INTERNAL EROSION NEWS: Informal report on GEO-RISK, Denver, June 4-6, 2017, organised by the ASCE Geo-Institute

Risk assessment has been the means by which the internal erosion threat to water-retaining earth embankments has been investigated over recent years. Previously internal erosion had been a 'normalised deviance' (Vick, 2017), a weakness so widely accepted as being the most likely cause of failures that it was 'normalised' and ignored in favour of overtopping and slope stability, which had become amenable to analysis.

John France and Jennifer Williams (France and Williams, 2017) confirmed that risk assessments now primarily address internal erosion. They explained how an appreciation of the risks was making dams and levees in the United State safer. Sibley et al (2017) reported fully on quantitative risk-informed design of levees taking into account the new focus on life risk to prioritise infrastructure development and design reliability. Karen Knight (Knight, 2017) described the development of the quantitative risk assessment approach to dam safety in the USBR (United States Bureau of Reclamation). Over the past twenty years more than 1,500 assessments had been made, and many remediation projects completed. Her advice was to 'do it' in order to develop a good understanding of the likely performance of the dam under extreme loads, particularly against internal erosion.

As the loads causing internal erosion were not known, the risks, without necessarily appreciating it, may have been assessed by Bayes' theorem (Bayes and Price, 1763), as Professor Gregory Baecher in his keynote (Baecher, 2017) observed that most geotechnical engineers were 'intuitive Bayesians'. Bayes and other probabilistic methods are intended to deal with uncertainty, not unknowns such as those about the forces that cause internal erosion of susceptible soils.

However, with the new and growing understanding of the mechanics of internal erosion, as presented in ICOLD Bulletin 164 (ICOLD, 2016, 2015; Bridle, 2017), intuitive Bayesian approaches can become subordinate to consciously applied engineering analyses using Newton's third law (Newton, 1687) to estimate the 'actions' causing internal erosion and the 'reactions' that the soils in water-retaining embankments are able to mobilise to resist them. The 'actions' are the hydraulic forces applied by water seeping or flowing through water retaining earth embankments. High hydraulic loads occur when water levels are high during floods, and the probability of occurrence of the load that would cause internal erosion failure can be estimated from the flood hydrology. This, together with an estimate of consequences from dambreak studies, provides the two terms needed in the risk equation, as follows:

$$\text{Risk} = \text{Probability} \times \text{Consequences}$$

In these circumstances, the annual probability of occurrence is used as a scale of the magnitudes of the forces causing internal erosion failures.

The flood hydrology also provides the probability of occurrence of the water level (and of the magnitude of the hydraulic forces) that would cause failure by overtopping and surface scour of earth embankments.

The probability of occurrence (of the magnitude) of earthquake forces that would cause failure by slope instability can also be estimated. C Hsein Juang (Juang et al, 2017) reported on work in hand to assess the probability of occurrence (of the magnitude) of earthquakes that would cause liquefaction of susceptible soils.

An issue with risk assessments is that an acceptable level of risk must be adopted, balancing cost against the possible loss of life, damage to property and loss of function of dams and flood embankments. Dr Brian Simpson (Simpson, 2017) pointed out that in defining load and resistance factors the Eurocodes were in effect setting an acceptable level of risk, with the additional benefit of equalising it across all countries using the Eurocodes.

Bellew (2017) reported on ‘flood-fighting’ – building dikes around backward erosion outlets downstream of levees to reduce the hydraulic gradient and thereby reduce the probability of failure. The levees were subsequently extended by ‘seepage berms’ to permanently reduce gradients. Continuing efforts to understand and analyse internal erosion mechanisms were also reported. Navin and Shrewbridge (2017) had carried out seepage analyses to investigate situations where uplift below a confining layer may occur and become the site where 3D backward erosion could initiate. Schaefer et al (2017) reported on many backward erosion incidents, also mostly 3D through confining layers. None caused failure, although sand boils formed at several, showing how backward erosion pipes may initiate, but will not be sustained unless the hydraulic force is sufficient to initiate erosion, drive the pipe towards the reservoir or waterway, and transport eroded particles to the toe.

The hydraulic force causing failure in 2D situations is stated as H/L in Figures 2.5 and 4.4 in ICOLD (2015). As Schaefer et al (2017) explain, the water level that would cause backward erosion to failure through a single point in a confining layer, the 3D situation, is lower than in the 2D situation, where a continuous free outlet exists at the downstream toe of the embankment. This is because in 3D backward erosion the aquifer supplying water to initiate uplift and erosion at the toe, to drive the head of the pipe upstream and to drive eroded particles downstream along the erosion pipe is three-dimensional, surrounding and below the outlet, and therefore supplies copious quantities of water to the pipe. In the 2D situation the aquifer is limited, consequently a higher water level is needed to sustain the hydraulic forces that initiate and continue erosion at the head of the erosion pipe and drive the eroded particles along it.

Vandenboer et al (2014), Allan et al (2015) and Van Beek et al (2015) have investigated 3D backward erosion in more detail in laboratory tests. In the field it seems that hydrogeology, river morphology and geophysics might be applied to deliver parameters to assess the circumstances in which 3D backward erosion could cause failures of levees. Some aspects of this approach have been considered by Glynn et al (2012) and Poulanco-Boulware (2015).

3D backward erosion is the only significant omission from ICOLD Bulletin 164 (ICOLD 2015, 2016), which otherwise remains the most complete current account of the state-of the-art of all aspects of internal erosion, particularly internal erosion mechanics.

The conference concluded with an enjoyable visit to the USBR laboratories where hydraulic modelling and soils, concrete and specialist testing are carried out. Historic samples, of concrete from Hoover Dam, for example, were on display, and much work is in progress. It was pleasing to see a recently concluded large scale test for concentrated leak erosion in an updated crack box (see Bridle, 2016). The modern hydraulic models and laboratories are state-of-the art, the soils and rock testing facilities were excellent – Evan Lindenbach (elindenbach@usbr.gov) and Bobby Rinehart (rrinehart@usbr.gov) would welcome opportunities for collaboration.

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