9.0 STRUCTURAL DESIGN

9.1 REINFORCED CONCRETE

9.1.1 Design Approach

Reinforced concrete water control structures must be designed to satisfy both strength and serviceability requirements. The Limit States design approach is normally used, and the structures, structural members, and connections are designed such that the factored resistances are equal to or greater than the effects of factored loads.

Two CSA standards that have some applicability for aspects of water control structures are CSA-A23.3-94 Design of Concrete Structures and CAN/CSA-S6-00 Canadian Highway Bridge Design Code. The former is primarily intended for use in the design of structures for buildings, and the latter for the design of highway bridges including buried structures such as concrete pipes and box sections.

Thus, for water control structures, significant judgement is required in evaluating and establishing load factors that are appropriate for: a) various components; b) the importance of the structure; and c) various loading conditions (i.e. Usual, Unusual, or Extreme). Less stringent requirements may be appropriate when designing for loads due to an Unusual or Extreme Condition (i.e. that may be highly improbable over the design life of the structure and short in duration), for example.

Subject to the foregoing qualifications, CSA-A23.3-94 can generally be applied to reinforced concrete components of water control structures. For walls, pipes, and box sections that are subjected to earth loadings and for bridges, the provisions of CAN/CSA-S6-00 should be given consideration in establishing the appropriate load factors.

In addition to strength requirements, the serviceability of structure components should be checked using specified loads to ensure that they satisfy performance and durability criteria (deflection, crack width).

The applicability of crack control requirements specified in CSA-A23.3-94 and CAN/CSA-S6-00 should be reviewed relative to the performance requirements and exposure conditions of the structure or component thereof. For structure components that are exposed to continuous or almost continuous contact with water and, where leakage is a concern, the resulting crack width using specified loads due to Usual Conditions should generally be limited to a maximum value of 0.2 mm. In cases such as a syphon conduit, where the structure will operate under significant hydrostatic pressure, a narrower crack width limit should be considered. For example, a crack width limit of 0.17 mm was used in the design of the conduit for the recently completed East Arrowwood Syphon (1999).

In general, other non-hydraulic components may be designed in accordance with CSA-A23.3-94, and vehicle access bridge components in accordance with CAN/CSA-S6-00.

9.1.2 Reinforcement Details

It is generally preferred that the concrete cover for reinforcement conform to the values shown on Table 9-1, AENV (2000). For water control structures with thin elements, lower cover than shown on Table 9-1 (e.g. such as those indicated in CSA-A23.3-94) may be considered, however in no case should it be less than 50 mm. For very thick elements with heavy reinforcement greater cover than shown on Table 9-1 should be considered.

In addition, depending on the exposure condition, the minimum concrete cover should be at least 1.5 times the nominal maximum aggregate size or 1.5 times the diameter of the reinforcing bar, as noted in CAN/CSA-A23.1-00.

Table 9-1
Concrete Cover for Reinforcement

Exposure Condition	Cover[(2)] (mm)
Face of concrete exposed to water velocities less than or equal to 3 m/s	75
Face of concrete exposed to water velocities greater than 3 m/s	100
Face of concrete exposed to water velocities greater than 3 m/s and potential abrasion erosion damage.	125 to 150
Concrete cast directly against earth or rock	100
Concrete cast directly against foundation concrete or insulation	75
Concrete exposed to weather or earth	75
Face of concrete at contraction and expansion joints	50
Decks not exposed to chlorides [(1)]	50
Decks exposed to chlorides [(1)]	75

(1) Also refer to the requirements of CAN/CSA S6-00.
(2) For thin elements, the requirements of CSA-A23.3-94 may be considered.

Waterborne sand, gravel, rocks and other debris flowing over the concrete surface can cause abrasion erosion damage. In general, the floor slab, blocks, and end sill within hydraulic jump basins, and the floor slab within flip buckets are particularly susceptible to abrasion damage. Since increasing the concrete cover will only have a limited benefit on its resistance to abrasion, the hydraulic design of the structure should include provisions, where practicable, to minimize or eliminate the potential for abrasion erosion damage to occur.

Temperature and shrinkage reinforcement should be uniformly distributed along side faces of structure elements to control cracking due to temperature changes, creep, and shrinkage. The minimum ratio of reinforcement, based on the gross concrete cross sectional area, recommended in AENV (2000) is shown on Table 9-2. These ratios are similar to those suggested in ETL 1110-2-340 (1993). In cases where the concrete element is greater than 0.8 m in thickness, a thickness of 0.8 m may be used in determining the minimum temperature and shrinkage reinforcement required in each face. For a very long continuous member, the minimum reinforcement requirements to limit the width and spacing of cracks as derived for a continuously reinforced member should be considered as discussed in Section 12.6.4.

Depending on the thickness of the structural element, it is preferred that the centre-to-centre spacing of the primary and secondary reinforcement be equal to or less than 300 mm; however, in no case should it exceed 450 mm. The minimum clear distance between bars should not be less than 1.4 times the bar diameter or 1.4 times the nominal maximum size of the coarse aggregate, whichever is greater. This requirement also applies to the clear distance between a contact lap splice and adjacent splices and bars.

Table 9-2
Temperature and Shrinkage Reinforcement

Face	Minimum Ratio of Reinforcement Required
Face adjacent to earth with joints (both ends free) not exceeding 9 m.	0.0010
Face not adjacent to earth nor exposed to freezing or direct sun and with joints (both ends free) not exceeding 9 m.	0.0015
Face not adjacent to earth but exposed to freezing or direct sun and with joints (both ends free) not exceeding 9 m.	0.0020
If a member exceeds 9 m in a direction parallel to the temperature and shrinkage reinforcement being considered, increase the ratio of reinforcement to account for the increased length. If a member is fixed at one end and free at the other, double the length of the member to determine whether it exceeds the 9 m length.	+ 0.0005 (Add to above values to account for the increased length)

Splices for reinforcement should be clearly shown and detailed. Normally, splices at points of maximum tensile stress should be avoided, however where such splices must be made they should be staggered so that no more than half of the bars are spliced within the required lap length. The length of lap splices should conform to the requirements of CSA-A23.3-94.

9.2 STEEL

9.2.1 Design Approach

In general, the structural design of large steel components subjected to hydraulic loads (e.g. gates) on the Province's projects has been performed using the Working Stress design method. For a water control structure that is not subjected to significant dynamic loading and is maintained and inspected on a regular basis, the allowable steel stresses using the WSD method have generally been limited to the following, where F_y is the specified minimum yield strength of steel.

- Usual Condition of Loading: $0.50F_y$
- Unusual Condition of Loading: $0.66F_y$
- Extreme Condition of Loading: $0.80F_y$

In addition to the loading condition, the importance of a particular element to the overall integrity and performance of the structure is also considered in establishing the allowable steel stress for that element. For example, for a radial gate, a higher allowable stress may be permitted on the gate skin assembly versus the trunnion assembly under a particular loading condition.

More recently the USACE, which had previously also used the Working Stress method for the design of hydraulic steel structures, has moved toward a Load and Resistance Factor Design (LRFD) method as outlined in EM 1110-2-2105 (1993), EM 1110-2-2701 (1997), and EM 1110-2-2702 (2000). The LRFD method is a Limit States design approach. Therefore, the applicability of the USACE LRFD method for the design of a particular hydraulic steel structure should be reviewed and, where deemed appropriate, considered in the design.

Further information on the Limit States design of steel structures is available in CAN/CSA-S16.1-94 (steel structures) and CAN/CSA-S6-00 (bridges). Although these standards are not designated specifically for water control structures, they provide additional information, particularly related to load and resistance factors that may be useful in determining the appropriate factors that should be used.

Significant judgement is required in evaluating and establishing load factors that are appropriate under each condition of loading (i.e. Usual, Unusual, and Extreme) for a specific structure.

In addition to structural requirements, serviceability and performance criteria such as deflection, expansion/contraction, fatigue and fracture control need to be considered.

In general, other non-hydraulic components should be designed in accordance with CAN/CSA-S16.1-94, and vehicle access bridge components in accordance with CAN/CSA-S6-00.