 Coatings (Bond Breaker)

At a joint location where bonding between adjacent concrete structure components is not desired, a bituminous paint conforming to CGSB 37.2-88 is ordinarily applied to the hardened concrete prior to placing new concrete.

In general, the thickness of the bituminous paint will depend on the design conditions required. In the case where simple tension is expected, the paint thickness should be as thin as possible; however, when applied on a surface where sliding is expected, some modest thickness should be used.

It is important that a uniform thickness of bituminous paint (i.e. without any sagging) is applied and maintained in order to avoid potential stress concentrations if and when the joint closes under load.

3.7.6 Cover Plates

Removable galvanized steel or stainless steel cover plates are sometimes provided at the water face of an expansion joint to prevent water and debris from entering the joint. Galvanized plates are generally used because of their lower cost; however, in most cases stainless steel bolts are used to fasten the cover plates to the embedded metalwork.

Typically, embedded galvanized steel angles are provided at both sides of the expansion joint, and the cover plate is fastened to the upstream angle. In designing the embedded metalwork, consideration should be given to including provisions to permit temporary bolting of the metalwork to the formwork to facilitate installation, and vent (bleed) holes to allow air to escape during concrete placement and thereby avoid the formation of voids between the concrete and the underside of the angles.

3.7.7 Dirt Stops

Dirt stops are normally used on the earth side of expansion joints to prevent the infiltration of backfill materials. Materials typically used include external base seal-type waterstop, joint sealant, or geotextile fabric covered with treated timber.

3.8 Post Tensioned Anchors

On some water control structures, post-tensioned threadbar anchors have been used as foundation anchors and as trunnion anchors for radial gates.

The threadbars ordinarily consist of hot rolled and proof stressed alloy steel bars conforming to ASTM A722-98(2003). Minimum yield strength (f_y) and minimum ultimate strength (f_u) of the threadbars is normally 835 MPa and 1030 MPa, respectively. Higher steel grades are available on special order. The relaxation of the threadbars when subjected to 70% of the ultimate stress for 1000 hours should typically not exceed 3%.

Special consideration is warranted to ensure that proper corrosion protection of the post-tensioned anchors is provided. A single corrosion protection system and a double corrosion protection system are typically available for use depending on the purpose, service life, and exposure environment of the anchors. For foundation anchors, trunnion anchors, and other critical applications, double corrosion protected threadbar anchors are normally used.

For permanent post-tensioned anchors, only high quality products with a long-standing, proven performance records should be used.

3.9 Geomembranes

Geomembranes are typically comprised of polymeric materials that are thin, flexible, and watertight. In general, a wide range of polymers is used to manufacture geomembranes including poly vinyl chloride (PVC), high-density polyethylene (HDPE), polypropylene (PP), and ethylene propylene diene monomer (EPDM).

Geomembranes have primarily been by used by the Province as a liner within main canals to reduce seepage losses. The liner typically consists of a 0.5 mm (20 mils) thick PVC membrane manufactured using a premium quality homopolymer vinyl chloride resin Type GP conforming to ASTM D1755-92(2001) that is formulated to impart durability. For winter installation, careful selection of the PVC liner material is necessary to ensure that it can be handled, installed, and seamed under cold weather conditions.

Geomembranes have also been used instead of impervious backfill to cover drainage systems (granular drainage materials) that are located adjacent to the outside of spillway chute walls to minimize the infiltration of surface water.

3.10 Geotextiles

Geotextiles (also sometimes referred to as filter fabric) typically consist of thin, flexible, permeable, woven or non-woven membranes primarily manufactured from polypropylene or polyester.

Non-woven geotextiles have been used as a filter to limit the migration of soil particles into coarser materials or to prevent soil materials from infiltrating through pipe or structure joints. When proposed for use as a filter beneath rock or granular materials (e.g. riprap or bedding) on a sloped surface, the lower frictional resistance provided by the geotextile and its impact on stability of the overlying materials should be considered.

The Province does not use geotextiles in place of filter sand in critical areas, such as embankment filters, structure drainage/seepage discharge locations, beneath concrete structures, or as a filter for drainpipes of underslab drainage systems, where its failure could have catastrophic consequences. In addition, geotextiles should generally not be used beneath rock or gabion chutes or similar installations, where high velocity flows can find their way between the geotextile and the foundation and cause failure.

Given the vast array of geotextile products available, care is required in choosing and specifying the proper material for particular design and installation conditions. When used as a filter beneath riprap and other erosion protection materials, non-woven geotextiles should have the properties shown on Table 3-3:

Table 3-3
Physical Properties for Non-Woven Geotextile

Property	Specification	Minimum Values
Puncture	ASTM D4833-00	900 N
Grab Strength	ASTM D4632-91	1200 N
Grab Tensile Elongation	ASTM D4632-91	50%
Trapezoidal Tear Strength	ASTM D4533-91	575 N
Mullen Burst Strength	ASTM D3786-01	4500 kPa
Apparent Opening Size	ASTM D4751-99	150 – 225 μm
Permittivity	ASTM D4491-99	0.7 – 0.9 sec^{-1}
Flow Rate	ASTM D4491-99	34 - 44 $L/s/m^2$

3.11 Insulation

In general, rigid closed-cell extruded polystyrene foam insulation may be used to protect buried utility lines from freezing and to protect pavements and structure foundations from frost heave.

On the Province's water control structures, the use of rigid polystyrene foam insulation, particularly beneath a structure, is limited to locally protecting underslab drainpipes. This limitation is primarily due to concerns about the long-term performance of the insulation, including the potential for physical degradation and deterioration of its insulating value. Therefore, the first preference is to locate the structure on a foundation that is not frost susceptible. As a second choice, subject to technical and cost considerations, it is preferred that frost-susceptible foundation materials be removed and replaced with adequately drained granular materials, or that adequate drainage systems be provided, rather than providing insulation.

Typically, extruded polystyrene closed-cell rigid board insulation meeting the requirements of CGSB-51.20-87, Type IV, and with compressive strengths ranging from 210 KPa to 690 KPa are used. As outlined below, the use of insulation can adversely affect other design parameters, and precautions are required to protect it from degradation. Therefore, careful consideration is required prior to its use.

- Installation of rigid board insulation will create seepage paths (i.e. void spaces at the insulation to foundation interface, gaps between boards).

- Installation of rigid board insulation will affect the friction at the structure to foundation interface.

- The design compressive strength of the insulation is typically based on a specific amount of deformation. This deformation should be taken into consideration in the design.

- Insulation is buoyant.

- Insulation must be protected against exposure to direct sunlight, physical damage, incompatible chemicals (solvents, petroleum products, etc.), and open flame or other ignition sources.

- Physical degradation of the insulation as well as loss of insulating value may occur over time.

3.12 Erosion Protection

3.12.1 General

Typical erosion protection measures include riprap, cast-in-place concrete, gabions, precast concrete blocks and other proprietary systems. Riprap and cast-in-place concrete are discussed in

Sections 3.2.3 and 3.3, respectively.

3.12.2 Gabions

In general, gabions are used in the construction of water control structures and retaining walls, and as erosion protection. Typically the gabion baskets and mats are fabricated from galvanized hexagonal (80 x 100 mm) wire mesh that can be further protected against corrosion with a PVC coating. Each gabion unit is filled with reasonably well-graded, clean, hard, durable, rounded stones ranging in size from 100 mm to 200 mm.

3.12.3 Precast Concrete Blocks and Other Proprietary Systems

Over the years, various precast concrete block and other proprietary erosion control systems have been developed by a number of different manufacturers. In general, these systems have included interlocking concrete blocks, concrete blocks tied together with cables to form a mat, and a fabric form that is filled with fine aggregate cast-in-place concrete. A few types and trade names of these products are listed in Table 3-4. In some cases, the products may no longer be available.

In general, the performance of some of these products has been mixed, therefore caution should be exercised where there is a lack of experience with their use for a particular application under conditions similar to those in Alberta.

Table 3-4
Various Types of Erosion Control Systems

Type of System	Trade Name
1. Interlocking Precast Concrete Blocks	Mini-Slab, Trilock
2. Precast Concrete Blocks Connected with Cable	Petraflex, Cable Concrete
3. Fabric Form Filled with Cast-in-Place Concrete	Fabriform, Texicon, Hydrotex

3.12.4 Bedding Requirements

As discussed in Sections 11.2 and 11.3, granular bedding materials and/or geotextiles are typically provided to prevent the migration of insitu or fill materials particularly where gabions or precast concrete blocks are employed.