Ice loads

The resistance of river training works against the forces exerted by ice is of particular importance, eg along the shores of lakes and large rivers in arctic areas. The specific problems that have to be solved in such conditions are highlighted here. Ice riding up the embankment slope may damage the armour layer and in some instances the horizontal forces may become so large that the top part of a guide bund or dike is pushed backwards – inducing *decapitation*.

NOTE: Considerations for design with ice loads

In fact, ice has both beneficial and detrimental effects. On one hand the presence of ice limits the wave climate and erosion. On the other hand, ice can damage slope protection, and can ride up and damage surface facilities. Breakwaters designed to withstand wave attack are often able to withstand ice forces. However, there is a delicate balance between the smoothness required to encourage ice bending (to minimise the ice load and movement of individual stones) and the roughness required to dissipate wave energy.

Armourstone can be subject to normal and shear stresses along the surface. These stresses will introduce a rotation, dislodging the individual stones. It is therefore desirable that the surface of the armourstone is relatively smooth and the stone layer is well keyed. Angular stones tend to nest together and interlock. The friction coefficient of ice on rock slopes varies between 0.1 and 0.5. It is obvious that smoother stone surfaces reduce the shear stress. Another disadvantage of a rough slope with relatively large surfaces of individual stones is the possibility of rigidly frozen ice that can remove the armourstone and float it away from the site.

From experience with ice and armourstone in bank protection works several rules of thumb can be defined:

- widely graded armourstone (or rip-rap) should be avoided; standard heavy gradings are preferred (see Section 3.4.3)
- for about 0.7 m thick ice, a standard heavy grading of 300–1000 kg or greater should be used
- generally, when there are significant water level changes and concerns over plucking out of individual stones, the median nominal stone size, D_{n50} (m), should exceed the maximum ice thickness, $t_{ice;max}$ (m)
- the slope of the armour layer should be less than 30° to minimise the shear stress
- slopes below the waterline should be less steep than slopes above the waterline to encourage rubbling and prevent ice ride-up.

Further reference is made to Section 5.2.4 and McDonald (1988), and Wuebben (1995).

Designing with the above rules of thumb in mind often implies that conflicts (of interest) arise: stability requirements lead to angular, relatively heavy stone as armouring of the revetment, whereas coping with the ice loading effects leads to a smooth surface. In that case alternative materials may be attractive, such as some types of concrete armour units (see Sections 3.12 and 5.2.2.3), concrete block or gabion mattresses, and grouted stone (see Section 3.15, 5.2.2.7 and 8.6.2).