EROSIVE CAPACITY, RESISTANCE AND PROCESS

GEORGE W. ANNANDALE, D.ING., P.E.
Engineering and Hydrosystems Inc., Denver, Colorado

1 INTRODUCTION

The paper stresses the importance of engineering judgment when conducting scour studies. Engineering judgment is a continuous process that is based on basic physical principles, empiricism and practical experience. Solving problems requires analysis using basic theory and empirical techniques to identify relevant scour trends. The results of such analyses are synthesized with engineering experience and objective and subjective reasoning. In order to allow engineers to make good judgment a solid understanding of basic physical principals and processes is required. This paper stresses the importance of understanding scour processes in engineering practice and discourages the blind use of empirical techniques, as often encountered in practice.

2 EROSIVE CAPACITY

Simple explanation of the concept of erosive capacity is elusive and requires deeper investigaton of the flow processes leading to erosion and scour. In order to do this it is important to distinguish between laminar and turbulent flow as the flow processes leading to erosion and scour by these two modes of flow differ. Exact quanficatoin of the magnitude of erosive capacity has not been accomplished yet, although attempts are made in practice to quantify its relative magnitude. This is normally done by either quantifying the magnitude of the shear stress, velocity or stream power of flowing water. The paper demonstrates that the use of conventional means of quantifying the relative magnitude of the erosive capacity of water leads to inconsistencies that are difficult to justify. These inconsistencies are illustrated by considering the effects of channel roughness on changes in shear stress, flow velocity and stream power. The illustration shows that the trends in these three parameters differe significantly and provide different indications of the potential value of roughening a channel bed.

A argument is made that more attention should be given to understanding the basic processes involved in flow of water and how these processes determine the erosive capacity of the water. It is argued that the concept of using shear stress as an indicator of the erosive capacity of water is principally applicable to laminar flow conditions, and that its application to turbulent flow conditions leads to loss of information. Similarly, it is argued that he use of flow velocity as an indicator of the relative magnitude of the erosive capacity of water is also inappropriate.

The erosive capacity in turbulent flowing water is principally dependent on turbulence generation. The development of turbulent eddies in the near-bed region through the formation of hairpin vortices lead to pressure fluctuations that are the principal cause of incipient motion of sediment and other earth materials. It is shown that the rate of trubulence production, which result in fluctuating pressures, is equal to the applied stream power in the boundary layer and that quantification of the latter could potentially result in a more accurate quantification of the relative magnitude of the erosive capacity of water.

The role of pressure flucatuations in scour initiation and maintenance is discussed in the next section.

3 PROCESS

The initiation and maintenance of the scour process is based on an interaction between flow geometry, flow magnitude and material properties. Quantification of the relationship between these three parameters provides insight into scour processes. The hydraulic roughness of flow is considered part of the geometry, and it is argued that a good understanding of the impact of roughness on flow provide insight into the potential occurrence and extent of scour. By referring to work by Bollaert (2002) the importance of recognizing the role of pressure fluctuations is emphasized, and the need for developing practical methods that quantify the role of such pressure fluctuations in scour processes is emphasized.

The difference in behavior between non-cohesive and cohesive soils and rock when subjected to the erosive capacity of water is described in an effort to explain the factors determining the rate of erosion of earth materials. The rate of scour of non-coheisve earth material is solely dependent of the uplift forces introduced by fluctuating pressures in the flow of water, while the rate of scour of rock, and possibly cohesive earth material, is dependent not only on the magnitude of flucatuating pressures, but also on their frequency.
Earth Material Resistance / Characterization

The characterization of earth material properties normally encountered in practice is challenging due to their complexity. Engineers often have to deal with non-cohesive and cohesive soils, vegetated soils and rock. Although assessment of the erosion resistance of non-cohesive materials has been studied in detail for many years and the parameters defining their resistance are more clearly defined it is often not possible to define erosion thresholds to an acceptable degree of accuracy.

Earth materials encountered in practice are seldom of a purely non-cohesive nature and novel concepts and methodologies for their characterization are requied. Development of new concepts that can assist in characterizing the erosion and scour resistance of earth materials can possibly be based on Percolation Theory. This theory principally deals with phase transformation of materials and distinguishes between chemical and physical gels. Such distinguishment is of great assistance in field characterization of materials and helps in understanding anticipated earth material behavior when subjected to the erosive power of water.

Rock or cohesive materials are examples of chemical gels, while non-coheisve soil is an example of a physical gel. These two gel types are not only dependent on the bond between the individual soil elements, but should also be interpreted in terms of scale. Scaling becomes very important, as it normally is in fluid mechanics. Determinination of the characteristic scale of the earth material subject to the erosive capacity of water play an important role in characterization. For example, rock may be viewed as a chemical gel when water gently flows over it, but becomes a physical gel when a large jet plunges onto it from a significant height. In the latter case the pressure fluctuations introduced by the jet penetrates the rock discontinuities, possibly ejecting blocks of rock. The essential fibre of the rock blocks (which are considered to represent a chemical gel) no longer comes into play because the forces introduced by the jet are so large that the scale of the individual rock blocks relative to the scale of the hydraulic forces allows characterization as a physical gel. Similarly, when investigating the erosion of cohesive material like clay, the material should be characterized relative to the scale of the flow of the water imposing its erosive capacity onto the soil.

Characterization of earth materials therefore requires implementation of multiple techniques to understand its potential erosion resistance and behavior. These include specimen testing, indexing, visual observation and uncerstanding of the geological history and context of the earth material. Tests that can be used to estimate the rate of erosion of weak chemical gels, such as clays, include the Erosion Function Apparatus (EFA), the Horizontal Erosion Test (HET) and the Vertical Jet Tester (VJT). By combining these test resuls with seismic and indexing techniques it is possible to gain reasonable understanding of the erosion and scour resistance of earth materials in practice. Indexing techniques that can be used include the Erodibility Index Method.

When considering the erosion resistance of vegetated soils it is useful to analyze the root architecture and root habit of plants used to protect agains erosion. These two elements combined with the role that foliage plays in reducing the proportion of the erosive capacity of the water in direct contact with the bare soil play dominant roles in determining the ability of vegetated soils to resist erosion and scour. A method for assessing the role of these two elements is presented.

The role of the mass strength of earth materials, block or particle size, shear strength and orientation are explained, particularly as it relates to scour of rock. The role of these elements in determining block removal, and brittle and sub-critical failure of rock subject to the erosive power of water is discussed. The relevance of using these parameters to characterize other earth materials, such as non-cohesive and cohesive soils is discussed.

An example of applying indexing, laboratory testing and seismic testing to characterize the erosion and scour resistance of materials is presented.

4 CONCLUSION

The role of engineering judgment in scour analysis has been amplasized. In order to make good engineering decisions a clear understanding of erosion and scour processes is required. Current methods that are generally used in practice do not fully account for the processes involved in erosion and scour, and a need for combining fundamental research with the development of engineering techniques exists. Fundamental research into scour processes will provide practicing engineers with a better understanding of the actual processes and will assist them in interpreting results obtained from applying standard engineering techniques. The paper argues that the use of shear stress and flow velocity to quantify the relative magnitude of the erosive capacity provides contradicting results. More emphasis should be placed on the role of pressure fluctuations and how the latter can be quantified in a pragmatic manner for use in practice.