6.0 SEEPAGE AND DRAINAGE

6.1 General

Measures to control seepage normally include provisions to increase the length of the seepage path and otherwise reduce seepage flows, and provisions to filter and drain the seepage water. Given the high importance of controlling seepage on the safety and stability of the structure, adequate redundancy should be incorporated when designing seepage control measures.

For water control structures, the main seepage reduction zone is normally provided at the upstream area of the structure. Downstream of the seepage reduction zone, drainage with adequate filters to prevent piping is provided to intercept any water that seeps through the seepage reduction zone or foundation, and to relieve hydrostatic pressures.

6.2 Hydraulic Gradients and Creep-Head Ratios

Seepage flow will inherently travel along the path of least resistance as it seeps from the headwater side of the water control structure to the tailwater side. If the seepage path is too short, a steep hydraulic gradient will exist, and depending on the foundation material, piping may occur.

Depending on the foundation and/or fill material, the length of the seepage path (L) required to prevent piping at a structure subjected to a differential head (H) can be established using the creep-head ratio (H/L) originally proposed by Bligh (1912), and later modified to the weighted creep-head ratio by Lane (1935). The creep-head ratio required for a particular structure will depend on the material type, confinement of the soil particles, and whether or not filter drains, as discussed in Section 6.4, are provided. Information on creep-head ratios can be found in Smith (1995), PCA (1980), and USACE EM 1110-2-1901 (1993). Care is required when applying the creep-head ratio since it presumes that the critical head depends on the average gradient along the shortest seepage path rather than on the greatest hydraulic gradient at which water flows out of the ground. Generally, H is taken as the difference between headwater and tailwater levels for Usual Conditions, rather than those associated with Unusual or Extreme Conditions. However, the applicability of this approach for a specific structure should be reviewed.

Additional seepage and piping analyses using more rigorous methods (e.g. flow nets) may be required to assess hydraulic gradients, uplift pressures, and seepage flows depending on the purpose and size of the structure, the operating conditions (e.g. high differential head), nature of the existing foundation conditions, and nature of seepage reduction provisions.

6.3 Seepage Reduction Provisions

Provision for increasing the seepage path and reducing seepage can include upstream blankets, cutoff or core trenches with impervious backfill, embankments constructed of impervious fill; grout curtains; concrete cutoff walls; slurry trenches using a mixture of soil, bentonite, or cement; sheet pile walls; or a combination of the above.

6.4 Filtering and Drainage Provisions

Filtering and drainage provisions for various kinds of water control structures commonly include a filter/drainage blanket, perforated pipes, and/or pressure relief drains.

Where significant volumes of seepage are possible, a filter/drainage blanket may be required, typically consisting of a fine filter zone and at least one coarse drainage zone. The fine filter zone is used to prevent the insitu foundation materials and fill materials from migrating into the coarse drainage zone. In some instances, depending on the drainage capacity required, potential for frost heave, practicality of placing more than one zone, and economics, consideration may be given to using a single zone of fine filter material.

As outlined in Section 3.2.2, the fine filter zone is usually comprised of sand, and the coarse drainage zone of gravel. The gradation of these materials should normally be derived using the following accepted filter design criteria which are based on work originally carried out by Terzaghi, and subsequently modified by Bertram (1940), USACE EM 1110-2-1901 (1986), and USBR (1987). The work of Sherard et al. (1984, 1889) is also relevant.

- $$\frac{D_{15FILTER}\ (\text{Max. *})}{D_{85BASE}\ (\text{Min. *})} \leq 5 \text{ to prevent particle migration,}$$

- $$\frac{D_{50FILTER}\ (\text{Max. *})}{D_{50BASE}\ (\text{Min. *})} \leq 25 \text{ to prevent particle migration,}$$

- $$\frac{D_{15FILTER}\ (\text{Min *})}{D_{15BASE}\ (\text{Max. *})} \geq 5 \text{ to provide adequate drainage.}$$

  * Coarse and fine limits of the specified gradation envelopes.

- For the filter material, the percentage of fines (minus 80 μm) in the filter after placement should usually be limited to no more than 3% to provide adequate permeability. It is noted that attempts to limit the percentage of fines to less than 2% rather than 3% has resulted in problems with maintaining C_u within the prescribed range, due to fine sand being washed out along with the silt and clay during processing.

- The filter and drain materials should be well-graded, and their gradation envelopes should be approximately parallel to one another.

- Drainage gravel should preferably have a nominal 20 mm particle size (i.e. maximum particle size of 28 mm) to protect against segregation.

- Special care is also required when designing filter materials for foundation materials where dispersive clays are present.

In general, for foundation materials consisting of silts or clays (as classified by the PFRA modified Unified Soils Classification system with a minimum of 50% passing the 80 μm sieve size), experience has demonstrated that the use of concrete sand, as discussed in Section 3.2.2, is appropriate even though the above filter criteria for particle migration may not be fully satisfied. However for significant earth dams or major concrete structures where large quantities of filter materials are required, the requirement for project specific gradations may be warranted.

As discussed in Section 3.2.2, the use of more readily available standard concrete sand and concrete coarse aggregate (28 mm maximum) as filter and drain materials, respectively, should be considered for small structures where the premium cost of processing project specific materials is not warranted.

Where perforated or slotted pipes are provided within the coarse drainage zone to collect seepage water and convey it into either a gravity or pumped discharge system, the maximum perforation diameter or slot width should be sized to prevent the drainage materials from entering the pipe. Typically, the maximum perforation diameter or slot width should be based on the smaller value determined using the following criteria:

- $D_{85FILTER}$/Perforation Diameter or Slot Width $\geq$ 2.0 (USBR, 1987)

- $D_{50FILTER}$/Perforation Diameter or Slot Width $\geq$ 1.0 (ASCE, 1993)

- The $D_{85FILTER}$ and $D_{50FILTER}$ values are normally derived using the finer limit of the specified gradation envelope.

Pressure relief drains are typically installed in holes drilled into the foundation. The drains generally consist of well screens packed with filter sand.

Provisions should be incorporated for measuring seepage flows wherever feasible as noted in Section 23.4. Water collected by the drainage systems can be discharged by gravity or by pumping. Gravity discharge systems are preferred over pumped systems because they are more reliable, require less maintenance, and have no operating costs.

Access for conducting inspections and maintenance work of the drainage systems should be provided.