ERODIBILITY OF A COHESIVE SOIL USING A SUBMERGED CIRCULAR TURBULENT IMPINGING JET TEST

Kerry A. Mazurek, Assistant Professor, Department of Civil and Geological Engineering, University of Saskatchewan, 57 Campus Drive, Saskatoon, Saskatchewan, Canada, Ph: (306) 966-5477 Fax: (306) 966-5427 e-mail: Kerry.Mazurek@usask.ca

Abstract Currently there is no widely accepted method for the quantitative assessment of soil erosion resistance and potential erosion rates for clay-rich or "cohesive" soils. This is because both the stresses created by the turbulent water flow on the soil surface and many of the factors that affect cohesive soil erodibility are difficult to measure and assess. One of the techniques to determine soil erodibility that is becoming more widely accepted in practice is the jet test. In this technique, a submerged circular turbulent impinging jet is used to create scour in a soil sample and the progress of scour is monitored with time. The results can be used to determine both the critical shear stress and erodibility coefficient of the soil. This paper presents the results for soil erodibility from a study of scour by a vertical circular jet in a cohesive soil where several samples of similar properties were tested. The critical shear stress was evaluated using two techniques, which gave average values of critical shear stress that differed by 41 Pa. The results for the erodibility coefficient K were seen to strongly vary with test duration (by an order of magnitude).

INTRODUCTION

Estimating the erodibility of clay-rich soils is important for assessing scour below or around hydraulic structures, stream channel degradation, riverbank stability, soil losses from fields, potential landform evolution for mine covers, and the stability of embankments. Erodibility is typically defined by two parameters: the critical shear stress, τ_c, which is the shear stress created by the flow on the soil surface for which (significant) erosion first starts to occur; and the erodibility coefficient, K, which represents the ratio of the erosion rate of the soil to the excess shear stress on the bed (the difference between the shear stress created by the flow on the soil surface and τ_c). Currently, there is no widely accepted, reliable method to estimate these parameters for clay-rich soils based on the soil properties. The best approach to determine these parameters is to measure them.

Many techniques to determine erodibility of soils have been developed for use both in the laboratory and in-situ. These have included a rotating cylinder apparatus (Moore and Masch 1962), a rotating annular flume (Krishnappan 1993), open-channel flume tests (Hanson 1990a), closed-channel tests such as the Erosion Function Apparatus (Briaud et al. 2001), and the use a vertical impinging jet in a number of different geometries with varied methods of analysis of the results (Bhasin et. al 1969; Hollick 1976; Hanson 1991; Tolhurst et al. 1999; Hanson and Cook 2004). For reliability, an in-situ technique for determining erodibility is preferable. This because the soil is not disturbed by sampling and tests can be conducted using the in-situ water, as eroding water chemistry is known to affect soil erosion resistance (Arulanandan et al. 1975). An impinging jet-type apparatus is the technique most often used for in-situ measurements.

Of the different impinging jet-type techniques, the methods presented in Hanson and Cook (2004) and in the ASTM Standard D5852 (ASTM Standard D5852, 2000 (2007)) are increasingly being used to assess soil erodibility (Allen et al. 1997; Shugar et al. 2007; Thoman and Niezgoda 2008; Clark and Wynn 2007). In the jet-test methodology described in the standard, a qualitative description of erodibility is produced using the quantitative jet scour measurements, although a method for assessing the erodibility coefficient when the value of the critical shear stress is very small is also given. However, Hanson and Cook (2004) present analytical procedures for using the jet test for quantitative estimation of both the critical shear stress and erodibility coefficient of a soil based on the time development of scour in the soil.

There are still some concerns about the reliability of a jet-type test for assessment of soil erodibility (Annandale 2006). The objective of this paper is to gain an improved appreciation for the variability of results from this type of test by assessing the critical shear stresses and erodibility coefficients for several samples of one clay soil where the time development of scour in each sample was measured. These tests were long-term (lasting up to 147 h) and many of the scour holes in the samples appeared to reach an equilibrium size. The variation of the erodibility coefficient with a change in test duration is also assessed.

EXPERIMENTS AND EXPERIMENTAL SETUP

The soils samples were pottery clay obtained from Plainsman Pottery Supply of Medicine Hat, Alberta, Canada (M390 type clay). Pottery clay was used so that many samples of similar properties could be tested. In the manufacture of this clay, the mined, clayey material was first dried in an oven to remove excess moisture and then passed through a series of hoppers to ensure the material was well mixed. From the final hopper, the material moved into a mixing section that looked very much like an auger. In this mixing section, water (City of Medicine Hat, Alberta tap water) was added to the clay mixture. The amount of water added was based on the experience of the technicians working at the plant. The wetted clay was then moved in a rectangular vacuum chamber by a continuous feed to be consolidated into a long rectangular block. Figure 1 shows this chamber. The vacuum chamber was effective in removing any voids in the samples, as noted from experience in jet testing the material. The long rectangular block was then cut into smaller pieces (the test samples for the experiments described herein), which were then sealed in plastic bags.

Samples from two batches of pottery clay were used for the present tests. The first batch (Batch 34283418) had a clay content of about 40 %, a liquid limit of 34.8 %, a plastic limit of 18.5 %, and an activity of 0.42. The second batch (Batch 334027107) varied slightly from the first with an average clay content of 42 %, a liquid limit of 38.6 %, a plastic limit of 18.1 %, and activity of 0.49. On average, the soils were about 40 % clay, 53 % silt, and 7 % fine sand. The dry density for the samples averaged 1540 kg/m^3. Electron micrographs showed that the clay had an aggregated structure with random particle orientations. X-Ray diffraction showed that the clay component of the soil consisted of kaolinite and illite. Saturation of the samples averaged 97 % before being submerged for jet testing. The water content of each test sample was measured just after it was trimmed for testing, w_c, just prior to testing, w_p, and immediately after each test, w_f.

Figure 1 Vacuum extruder used to consolidate the pottery clay samples.

The material for assessing w_f was taken from the top 30 mm from the surface of the sample immediately beside the scour hole. These water contents are reported in Table 1. The samples were prepared for testing by first pushing a 0.5 mm thin rectangular metal band into the clay block. The surface of the clay was then cut with a thin metal wire to create smooth, even sample surface. The final sample size was 244 mm long, 175 mm wide, and 85 mm high.

The scour tests were conducted within an octagonal tank of 610 mm height and 570 mm diameter. Each sample was set within the tank on a table and centered below the jet. For the tests reported herein, the jet diameter, *d*, was 8 mm, which was set at a height *H* above the soil surface of 65 or 116 mm. The relative impingement height *H/d* was thus either 8.1 or 14.5 so that for all experiments the jet was set at a large impingement height (Beltaos and Rajaratnam 1974). The jet of velocity U_o of 6.17 –9.93 m/s was created by pumping City of Edmonton, Alberta tap water through an 826 mm long, 120 mm diameter plenum, a 125 mm long contraction section, and then through a well-designed nozzle of final diameter *d*. The flow rate was measured using a magnetic flow meter, which was periodically checked by volumetric measurements. Jet Reynolds numbers, $R = \rho U_o d / \mu$ were in the range of 43343-76829, where ρ and μ are the density and dynamic viscosity of the eroding fluid. Figure 2 shows the apparatus. Mazurek (2001) and Mazurek et al. (2001) give more details of the experimental setup and experiments.

For each test, the maximum scour depth, centerline scour depth, and volume of scour, were measured at times of approximately 2 min, 5 min, 15 min, 1 h, 2 h, 4 h, 8 h, 24 h, 48 h, 72 h, and 96 h, and then at 24 h intervals until asymptotic state, or equilibrium, was reached. Table 1 gives the test conditions and results for each experiment. Mazurek (2001) provides the full data set giving the scour depth measured with time for each experiment. In two of the tests reported here (8/8.1/6.1/2 and 8/8.1/9.9/1), the scour holes did not reach equilibrium as the clay blocks failed.

Figure 2 Experimental setup.

METHOD OF ANALYSIS

Critical Shear Stress, τ_c The critical shear stress, τ_c, and erodibility coefficient, K, were determined from the time development of centerline scour depth for each experiment. The critical shear stress was calculated from the centerline scour depth at equilibrium, which was determined by two methods. The first was that measured in the experiments, ε_{clme}. This scour depth was measured from the level of the original, unscoured soil surface and not from the origin of the jet at the nozzle. In the experiments, equilibrium was assumed to have been reached when there was no significant change in the scour hole volume over 24 h (less than 0.5 mL). Additional information taken to be evidence of equilibrium state was that a plot of the scour depth versus the logarithm of the time showed a sudden change to a flat slope from what is typically a straight-line relationship between the two values (Mazurek et al. 2001). The second means of determining the equilibrium centerline scour depth was the use of the curve fitting procedure developed by Blaisdell et al. (1981), who suggested a hyperbolic logarithmic equation for the relationship between the scour depth and the time from the start of a test. This procedure was demonstrated and outlined by Hanson and Cook (2004). The equilibrium scour depth

Table 1 Experiments and results

Clay Lot	Test No.	H (mm)	d (mm)	H/d	U_o (m/s)	Temp (°C)	R	w_c (%)	w_p (%)	w_f (%)	ε_{clme} (mm)	ε_{clBe} (mm)	τ_{cm} (Pa)	τ_{cB} (Pa)	K_m (< 8h) cm^3/(N-s)	K_B (< 8h) cm^3/(N-s)	t_d (h)	K_B (all data) cm^3/(N-s)
34281348	8/8.1/6.1/2	65	8	8.1	6.17	15.1	43343	-	-	-	-	66.5	-	23.2	-	0.015	7.6	0.0146
	8/8.1/7.0/1	65	8	8.1	6.96	18.9	53605	26.2	30.0	27.4	12.7	39.6	84.7	46.7	0.020	0.015	118.0	0.0009
	8/8.1/7.4/1	65	8	8.1	7.44	18.3	56123	26.2	28.2	27.6	20.8	60.3	79.3	37.2	0.038	0.017	146.7	0.0010
	8/8.1/8.4/1	65	8	8.1	8.36	15.6	58585	26.4	30.4	-	40.5	117.0	66.2	22.2	0.072	0.034	115.8	0.0028
	8/8.1/9.0/2	65	8	8.1	8.95	22.3	76829	26.2	-	27.9	35.0	127.3	84.5	22.8	0.054	0.016	44.7	0.0042
	8/8.1/9.0/3	65	8	8.1	8.95	19.9	69458	25.5	29.6	27.4	32.5	102.9	88.9	30.0	0.032	0.017	122.8	0.0014
	8/8.1/9.0/4	65	8	8.1	8.95	11.8	62769	26.5	26.5	27.3	43.5	131.8	71.9	21.8	0.040	0.021	116.8	0.0022
	8/14.5/9.0/1	116	8	14.5	8.95	20.1	70188	26.1	30.1	27.8	8.0	28.9	55.0	40.3	0.037	0.009	97.4	0.0022
	8/14.5/9.0/4	116	8	14.5	8.95	22.2	74713	-	29.5	27.2	7.5	20.2	55.4	45.6	0.099	0.029	68.6	0.0053
334027107	8/8.1/8.1/1	65	8	8.1	8.06	18.3	43647	26.2	28.2	27.6	42.2	38.1	59.6	64.5	0.021	0.022	68.5	0.0029
	8/8.1/9.0/8	65	8	8.1	8.95	19.0	69278	26.0	29.0	-		60.2	-	54.0	-	0.007	22.4	0.0035
	8/8.1/9.9/1	65	8	8.1	9.93	16.9	73035	26.9	29.2	28.6	37.0	72.2	100.0	55.2	0.046	0.026	117.4	0.0023

calculated by the Blaisdell et al. (1981) approach is referred to as ε_{clBe}. Table 1 gives the values for the equilibrium depth of scour seen in each experiment.

To find the critical shear stress from the equilibrium scour depth, the method developed by Hanson and Cook (1997) was followed. This method was adapted for use in scour by submerged vertical circular impinging turbulent jets by Hanson and Cook (1997) from the theory developed by Stein et al. (1993) to predict the time development of scour produced by obliquely impinging plane jets. In developing this method, first consider the present case of the submerged vertical circular turbulent impinging jet of velocity U_o and diameter d at the nozzle (jet origin) set at a height H above the surface of the soil. In the free jet region of the jet, extending immediately from the nozzle, the jet has a potential core where the velocity remains at U_o along the jet centerline. After the potential core, the decay of the maximum velocity, u_m, of a circular free jet along its centerline can be given by (Beltaos and Rajaratnam 1974)

$$\frac{u_m}{U_o} = C_d \left(\frac{d}{x} \right) \tag{1}$$

where x = distance from the nozzle; and C_d = diffusion coefficient. Rajaratnam (1976) suggested that C_d=6.3 and this value is used by Hanson and Cook (1997, 2004). This value of C_d gives a potential core length of $x_p=6.3d$. Eq. 1 applies only for $x>x_p$.

Hanson and Cook (1997) next consider the maximum shear stress, τ of the jet with distance from the nozzle. They assume

$$\tau = c_f \rho U_o^2 \qquad \text{for } x \le x_p . \tag{2}$$

$$\tau = c_f \rho u_m^2 \qquad \text{for } x > x_p . \tag{3}$$

where c_f is the local friction coefficient. Hanson and Cook (2004) used c_f=0.00416 based on some experimental work discussed in Hanson et al. (1990). For comparison, Beltaos and Rajaratnam (1974) found c_f= 0.00403 for a jet impinging on a flat, rigid smooth bed.

Next, to determine the critical shear stress of the soil, τ_c, it is assumed that the equilibrium state of scour represents the conditions in the scour hole when the maximum shear stress on the bed is equal to τ_c. If the distance from the nozzle to the scour bed along the jet centerline at equilibrium is $H + \varepsilon_{cle}$, combining Eqs. 1 and 3 gives

$$\tau_c = c_f C_d^{\,2} \rho U_o^2 \left(\frac{d}{H + \varepsilon_{cle}} \right)^2 \tag{4}$$

where ε_{cle} is the centerline scour depth at equilibrium measured from the original bed level. For the calculations herein, it was assumed that C_d=6.3 and c_f=0.416.

Erodibility Coefficient, *K* The erodibility coefficient K was also determined following the procedures outlined in Hanson and Cook (1997, 2004), which again is based on the work of Stein et al. (1993). In this method, it is assumed that the rate of change of the scour depth is proportional to the excess shear stress on the bed, given as

$$\frac{dH_t}{dt} = K\left(\tau - \tau_c\right) \tag{5}$$

where $H_t = H + \varepsilon_{clt}$; ε_{clt} is the depth of scour as measured from the unscoured soil surface along the jet centerline at time *t* from the start of a test; *K* is erodibility coefficient; and τ is the shear stress on the bed at the jet centerline, as given by Eqs. 2 and 3. With some manipulation and following Stein et al. (1993), Hanson and Cook (1997, 2004) showed that the relationship between the time of scouring measured from the start of a test, *t*, and the scour depth can be expressed as

$$t = T_r\left(0.5\ln\left(\frac{1+H_*}{1-H_*}\right) - H_* - 0.5\ln\left(\frac{1+H_{i*}}{1-H_{i*}}\right) - H_{i*}\right) \tag{6}$$

where T_r is a reference time defined as $T_r = H_{te}/(K\tau_c)$; H_{te} is the sum of the impingement height H and the equilibrium depth of scour at the jet centerline; H_* is the dimensionless scour depth, defined as $H_* = H_t/H_{te}$; and H_{i*} is the initial height of the soil surface expressed in dimensionless form as $H_{i*} = H/H_{te}$.

To determine *K*, the critical shear stress was first determined by the methods described above. Then, measurements for the time from the start of the test and centerline scour depth measured at that time, expressed as H_*, were plotted. Equation 6 was then fit to the data by minimizing the least square errors to find T_r. This was done using the general fit development procedures in the plotting and statistical software KaleidaGraph (V4.03), which uses the Levenberg-Marquardt algorithm for the least squares fitting. The T_r found from the curve-fit was then used to find K.

In determining *K*, it was found that length of time into a test for which scour data was included for the regression significantly influenced the results. This is discussed in more detail below. The critical shear stress for the soil also affects the results for *K*. Thus, *K* was determined using both calculated critical shear stresses for each test (that based on the measured equilibrium scour depth, τ_{cm}, and that calculated by the Blaisdell et al. (1981) curve-fitting approach, τ_{cB}). For both sets of results, *K* was calculated by including only scour data for a test duration less than 8 h. This is because these jet-scour tests are typically run for relatively short time since they are often in-situ tests; it was desirable to compare the present results to previous work. However, for comparison, for the Blaisdell results for the equilibrium scour depth and critical shear stress, *K* was also calculated for the full data set. The test duration used for these calculations is given as

t_d in Table 1. Additionally, for two tests the relationship between the calculated K and the test duration for which scour data was included in the regression of Eq. 6 was assessed.

RESULTS AND DISCUSSION

In interpreting the results, it first should be noted that the values reported herein are for scour holes formed by mass erosion. Mass erosion is the erosion of lumps or chunks of soil. For the present tests, these chunks ranged in size from small cubically shaped lumps that were about 3 mm long, 2 mm thick, and 2 mm wide up to large chunks that were more angular shape and up to 140 mm by 40 mm by 20 mm in size. Mass erosion occurred intermittently and there was no obvious pattern to the soil removal in time or location, except that larger chunks tended to be eroded earlier on in a test.

As seen in Table 1, the results for the critical shear stress showed significant variability both between samples and between methods in its calculation. The values for the critical shear stress based on the measurements on the equilibrium scour depth varied from 55-89 Pa with an average value of 73 Pa for the samples for clay lot 34281348 and 60-100 Pa with an average of 80 Pa for the samples from lot 334027107. The critical shear stress values produced from the Blaisdell method for estimating the equilibrium scour depth produced smaller values with a range of 22-47 Pa and an average of 32 Pa for clay lot 34281348. Similarly, for clay lot 334027107, the critical shear stress range from 54-65 Pa, with average value of 58 Pa. This variation could partly be a result of an underestimation of the equilibrium depth of scour in the experiments (i.e. the tests were stopped too soon and the scour hole may have not actually reached an equilibrium state). However, it more likely indicates a need for improved theoretical prediction of the equilibrium scour depth from “early in the scour process” measurements, as well as problems with the prediction of the shear stresses within a scour hole (for which there is very limited data).

Table 1 also gives the results of the erodibility coefficient determinations. For clay lot 34281348, it is seen that K varied between 0.02-0.1 cm^3/N-s with an average value of 0.05 cm^3/N-s based on the measured value of the equilibrium scour depth. For these calculations, only scour data up to 8 h of testing were used. Based on the Blaisdell et al. (1981) method of determining the equilibrium depth of scour and using scour data up to 8 h of testing, K varied from 0.009 to 0.03 cm^3/N-s, with an average value of 0.02 cm^3/N-s. If the entire data set is used for the Blaisdell et al. (1981) method results for the regression of Eq. 6 to the scour data (i.e. the entire test duration), the estimated erodibility coefficients drop by approximately an order of magnitude. It is seen the range for K drops to 0.0009 to 0.015 cm^3/N-s, with an average value of 0.004 cm^3/N-s.

A further investigation into the effect of the test duration on the estimated valued of K was carried out for tests 8 8.1 9.9 1 and 8 8.1 9.0 4. Figure 3 shows the variation of K with the test duration for these experiments, where there appears to be a systematic variation of K with test duration. However, an 8 h test duration gave approximately the average value of the calculated K’s for the tests.

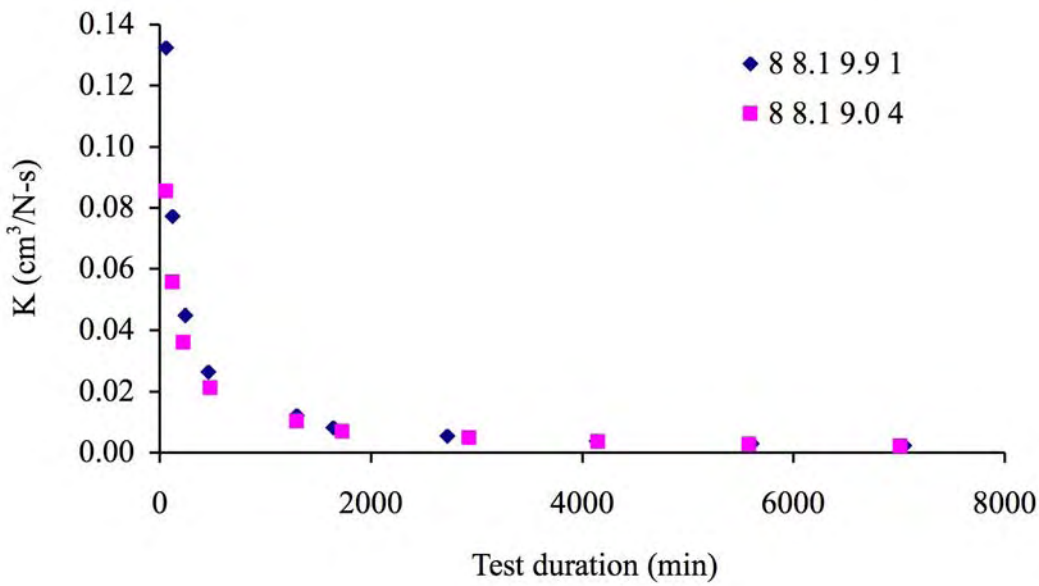

Figure 3 Variation of erodibility coefficient with test duration for tests 8/8.1/9.9/1 and 8/8.1/9.0/4.

CONCLUSIONS

The results of vertical jet testing of one cohesive soil showed significant variability between samples for both the critical shear stress and erodibility coefficient K. Two different methods for estimating the equilibrium scour depth, by measuring it and by the approach suggested by Blaisdell et al. (1981), produced average values of critical shear stress of 73 and 32 Pa. The average values for the erodibility coefficient between the two methods were 0.05 and 0.02 cm^3/N-s. The calculated erodibility coefficient was seen to strongly depend on the test duration. There appears there may be a systematic decrease in the K produced from a jet test with an increase in test duration. These results indicate that a better method for estimating the critical shear stress from jet test results is likely required. The model for the time development of scour used in determining K for a soil also appears to need further assessment.

ACKNOWLEDGEMENTS

The author acknowledges the Natural Sciences and Engineering Research Council of Canada for financial support for this work in the form of a Discovery Grant.

REFERENCES

Annandale, G.W. (2006). Scour Technology: Mechanics and Practice. McGraw Hill, New York.

Allen, P.M., Arnold, J., and Jakubowski, E. (1997). “Design and testing of a simple submerged-jet device for field determination of soil erodibility,” Environmental & Engineering Geoscience, 3(4), pp 579-584.

Arulanandan, K., Loganathan, P., and Krone, R. (1975). "Pore and eroding fluid influences on surface erosion of soil,” J. Geotech. Div., ASCE, 101(GT1), pp 51-66.

ASTM Standard D5852, 2000 (2007) (2007). “Standard test method for erodibility determination of soil in the field or in the laboratory by the jet index method,” ASTM International, West Conshohocken, Pennsylvania, USA.

Bhasin, R.N., Lovell, C.W., and Toebes, G.R. (1969). “Erodability of sand-clay mixtures as evaluated by a water jet,” Technical Report No. 8, Purdue University Water Resources Research Center, Purdue University, Lafayette, Indiana.

Beltaos, S., and Rajaratnam, N. (1974). “Impinging circular turbulent jets,” J. Hydr. Div., ASCE, 100(10), pp 1313–1328.

Blaisdell, F.W., Anderson, C.L., Hebaus, G.G. (1981). “Ultimate dimensions of local scour,” J. Hydraulics Division, ASCE, 107(HY3), pp 327-337.

Briaud, J.L., Ting, F.C.K., Chen, H.C., Cao, Y., Han, W., and Kwak, K.W. (2001). “Erosion function apparatus,” J. Geotech. Geoenv. Engr., ASCE, 127(2), pp 105-113.

Clark, L.A., and Wynn, T.A. (2007). “Methods for determining streambank critical shear stress and soil erodibility: Implications for erosion rate predictions,” Trans. ASABE, 50(1), pp 95-106.

Hanson, G.J. (1990a). “Surface erodibility of earthern channels at high stresses: Part I,” Trans. ASAE, 33(1), pp 127-131.

Hanson, G.J. (1991). “Development of a jet index to characterize erosion resistance of soils in earthern spillways,” Trans. ASAE, 34(5), 2015-2020.

Hanson, G.J., and Cook, K.R. (2004). “Apparatus, test procedures, and analytical methods to measure soil erodibility in-situ,” Trans. ASAE, 20(4), pp 455-462.

Hanson, G.J., and Cook, K.R. (1997). “Development of excess shear stress parameters for circular jet testing,” Proc., 1997 ASAE Annual International Meeting, Minneapolis, Minnesota, Paper 972227.

Hanson, G.J., Robinson, K.M., and Temple, D.M. (1990). “Pressure and stress distributions due to a submerged impinging jet,” Hydr. Engineering, Proc. 1990 National Conference, ASCE, Reston, VA, pp 525-530.

Hollick, M. (1976). “Towards a routine assessment of the critical tractive forces of cohesive soils,” Transactions of the ASAE, 19, pp 1076-1081.

Krishnappan, B.G. (1993). “Rotating circular flume,” J. Hydr. Eng., 119(6), pp 758-767.

Mazurek, K.A. (2001). Scour of Clay by Jets, PhD Thesis, University of Alberta, Edmonton, Alberta, Canada.

Mazurek, K.A., Rajaratnam, N., and Sego, D.C. (2001). “Scour of cohesive soil by submerged circular turbulent impinging jets,’’ J. Hydr. Engr., 127(7), pp 598–606.

Moore, W.L, and Masch, F.D. Jr. (1962). “Experiments on the scour resistance of cohesive sediments,” J. Geophysical Research, 67(4), pp 1437-1449.

Shurgar, D., Kostaschuk, R., Ashmore, P., Desloges, J., and Burge, L. (2007). “In situ jet-testing of the erosion resistance of cohesive streambeds,” Can. J. Civ. Eng., 34, pp 1192-1195.

Stein, O.R., Julien, P.Y., and Alonso, C.V. (1993). "Mechanics of jet scour downstream of a headcut," J. Hydraulic Research, 31(6), pp 723-738.

Thoman, R.W., and Niezgoda, S. (2008). “Determining erodibility, critical shear stress, and allowable discharge estimates for cohesive channels: Case Study in the Powder River basin of Wyoming,” J. Hydr. Engr., ASCE, 134(12), pp 1677-1687.

Tolhurst, T.J., Black, K.S., Shayler, S.A., Mather, S., Black, I., Baker, K., and Paterson, D.M. (1999). “Measuring the in-situ erosion shear stress of intertidal sediments with the cohesive strength meter (CSM),” Estuarine, Coastal, and Shelf Sci., 49, pp 281-294.