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Application of the Erodibility Index Method to Estimate Scour at Bridge Piers

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SUMMARY

The Erodibility Index Method (EIM) [2] is a new method that can be used to estimate the erosion threshold of a wide variety of earth materials, including cohesionless granular material, cohesive soils and rock. The EIM defines the erosion threshold for earth materials by relating the erosive power of water and a geo-mechanical index. The geo-mechanical index quantifies the relative ability of earth materials to resist erosion. It is a function of mass strength, block or particle size, inter-particle shear strength, dip and strike of rock, and its relative shape. The erosive power of water is expressed in terms of rate of energy dissipation. Existing methods to predict scour at bridge piers assume that the piers are founded on cohesionless granular material. These methods do not fully account for the resistance to scour offered by more complex earth materials, such as clay and rock, and can lead to over-prediction of scour. Prediction of bridge pier scour by using the EIM allows engineers to take account of the resistance to scour that is offered by materials as diverse as cohesionless granular material, cohesive soils and rock. This paper outlines the approach for using the EIM to calculate scour around bridge piers.

1 INTRODUCTION

Conventional bridge pier and abutment scour equations were developed in laboratory flumes using cohesionless granular soil (see e.g. [3] and [4]). Such equations do not account for resistance to scour offered by more complex earth materials, such as rock or clay. A generalized erosion threshold that is defined by Annandale's Erodibility Index Method [2] can be used to quantify the relative ability of any earth material (ranging from silt, through sand, gravel, clay and rock) to resist erosion. This paper outlines the application of this method to calculate ultimate scour depth at bridge piers.

2 CONCEPTUAL APPROACH

A comparison between scour depths calculated with conventional pier scour equations (e.g. [3]) and with the method proposed in this paper is conceptually shown in Figure 1. The scour depth calculated with a conventional pier scour equation is considered to be the maximum possible scour depth. Such estimates do not take account of resistance to scour offered by foundation material. Conceptually, the ultimate scour depth estimate that takes account of foundation material properties will be equal to or less than the maximum possible value.

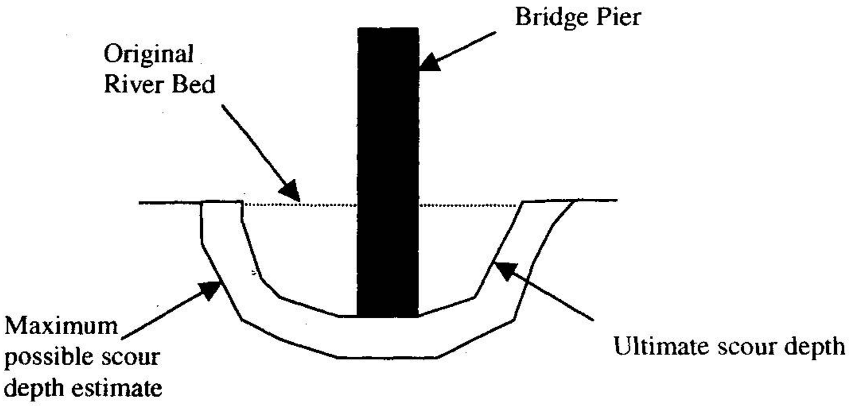

Figure 1. Relationship between the maximum possible scour depth estimated with conventional pier scour equations and the ultimate scour depth estimated with the method proposed in this paper.

The basis of the approach that is used to estimate ultimate scour depth by taking account of material properties, is explained in Figure 2. This figure shows a relationship between the erosive power of water and elevation below the original river bed. The two curves on the figure represent the **available** erosive power at the base of the pier as the scour hole increases in depth, and the erosive power that is **required** to cause scour at different elevations below the original river bed. The **available** erosive power at the base of a pier is a function of scour hole depth. The erosive power that is **required** to cause scour of the earth material is determined from the Erodibility Index Method. Normally the strength of earth material, especially rock, increases as a function of elevation below the original river bed. In such cases the erosive power that is **required** to scour the earth material also increases as a function of elevation below the original river bed. Research (see e.g. [6]) has shown that the erosive power of water at the base of a bridge pier decreases as the scour hole increases in depth . The maximum scour depth will occur at the cross-over elevation where the available erosive power is equal to the power that is required to cause scour. This approach has been successfully confirmed with prototype scale tests ([1] and [7]).

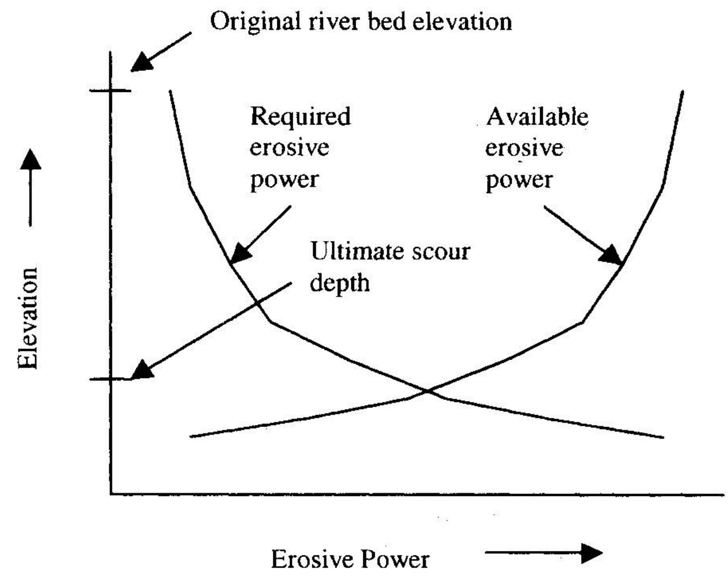

Figure 2. Calculation of ultimate scour depth by comparing the available erosive power at the base of a bridge pier and the erosive power that is required to scour earth material

3 RESISTANCE TO SCOUR

The erosion threshold shown in Figure 3 relates a geo-mechanical index (known as the Erodibility Index) and the erosive power of water [2]. This relationship holds for a wide variety of flow conditions and earth materials. The relative ability of earth material to resist erosion can be quantified by making use of the erosion threshold line in Figure 3.

The stream power required to scour earth material is determined by first indexing the earth material by means of the Erodibility Index. The Erodibility Index is a function of mass strength, block / particle size, shear strength, relative orientation and shape. Tables that can be used to quantify the Erodibility Index are presented in [2]. Once the earth material has been indexed a line is drawn vertically from the abscissa at the associated value on Figure 3 to meet the dotted erosion threshold line. From this location it is then drawn parallel to the abscissa to determine the required stream power value on the ordinate. This procedure is repeated for various elevations below the river bed. These pairs of values (elevation and **required** stream power) are plotted on a graph similar to Figure 2.

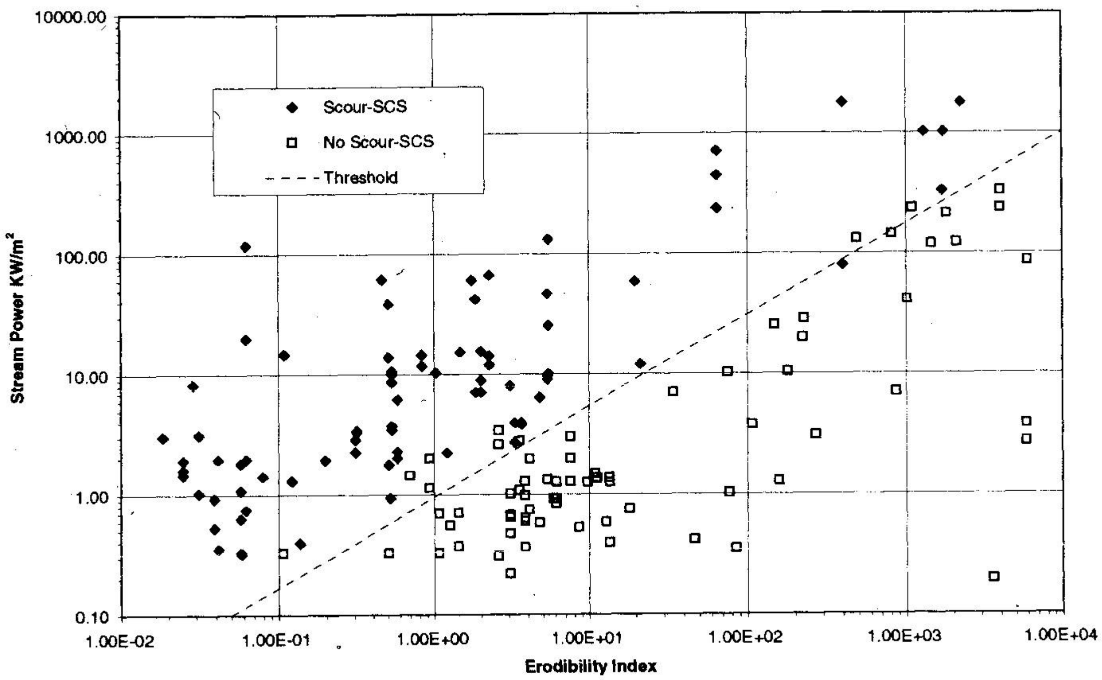

Figure 3. Erosion Threshold for a Variety of Earth Materials

4 EROSIVE POWER OF WATER

The change in the erosive power of water around a bridge pier as a function of elevation is determined by making use of graphs that were developed for this purpose (see e.g. [6]). These graphs relate dimensionless stream power at the base of a pier and dimensionless scour depth, following the general shape of the curve in Figure 4. The variable on the ordinate of this graph represents the ratio between the magnitude of the stream power at the base of the scour hole (P_p) and the stream power in the river section upstream of the bridge (P_r). The variable on the abscissa represents the ratio between variable scour depth (Y_s) and maximum scour depth (Y_{max}). When the latter variable is zero, it indicates the elevation of the original river bed before commencement of scour. When the same has a value of one, it represents the maximum scour depth. Values in between zero and one represent potential ultimate depths of scour.

The stream power is quantified by multiplying the various values of the ratio on the ordinate in Figure 4 with the stream power in the river upstream of the pier. The latter is quantified as the product of the unit weight of water (γ - kN/m^3), unit discharge (q – m^3/s/m) and energy slope (s), i.e.

$$\text{Power in river upstream of pier} = \gamma \, . \, q \, . \, s \qquad \text{(Equation 1)}$$

The scour depth on the abscissa is quantified by multiplying the various values of the ratio on the abscissa with the maximum scour depth estimate calculated with conventional pier scour equations (e.g. the equations in [3]). Once both the stream power and the potential scour depths in Figure 4 are quantified, the information is transferred to Figure 2. The latter curve represents the **available** stream power.

5 ULTIMATE SCOUR DEPTH

The ultimate scour depth is determined by plotting the required and available stream power as a function of elevation (Figure 2). The ultimate depth is located at the elevation where the **available** stream power is equal to the **required** stream power.

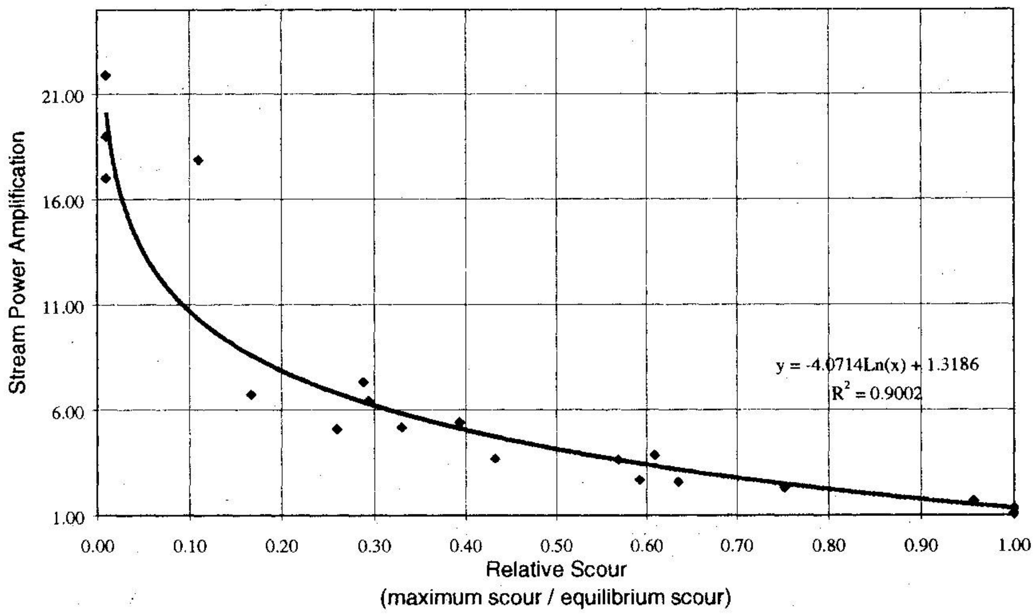

Figure 4. Stream power amplification at square bridge piers as a function of relative scour depth [6].

6 SUMMARY

A method that can be used to calculate ultimate scour depth by taking account of bed material properties is outlined in the paper. The method is based on comparison between the available erosive power and the erosive power that is required to scour a particular earth material. The relative magnitude of the erosive power of water around a bridge pier is determined by making use of dimensionless relationships that were developed for this purpose. The power that is required to scour the earth material is estimated at various elevations below the original river bed by making use of the Erodibility Index Method. The power that is available to cause scour is then compared to the power that is required to scour the earth material under consideration. This comparison is done at various assumed scour depths. The scour depth where the available erosive power is less than the power that is required to scour the earth material is considered to be the ultimate scour depth.

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