For the stability of the armourstone on a near-bed structure under currents only, the start of movement of stones is an important design criterion. Because the load of currents on the structure is present at a more or less constant level, especially compared with wave loads, a certain critical velocity should not be exceeded. The formulae by Hoffmans and Akkerman (1999) are based on the Shields parameter using such a velocity, U (see Equation 5.227). Equation 5.228 gives the relationship between the required stone sieve size, D_{50} (m), and the relevant hydraulic and structural parameters:

$$D_{50} = 0.7 \frac{\left(r_0 U\right)^2}{g \Delta \psi_{cr}} \tag{5.228}$$

where ψ_{cr} is the Shields parameter (-) and r_0 is the turbulence intensity (-); $r_0 = \sigma/u$, where σ is the standard deviation of the time-averaged flow velocity u (m/s), more precisely defined in Equation 5.229:

$$r_0 = \sqrt{c_s + 1.45 \frac{g}{C^2}} \tag{5.229}$$

where C = Chézy coefficient ($m^{1/2}/s$) (see Equations 4.131 to 4.133 in Section 4.3.2 and see also Section 5.2.1.8 with transfer relationships), and c_s is a structure factor (-), defined by Equation 5.230:

$$c_s = c_k \left(1 - \frac{d}{h}\right)^{-2} \tag{5.230}$$

where c_k is a turbulence factor related to the structure (-) and d is the near-bed structure height (m). For values of c_k (and hence c_s) see below.

The Equations 5.228 to 5.230 as derived by Hoffmans and Akkerman (1999), take the turbulence into account. These empirical formulae fit very well for uniform, as well as for non-uniform flow conditions, although the factor 0.7 in Equation 5.228 can only be derived theoretically for uniform flow conditions.

In uniform flow the parameter (1.45 g/C^2) is about 0.01, resulting in $r_0 = 0.1$, which is a well-known value. In the vicinity of structures non-uniform flow conditions are present and the turbulence is higher. Therefore the parameter c_s has been introduced, which depends on the relative structure height and c_k. The value of c_k depends on the structure type. Based on tests a value of $c_k = 0.025$ is recommended. For $d/h = 0.33$ (maximum structure height) the value of c_s becomes about 0.056 and consequently, the value of r_0 becomes about 0.26. For design purposes it is recommended not to exceed a value of $\psi = 0.035$ for the Shields parameter.

5.2.3.3 *Toe and scour protection*

Adequate protection of the toe of a slope or bank is essential for its stability as many of the failure mechanisms result from reduced strength at the base of the slope (see Section 5.4). In situations where there is no continuous lining of the bed and banks there are two main ways of ensuring toe protection: by providing sufficient material at a sufficient depth to account for the maximum scour depth predicted; or by provision of a flexible revetment (such as rip-rap) that will continue to protect the toe as the scour hole develops. From the above it is clear that the estimation of scour can be an important step in the design of stable rock structures.

The stability equations used for the design of bed and slope protection works are still applicable to the design of the toe protection, any differences are mainly due to construction aspects such as the thickness of the armourstone layer provided at the toe, the depth at which it is built and the way in which it is constructed (underwater or dry construction). Therefore, Equations 5.219, 5.223 and 5.224 in Section 5.2.3.1 and Equation 5.228 in Section 5.2.3.2 can be used for toe design. The choice of materials can however be wider than that available for slopes, since the toe will in many cases be underwater (eg river banks) and partly buried. Materials that are less aesthetically pleasing or that have limited scope for providing amenity improvement, can be adequate choices for that part of the structure.