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Chapter 52 Field Procedures Guide for the Headcut Erodibility Index

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Contents:

Figure

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628.5200 Introduction

This chapter presents field procedures and terminology used in the determination of the parameters that form the headcut erodibility index, K_h, given in equation 51–13 of Part 628, Chapter 51, Earth Spillway Erosion Model. The criteria were developed primarily from the analysis of data collected by the U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS) and Agricultural Research Service (ARS). The data resulted from studies of spillway performance at 125 earth auxiliary spillways in 10 states between 1983 and 1993.

The concept of a headcut erodibility index was first developed by Moore et al. (1994) based on the analogy between bulldozer drawbar power required for ripping earth materials and the hydraulic power associated with turbulent energy dissipation at a headcut. The classification system presented in Temple and Moore (1997) enables any type of earth material, whether engineered or natural, to be characterized quantitatively with regard to its hydraulic erodibility under various hydraulic conditions. The system, based closely on Kirsten's (1982, 1988) ripability index, allows earth material to be classified on a continuous basis from loose granular or soft cohesive soils through extremely hard, massive rock. The geological parameters that constitute the index include earth material strength, block or particle size, discontinuity or interparticle bond shear strength, and shape of material units and their orientation relative to streamflow.

Trained professionals can conduct the identification procedures relatively easily and at low cost in the field. Each parameter is expressed in quantitative terms to avoid uncertain interpretation and is logarithmically scaled to improve accuracy of assessments. Terminology used in developing the field identification tests is, to the extent possible, consistent with industry usage.

The headcut erodibility index, K_h, represents a measure of the resistance of the earth material to erosion. The index is the scalar product of the indices for its constituent parameters. The index takes the general form:

$$K_h = M_s \times K_b \times K_d \times J_s \qquad [52\text{–}1]$$

where:

M_s = material strength number of the earth material
K_b = block or particle size number
K_d = discontinuity or interparticle bond shear strength number
J_s = relative ground structure number

The number, M_s, expresses the unconfined compressive strength of an intact representative sample of the material itself without consideration of innate geologic variability within the mass. The number, K_b, refers to the mean block size of intact rock material (the cube root of the volume) as determined by the spacing of discontinuities within the rock mass or mean grain size for granular material (Barton et al. 1974). The number, K_d, represents the shear strength of a discontinuity in a rock mass, or the strength of interparticle bonds of the gouge (soil material) within the aperture of a discontinuity; it also represents shear strength of interparticle bonds in granular soils (Barton et al. 1974). The number, J_s, accounts for the structure of the ground with respect to streamflow. It is a complex function that considers orientation and shape of individual blocks, as determined by the measurement of the spacing, dip angles, and dip directions of joint sets, with respect to direction of streamflow.

628.5201 Geological mapping

Engineering geological mapping includes identification, characterization, and spatial representation of zones of geologic material that meet similar engineering performance criteria. Geologic material (soil, rock) is mapped according to zones consistent in hydraulic erodibility characteristics expressed in terms of the headcut erodibility index, K_h.

Before initiating a fixed line survey of discontinuities (appendix 52A), conventional geological mapping must be conducted to determine soil and rock types; to delineate major geological structures, such as faults, dikes, and lithologic contacts; and to identify any significant stratigraphic discontinuities within the mass. Plane table, air photo, and conventional surveying techniques may be applied to develop a geologic evaluation map.

Each zone of geologic material at a site is identified according to formal nomenclature (e.g., St. Peter Sandstone) or assigned an informal name. If a geologic formation has multiple beds or units of widely differing erodibility, each unit may be identified alphanumerically, such as Rock Unit L-6. Mapping solely on the basis of lithology can, in some instances, be misleading (Dearman 1974). Mapping units should be delineated according to their similarities in hydraulic erodibility.

628.5202 Earth material classification

The term earth material (or geologic material) is considered to embrace the entire spectrum of soil and rock materials, whether natural or engineered. Earth materials range on a broad continuum from very loose, cohesionless, granular soil or very soft, cohesive soil through extremely hard, massive rock.

(a) Soil material

Soil material is classified in the field according to ASTM D 2488, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure). If greater precision is needed, representative samples may be collected for laboratory analysis and classified according to ASTM D 2487, Standard Test Method for Classification of Soils for Engineering Purposes.

(b) Transitional material

Earth material transitional between soil and rock is differentiated by strength rather than geologic origin. Material with a uniaxial (unconfined) compressive strength less than 1.25 MPa is normally taken to be soil (Geological Society of London (GSL) 1977). If, however, an earth material, regardless of origin, is in such a condition that it can be classified by criteria in ASTM D 2488, it shall be considered a soil when determining the headcut erodibility index. Appendixes in ASTM D 2488 provide additional guidance in dealing with unusual material.

(c) Rock material

Rock material is classified by a simplified geologic scheme based on genetic category, structure, composition, and grain size. Table 52–1 is a rock type classification modified from GSL (1979). Common rock type names are assigned in the field generally without need for costly lab tests or thin sections. Common terminology, such as schist, is preferred over technically correct, but jargon-rich terms, such as albite-epidote-amphibolite-schist. Detailed mineralogical and fabric descriptors are used only for correlation purposes or whenever they have engineering significance.

Table 52–1 Rock type classification (code number in parentheses)

Genetic Group	Predominant grain size, mm (sieve no.)	Detrital Sedimentary			Chemical Organic	Metamorphic		Pyroclastic	Igneous			
Usual Structure		Bedded			Bedded	Foliated	Massive	Bedded	Massive			
Composition			Grains of rock, quartz, feldspar, and clay minerals	At least 50% of grains are of carbonate	Salts, carbonates, silica, carbonaceous	Quartz, feldspars, micas, dark minerals	Quartz, feldspars, micas, dark minerals, carbonates	At least 50% of grains are of igneous rock	Quartz, feldspars, micas, dark minerals		Feldspar; dark minerals	Dark minerals
									Acid	Intermediate	Basic	Ultrabasic
Very coarse-grained		Rudaceous	Grains are of rock fragments Rounded grains: CONGLOMERATE (11) Angular grains: BRECCIA (12)	LIMESTONE (undifferentiated) (21) CALCIRUDITE (23)	CLINKER (31) SALINE ROCKS Halite (32) Anhydrite (33) Gypsum (34)	TECTONIC BRECCIA (41) MIGMATITE (42)	METACONGLOMERATE (51)	Rounded grains: AGGLOMERATE (61) Angular grains: VOLCANIC BRECCIA (62)	PEGMATITE (71)			
Coarse-grained	75 (3")	Rudaceous				GNEISS (43)	MARBLE (52) GRANULITE (53)		GRANITE (72)	DIORITE (81) GRANODIORITE (82)	GABBRO (91)	PYROXENITE (01)
Medium-grained	4.75 (4)	Arenaceous	Grains are mainly mineral fragments SANDSTONE (13) ARKOSE (14) GRAYWACKE (Argillaceous ss) (15)	CALCARENITE (24)	CALCAREOUS ROCKS	SCHIST (44)	QUARTZITE (54)	TUFF (63)	SYENITE (73)	ANORTHOSITE (83)	DIABASE (92)	PERIDOTITE (02)
Fine-grained	0.074 (200)	Arenaceous				Amphibolite (45)			APLITE (74)	MONZONITE (84)		DUNITE (03)
Very Fine-grained	0.005	Argillaceous or Lutaceous	MUDSTONE (16) SHALE: fissile mudstone (17) SILTSTONE>50% fine-grained particles (18) CLAYSTONE>50% very fine grained particles (19)	MARLSTONE (22) CALCISILTITE (25) CHALK (26) CALCILUTITE (27)	LIMESTONE (35) DOLOMITE (36)	PHYLLITE (46) Mylonite (47) SLATE (48)	HORNFELS (55)	Fine-grained TUFF (64) Very fine-grained TUFF (65)	RHYOLITE or FELSITE (75)	Dacite (85) ANDESITE (86)	BASALT (93)	NEPHELINE-BASALT (04)
Glassy Amorphous					SILICEOUS ROCKS Chert (37) Flint (38) CARBONACEOUS ROCKS LIGNITE/COAL (39)	Ultramylonite (49)		Welded TUFF (66) PUMICE (67)	VOLCANIC GLASSES OBSIDIAN (76)	PITCHSTONE (87)	TACHYLYTE (94)	

628.5203 Field procedure for evaluating constituent parameters

(a) Material strength number (M_s)

(1) Field identification

The material strength number is determined separately for cohesionless soil (table 52–2), cohesive soil (table 52–3), and rock (table 52–4). Standard definitions are relied on for distinction between these various materials. The values of the parameters are based on field identification tests, or, alternatively, rigorous standard testing. Scales of relative density, consistency, and hardness are correlated with ranges in strength. The relative density scales for cohesionless soil, cohesive soil, and rock are as used by Korhonen et al. (1971), Jennings et al. (1973), and GSL (1977), respectively.

The material strength number for cohesionless soils in table 52–2 are correlated with values for in situ deformation modulus (ASTM D 1194, Standard Test Method for Bearing Capacity of Soil for Static Load and Spread Footings), using Kirsten's (1988) unpublished data.

Table 52–2 Material strength number, M_s, for cohesionless soil 1/

Relative density	Field identification tests	SPT 2/ 5/ (blows/0.3 m) 4/ 5/	In situ deformation modulus (IDM) (MPa) 5/	M_s 3/
Very loose	Particles loosely packed. High percentage of voids. Very easily dislodged by hand. Matrix crumbles easily when scraped with point of geologic pick. Raveling often occurs on excavated faces.	< 5	< 0.005	< 0.02
Loose	Particles loosely packed. Some resistance to being dislodged by hand. Large number of voids. Matrix shows low resistance to penetration by point of geologic pick.	5 - 10	0.005 - 0.01	0.02 - 0.05
Medium dense	Particles closely packed. Difficult to dislodge individual particles by hand. Voids less apparent. Matrix has considerable resistance to penetration by point of geologic pick.	10 - 30	0.01 - 0.03	0.05 - 0.10
Dense	Particles very closely packed and occasionally very weakly cemented. Cannot dislodge individual particles by hand. The mass has very high resistance to penetration by point of geologic pick. Requires many blows of geologic pick to dislodge particles.	30 - 50	0.03 - 0.08	0.10 - 0.20
Very dense	Particles very densely packed and usually cemented together. Mass has high resistance to repeated blows of geologic pick. Requires power tools for excavation.	> 50	0.08 - 0.2	0.20 - 0.45

1/ Cohesionless soil is a material with a plasticity index (PI) less than or equal to 10. Use table 52–3 for cohesive soils.
2/ Standard Penetration Test, SPT (ASTM D 1586) used for most sandy-type cohesionless soils. In situ deformation modulus (IDM) (ASTM D 1194) used for most gravel-type soils and coarse detritus.
3/ M_s of a cohesionless soil is approximately determined from results of IDM testing by the following relationship:

$$M_s = 1.7\,(IDM)^{0.832} \text{ for IDM in MPa}$$

4/ Cohesionless soils in which blow counts are greater than 50 or IDM is greater than 200 kPa to be taken as rock, for which the hardness may be obtained from table 52–4.
5/ Correlation between SPT and IDM should be used as a guide only as results may vary in different geologic areas. Lab strength tests are recommended on soil materials to support SPT or field assessment tests.

Scales for consistency of cohesive soil (table 52–3) and hardness of rock material (table 52–4) are based on GSL (1977). These ranges are correlated with values for unconfined compressive strength as determined by ASTM D 2166 Standard Test Method for Unconfined Compressive Strength for Cohesive Soil and ASTM D 2938 Standard Test Method for Unconfined Compressive Strength of Rock Core Specimens, respectively. Field identification tests given in tables 52–3 and 52–4 are from GSL (1977), International Society for Rock Mechanics (ISRM 1981), and USDA (1978). Material strength numbers given in tables 52–3 and 52–4 represent rounded off products of uniaxial compressive strengths and coefficients of relative density. Penetrometer blow count data (ASTM D 1586, Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils) given in tables 52–2 and 52–3 are derived from Lambe and Whitman (1969).

Table 52–3 Material strength number, M_s, for cohesive soil

Consistency	Field identification tests	SPT (blows/0.3 m)	Unconfined compressive strength (UCS) (kPa)	M_s
Very soft	Exudes between fingers when squeezed in hand.	< 2	< 40	< 0.02
Soft	Easily molded with fingers. Point of geologic pick easily pushed into shaft of handle.	2 - 4	40 - 80	0.02 - 0.05
Firm	Penetrated several centimeters by thumb with moderate pressure. Molded by fingers with some pressure.	4 - 8	80 - 150	0.05 - 0.10
Stiff	Indented by thumb with great effort. Point of geologic pick can be pushed in up to 1 centimeter. Very difficult to mold with fingers. Just penetrated with hand spade.	8 - 15	150 - 300	0.10 - 0.20
Very stiff	Indented only by thumbnail. Slight indentation by pushing point of geologic pick. Requires hand pick for excavation.	15 - 30	300 - 625	0.20 - 0.45

Notes:
1. Cohesive soil is material with a plasticity index (PI) greater than 10. Use table 52–2 for cohesionless soils.
2. 1 kPa equals 1 kN/m^2.
3. Vane shear strength (ASTM D 2573, field; ASTM D 4648, lab) also may be used for unconfined compressive strength (ASTM D 2166).
4. Cohesive soils in which blow counts are greater than 30 or strengths greater than 625 kPa are to be taken as rock, for which the hardness can be obtained from table 52–4.
5. Cohesive soils must be evaluated for hardness in the saturated condition.
6. M_s of a cohesive soil also can be determined as the product of unconfined compressive strength (in MPa) times its coefficient of relative density. For most cohesive soils, M_s is approximately determined by:

   $$M_s = 0.78\,(UCS)^{1.09} \text{ for } UCS \leq 10 \text{ MPa, and } M_s = UCS \text{ for } UCS > 10 \text{ MPa.}$$
7. Correlation between SPT and UCS should only be used as a guide, as results may vary in geologic areas. Lab strength tests are recommended on soil materials to support SPT or field assessment tests. Vane shear strength values also are applicable in the lower strength ranges.

The material strength number of soil material is equal to the product of its unconfined compressive strength times the coefficient of relative density. To support the field assessments, laboratory tests for strength and bulk density are recommended for representative undisturbed soil samples.

Uniaxial compressive strength of intact rock material is normally determined by a standard laboratory test method (ASTM D 2938). Because large differences in rock strength are required to appreciably affect the headcut erodibility index, the precision afforded by expensive laboratory tests is rarely justified. Experience shows that conducting field estimates of rock material hardness is a practical way of obtaining adequate assessments of strength. The field identification tests for assessing rock material hardness are given in table 52–4.

Table 52–4 Material strength number, M_s, for rock

Rock material hardness 1/	Uniaxial compressive strength (MPa) 2/	Field identification tests	M_s 3/
Very soft rock or Hard, soil-like material	0.6 - 1.25	Scratched with fingernail. Slight indentation produced by light blow of point of geologic pick. Requires power tools for excavation. Peels with pocket knife.	0.45 - 1.0
Soft rock	1.25 - 5.0	Hand-held specimen crumbles under firm blows with point of geologic pick.	1.0 - 4.5
Moderately soft rock	5.0 - 12.5	Shallow indentations (1 to 3 mm) produced by light blows with point of geologic pick. Peels with pocket knife with difficulty.	4.5 - 12.5
Moderately hard rock	12.5 - 50.0	Cannot be scraped or peeled with pocket knife. Intact hand-held specimen breaks with single blow of geologic hammer. Can be distinctly scratched with 20d common steel nail.	12.5 - 50
Hard rock	50.0 - 100.0	Intact hand-held specimen requires more than one hammer blow to break it. Can be faintly scratched with 20d common steel nail.	50 - 100
Very hard rock	100.0 - 250.0	Intact specimen breaks only by repeated, heavy blows with geologic hammer. Cannot be scratched with 20d common steel nail.	100 - 250
Extremely hard rock	> 250.0	Intact specimen can only be chipped, not broken, by repeated, heavy blows of geologic hammer.	> 250

1/ Hardness categories are based solely on hardness characteristics, not geologic origin. For example, a highly weathered shale may classify as firm cohesive soil, and a partially lithified recent soil may classify as moderately soft rock. The transition, however, generally occurs within the 0.60 to 1.25 MPa range.
2/ 1.0 MPa approximately equals 145 pounds per square inch, or 10.4 tons per square foot.
3/ M_s is equal to the product of uniaxial compressive strength, UCS (ASTM D 2938), and coefficient of relative density. For most rock or rock-like materials, M_s is approximately determined by:

$$M_s = 0.78\,(UCS)^{1.09} \text{ for UCS} \leq 10 \text{ MPa, and } M_s = UCS \text{ for UCS} > 10 \text{ MPa.}$$

(2) Other identification methods

Other methods for determining hardness include:

- ASTM D 5873 Test Method for Determining Hardness of Rock by the Rebound Hammer Method—Used for rock categories that have hardnesses varying between very soft and very hard.
- The pocket penetrometer—Used for most soils with strength less than 2.00 MPa.

(b) Block/particle size number (K_b)

The term K_b represents the mean size of individual material units as determined by the spacing of discontinuities in a rock mass, or it is a function of particle diameter of cohesionless granular soils, including detritus and boulder formations. The number can be calculated by a variety of approaches.

(1) Rock and rock-like materials

For rock and rock-like materials, the primary method to calculate K_b is:

$$K_b = \frac{RQD}{J_n} \qquad [52\text{–}2]$$

where:
RQD = rock quality designation
J_n = joint set number

RQD, a standard parameter in drill core logging, can be determined from drill cores according to methods in Deere and Deere (1988) and ASTM D 6032, Standard Test Method for Determining RQD of Rock Core, or from a joint count per cubic meter of rock mass, as defined in Barton et al. (1974). RQD represents the sum of the length of core pieces greater than 0.1 meter divided by the total core run length (generally 1.5 meters), expressed in percent (Deere and Miller 1966 or Deere and Deere 1988).

The term, J_n, is the joint set number, table 52–5. The joint set number is a scale factor representing the effect of different individual discontinuity spacings relative to the average discontinuity spacing. The factor accounts for the shape of the material units or, alternatively, the relative occurrence of different joint sets.

Depending on the type of data available, RQD also can be determined in alternative ways, as summarized below, and for which 5 is less than or equal to RQD less than or equal to 100.

$$RQD = \left(115 - 3.3J_C\right) \qquad [52\text{–}3]$$

$$RQD = \left(105 - \frac{10}{D}\right) \qquad [52\text{–}4]$$

$$RQD = \left[105 - \frac{10}{\left(J_X J_Y J_Z\right)^{0.33}}\right] \qquad [52\text{–}5]$$

where:
J_c = joint count number representing the number of joints per cubic meter

$$J_c \cong \left(\frac{3}{D}\right) + 3 \quad \text{(as given in table 52–6)}$$

where:
D = mean block diameter, in meters

Mean block size is taken as the cube root of the product of the average spacings of joint sets, J_x, J_y, J_z, measured in three mutually perpendicular directions, x, y, z, as explained in Appendix 52A, The Fixed Line Survey, such that:

$$D = \left(J_x J_y J_z\right)^{0.33}, \text{ for } D \geq 0.10 \text{ m} \qquad [52\text{–}6]$$

Table 52–5 Joint set number, J_n

Intact; no or few joints	1.00
One joint set	1.22
One joint set plus random	1.50
Two joint sets	1.83
Two joint sets plus random	2.24
Three joint sets	2.73
Three joint sets plus random	3.34
Four joint sets	4.09
More than four joint sets	5.00

(2) Cohesive soils and coarse detritus, gravels, and boulders

For intact, cohesive soils and coarse detritus, gravels, and boulder formations for which D > 0.1 meter, $K_b = 1$. For strongly cemented materials that lack discontinuities, RQD = 100 and $J_n = 1$. If soil joints occur within the soil mass, use equation 52–3 to obtain RQD and apply the applicable value for J_n to obtain K_b by equation 52–2.

Whether material units erode as individual constituent particles or by blocks of material depends on the occurrence of discontinuities within the mass. In rock formations, only discontinuities that effectively break the mass into discrete blocks are to be considered.

(3) Identification of joint set spacing

Joint set spacing (J_x, J_y, J_z) is the average spacing of joints within a given set, expressed in meters. The fixed line survey method (appendix 52A) can be used to determine joint spacing.

Bedding plane partings form a systematic joint set. Although a different set of terms for bedding plane partings has been used for years in classic field geology, the recommendation is to use one set of terms common to both bedding plane partings and high angle joint sets. Descriptive terms should be consistent with the usage in table 52–7.

(4) Identification of particle size

Mean diameter (D_{50}) of granular soil materials is determined by the visual-manual procedures given in ASTM D 2488.

(c) Discontinuity/interparticle bond shear strength number

The discontinuity/interparticle bond shear strength number (K_d) is represented as:

$$k_d = \frac{J_r}{J_a} \qquad [52\text{–}7]$$

where:
J_r = joint roughness number
J_a = joint alteration number

J_r represents the degree of roughness of opposing faces of a rock discontinuity (table 52–8), and J_a the degree of alteration of the materials that form the faces (table 52–9).

(1) Discontinuity strength

The shear strength of a rock discontinuity is directly proportional to the degree of roughness of the opposing faces and inversely proportional to the degree of alteration. Joint roughness affects the shear strength

Table 52–6 Joint count number, J_c, from RQD 1/ 2/

No. joints per cubic meter (J_c)	Rock quality designation (RQD)	No. joints per cubic meter (J_c)	Rock quality designation (RQD)
33	5	18	55
32	10	17	60
30	15	15	65
29	20	14	70
27	25	12	75
26	30	11	80
24	35	9	85
23	40	8	90
21	45	6	95
20	50	5	100

1/ RQD ≅ 115 - 3.3 J_c; or
2/ For blocks with mean diameters, D ≥ 0.10 meter, J_c ≅ (3/D) + 3

Table 52–7 Spacing categories for joint sets

-------- Joint set spacing categories -------- Bedding plane partings	High angle joints	Spacing (meters)
Massive/unstratified	Extremely wide	> 6.000
Very thick-bedded	Very wide	2.000 - 6.000
Thick-bedded	Wide	0.600 - 2.000
Medium-bedded	Mod. wide	0.200 - 0.600
Thin-bedded	Mod. close	0.060 - 0.200
Very thin-bedded	Close	0.020 - 0.060
Laminated	Very close	0.006 - 0.020
Thinly laminated	Shattered	0.002 - 0.006
Fissile	Fissured	< 0.002

of a discontinuity particularly in cases of undisplaced and interlocked features, such as unfilled (open) joints. The relative influence of wall roughness on shear strength declines as aperture width or infilling thickness increases.

Values for J_r and J_a apply primarily to the joint set or discontinuity in the rock mass most likely to fail. Experience in stratified sedimentary rocks indicates this joint set is typically bedding plane partings, if parting spacing is significantly smaller than the spacing of major high-angle joint sets. If bedding plane partings classify as very thick bedded or unstratified, the joint set closest to being perpendicular to streamflow tends to be most adverse.

(2) Interparticle bond shear strength

If the material under consideration occurs as a soil mass or as gouge in the apertures of rock discontinuities, the interparticle bond shear strength number, K_d, is represented by the quotient J_r/J_a, that, in turn, is approximately equal to tan ϕ'_r, where ϕ'_r is the residual (minimum) friction angle. The residual friction angle can be estimated according to a relationship with soil index properties (Stark and Eid, 1994).

Figure 52–1 presents a correlation of drained residual friction angle (ϕ'_r) and liquid limit (LL) for shear tests conducted on cohesive clays at an effective normal stress of 100 kPa, a value considered typical of near surface materials. The data form three distinct curves according to three ranges of clay size fraction:

For ≤ 20% clay, $\phi'_r = 169.58\ (LL)^{-0.4925}$ [52–7]

For 25 – 45% clay, $\phi'_r = 329.56\ (LL)^{-0.7100}$ [52–8]

For ≥ 50 % clay, $\phi'_r = 234.73\ (LL)^{-0.6655}$ [52–9]

The interparticle bond shear strength number (K_d) of a cohesive soil is predicted by a rational correlation between soil index properties and residual shear strength by the following method (Moore, 2001).

Table 52–8 Joint roughness number, J_r

Joint separation	Joint roughness condition (intermediate scale; small scale)	J_r 1/
Joints are tight or become closed during hydraulic flow	Discontinuous joints; stepped	4.0
	Rough/irregular; undulating (e.g., tension joints, rough sheeting joints, rough bedding)	3.0
	Smooth; undulating (e.g., smooth sheeting, nonplanar foliation and bedding)	2.0
	Slickensided; undulating	1.5
	Rough/irregular; planar	1.5
	Smooth; planar (e.g., planar sheeting joints, planar foliation and bedding)	1.0
	Slickensided; planar	0.5
Joints are open and remain open during hydraulic flow 2/	Joints are either open or contain relatively soft gouge of sufficient thickness to prevent wall contact during hydraulic flow	1.0
	Joints contain swelling clays	1.0

1/ For intact, cohesive material J_r = 3.0.
2/ Consider joints open when aperture width exceeds amplitude of asperities (intermediate scale roughness) of joint faces.

1. Determine the liquid limit by ASTM D 4318, Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils, and report the result to the nearest one percent.
2. Determine clay content (the percent finer than 0.002 mm) by ASTM D 422, Standard Test Method for Particle-Size Analysis of Soils, and report the result to the nearest five percent.
3. Use the clay content value to select the appropriate equation (52–7, 52–8, or 52–9) to predict effective residual friction angle, ϕ'_r, and report the result to the nearest one-tenth degree.

Typical ranges of friction angles for various materials are provided in table 52–9. If the residual friction angle calculated by this method differs significantly from these values, consider conducting laboratory or in situ standard test methods, such as:

- ASTM D 3080, Direct Shear Test of Soils Under Consolidated Drained Conditions
- ASTM D 6467, Torsional Ring Shear Test to Determine Drained Residual Shear strength of Cohesive Soils

Once the friction angle is determined, the interparticle bond shear strength number, K_d, is determined by

$$K_d \cong \tan \phi'_r \qquad [52\text{-}10]$$

Table 52–9 Joint alteration number, J_a

Field identification of gouge (infilling)	J_a for aperture width < 1.0 mm [1/]	1.0 - 5.0 mm [2/]	≥ 5.0 mm [3/]	Typical ϕ'_r °
Joint tightly healed with hard, nonsoftening, impermeable mineral filling, e.g., quartz, calcite, or epidote.	0.75	1.0	1.5	- - -
Clean, open joint with fresh or discolored (unweathered) walls only; no infilling.	1.0	1.5	2.0	- - -
Discolored to disintegrated joint walls; infilling is sand or gravel with < 15% cohesionless fines in matrix; with or without disintegrated or crushed rock fragments.	2.0	4.0	6.0	(25 – 30)
Discolored to disintegrated joint walls; cohesionless, nonswelling, low to nonplastic fines in matrix; with or without disintegrated or crushed rock fragments.	3.0 [4/]	6.0 [4/]	10.0 [4/]	(15 – 24)
Disintegrated to decomposed joint walls; nonswelling, lean clay or clay matrix, or low friction clays, such as chlorite, talc, mica, serpentine, gypsum, graphite, kaolinite, or other sheet silicates; with or without disintegrated or crushed rock fragments.	4.0 [4/]	8.0 [4/ 5/]	13.0 [4/ 5/]	(10 – 14)
Disintegrated to decomposed joint walls; fat clay, swelling clay, such as montmorillonite, or clay matrix, with or without disintegrated or crushed rock fragments.	5.0 [4/]	10.0 [4/ 5/]	18.0 [4/ 5/]	(6 – 9)

1/ Joint walls effectively in contact.
2/ Joint walls come into contact after approximately 100 mm shear.
3/ Joint walls do not come into contact at all upon shear. Use this column to determine J_a for intact, cohesive granular materials, for which $J_r = 3.0$. Alternatively, $\tan \phi'_r$ can be substituted for the quotient J_r/J_a where ϕ'_r is the equivalent residual (minimum) friction angle.
4/ Values added to Barton et al. (1974) data.
5/ Also applies when disintegrated or crushed rock fragments occur in clay matrix without wall contact.

(3) Identification of joint roughness

Joint roughness (J_r) condition is described in simple terms based on two scales of visual observation: an intermediate scale (meters) and a small scale (centimeters).

The intermediate scale of roughness is divided into three categories: stepped, undulating, and planar. The small scale of roughness is superimposed on the intermediate scale and is also divided into three groups: rough, smooth, and slickensided. The term slickensided is used only if previous shear displacement is evident along the discontinuity.

The joint roughness number depends upon the roughness condition, whether the discontinuities are tight or become closed when subjected to hydraulic flow, and whether they become opened and remain open during flow (table 52–8). A joint is considered open when the aperture width exceeds the amplitude of the asperities (intermediate scale roughness) of the opposing faces.

To maintain uniformity in the assessment of joint roughness, typical examples of each category must be identified and photographed at each site where the roughness classification is used.

Values for J_r can range between 4.0 (for tight, discontinuous joints in massive rock) and 0.5 (for slickensided planar surfaces with a swelling clay infilling commonly associated with faulted rock).

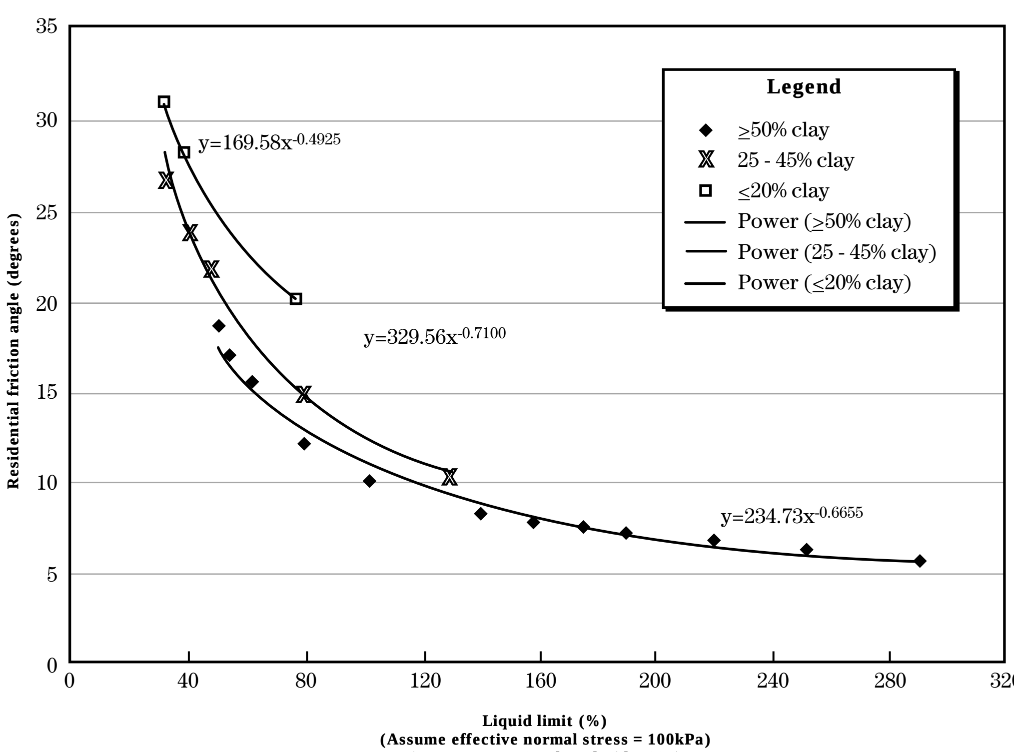
(4) Identification of joint alteration number

The joint alteration number (J_a) is a function of the nature of the infilling, the width of the aperture, and weathering condition of the joint face material. Use table 52–9 for values of J_a.

(5) Identification of infilling

Material occupying the aperture between joint faces is variously called infilling, gouge, breccia, or mylonite (for faults). Materials deposited in an opening include airborne or washed-in materials, such as silt, clay, and

Figure 52–1 Residual friction angle versus liquid limit for three ranges in clay content



other organic and mineral matter, or partly or completely remineralized vein deposits. Wide apertures may contain washed-in gravel or rock fragments disintegrated from the joint walls or crushed by faulting.

Infilling should be described and classified in the field according to ASTM D 2488 or in the laboratory by D 2487. Chemically precipitated or remineralized material should be identified by composition (quartz, calcite, gypsum, epidote).

The strength of the infilling is estimated by using the field tests given in tables 52–2 and 52–3 or by measuring with a pocket penetrometer or pocket vane shear tester.

(6) Measurement of aperture width

Aperture, or planar separation, refers to the opening between opposing faces of a joint, fracture, fissure, or fault. The aperture width is measured at a sufficient number of places along the trace of the joint to obtain an average for the joint. Table 52–10 provides categories of aperture width ranges to facilitate documentation of data. If the width varies across more than one range, record the length of the trace over which the width category applies. For example, a 20-meter-long joint has a narrow aperture width (6 to 20 mm) for 13 meters and widens to moderately narrow (20 to 60 mm) for 7 meters. The variability may be clarified by describing the joint in separately labeled segments and plotting the location of the joint on a geologic evaluation map.

Table 52–10 Aperture width

Aperture width category	Width range (mm)
Wide	> 200
Moderately wide	60 – 200
Moderately narrow	20 – 60
Narrow	6 – 20
Very narrow	2 – 6
Extremely narrow (hairline)	< 2

(7) Identification of weathering condition of joint face material

Weathering is the physical disintegration or chemical decomposition of earth materials that results in changes in the color, texture, composition, density, or form, with little or no transport of the loosened or altered material. The scope of weathering is limited to the condition of the joint face material. Use table 52–11 to classify the weathering condition of the joint face rock material of identified joints.

(d) Relative ground structure number

The relative ground structure number (J_s) represents the orientation of the effective dip of the least favorable discontinuity with respect to spillway flow. The number takes into account the effect of the relative shape of the material units (as determined by joint set spacings) or the ease with which the spillway flow penetrates the ground and dislodges individual material particles.

For practical expediency the rock mass is assumed to be intersected by two primary joint sets in the plane at right angles to spillway flow. The value of J_s is expressed in terms of the relative spacing of the two

Table 52–11 Weathering condition of joint face material

Descriptor	Weathering condition of joint face material
Fresh	No sign of weathering.
Discolored	Iron-stained or discolored, but otherwise unweathered.
Disintegrated	Physically disintegrated to a soil condition with original fabric still intact; material is friable; mineral grains are not decomposed.
Decomposed	Chemically altered to a soil condition with original fabric still intact; some or all of mineral grains are decomposed.

joint sets, the dip angle and the dip direction of the closer spaced set relative to the direction of spillway flow. In this methodology, soil material is considered intact (without structure), in which case $J_s = 1$.

To calculate the effective dip (q), the apparent dip of the bedrock is first determined by using the following relationship, expressing horizontal angles in degrees azimuth and vertical angles in degrees:

$$\tan a = (\tan b)(\sin c) \qquad [52–11]$$

where:

- a = apparent dip of discontinuity
- b = true dip of discontinuity
- c = (strike of discontinuity) – (spillway flow direction)

Effective dip is defined as the apparent dip of the discontinuity adjusted for the slope of the spillway channel, α. Dip direction is measured perpendicular to the strike. If the absolute value of the dip direction (expressed in degrees azimuth) minus the spillway flow direction (expressed in degrees azimuth) is less than 90 degrees (including 0°; i.e., north) or greater than 270 degrees, the dip direction is considered to be with the direction of spillway flow; otherwise, it is considered against the flow.

If the spillway flow direction is with the apparent dip

$$q = a - \alpha \qquad [52–12]$$

If spillway flow direction is against the apparent dip

$$q = a + \alpha \qquad [52–13]$$

Use the calculated value of effective dip to determine J_s from table 52–12.

The ratio of joint spacing, r, reflects the relative shape of the material unit. It is the quotient of the average spacing of the two most dominant high angle joint sets. Select a value for r nearest to 1:1, 1:2, 1:4, or 1:8. For values of r less than 1:8, J_s is taken as r = 1:8.

Table 52–12 Relative ground structure number, J_s

Dip direction [1/] of least favorable joint set (degrees)	Effective dip angle of least favorable joint set [2/] (degrees)	---- Ratio of joint spacing, r ---- 1:1	1:2	1:4	1:8
With flow:					
180/0	90	1.00	1.00	1.00	1.00
0	85	0.72	0.67	0.62	0.56
0	80	0.63	0.57	0.50	0.45
0	70	0.52	0.45	0.41	0.38
0	60	0.49	0.44	0.41	0.37
0	50	0.49	0.46	0.43	0.40
0	40	0.53	0.49	0.46	0.44
0	30	0.63	0.59	0.55	0.53
0	20	0.84	0.77	0.71	0.68
0	10	1.22	1.10	0.99	0.93
0	5	1.33	1.20	1.09	1.03
0/180	0	1.00	1.00	1.00	1.00
Against flow:					
180	5	0.72	0.81	0.86	0.90
180	10	0.63	0.70	0.76	0.81
180	20	0.52	0.57	0.63	0.67
180	30	0.49	0.53	0.57	0.59
180	40	0.49	0.52	0.54	0.56
180	50	0.53	0.56	0.58	0.60
180	60	0.63	0.67	0.71	0.73
180	70	0.84	0.91	0.97	1.01
180	80	1.22	1.32	1.40	1.46
180	85	1.33	1.39	1.45	1.50
180/0	90	1.00	1.00	1.00	1.00

1/ Use dip direction of least favorable joint set with respect to direction of spillway flow.
2/ Using the true dip angle (of least favorable joint set in vertical plane containing direction of streamflow), make corrections for apparent dip and the slope of stream channel to obtain effective dip using formulas 52–8, 52–9, and 52–10.
Note: For granular materials, $J_s = 1.00$.
For values of r less than 1:8, take J_s as for r = 1:8.

(1) Determination of orientation

Use a geological compass to measure the orientation of joints and spillway channel flow direction at the point where erosion initiates, such as, at an overfall (headcut). If the joint surface is exposed three-dimensionally, express its orientation in terms of strike-and-dip. If the outcrop is so smooth and flat that only the trace of the joint is discernible, express the orientation of the trace in terms of trend and plunge.

Plot the locations of all measurements on a geologic evaluation map using standard symbols for strike-and-dip or trend and plunge; record ground coordinates and elevation on field data sheets.

628.5204 Summary

Field procedures are presented for evaluating the constituent geological parameters that form the headcut erodibility index, K_h. The parameters include earth material strength, block or particle size, discontinuity shear strength or interparticle bond shear strength, and relative ground structure. The fixed line survey is recommended for conducting a systematic inventory of structural discontinuities in a rock mass. Soil properties are identified using ASTM standards. Earth material transitional between soil and rock is differentiated by strength rather than geologic origin. All parameters can be assessed rapidly in the field using simple identification tests and measurements. Because input values are based on logarithmic scales, adverse results from inaccurate assessments cannot occur easily for materials with strengths exceeding 1.0 MPa. Laboratory analyses for unconfined strength, bulk density, and shear strength are recommended for weaker materials to corroborate results of field assessments. However, in the absence of laboratory data, the method that results in the more conservative values is recommended.

628.5205 References

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Appendix 52A Fixed Line Survey

Definition

A fixed line survey is an inventory of all structural discontinuities that intersect a linear traverse of specified length and orientation.

Application

The fixed line survey is used to systematically inventory a variety of attributes of joints and fractures including joint set spacing and orientation, joint roughness, joint face alteration, aperture width, and type of infilling.

In complex structural domains where joint and fracture patterns are difficult to discern, a fixed line survey can be applied to inventory a representative sample of the joints for assessment of joint attributes. Subtle joint patterns can often be differentiated using statistical analysis afforded by joint orientation diagrams.

The line survey method is unlikely to bias results as compared to fracture set sampling, area sampling, or other sampling methods that rely heavily on observer judgment (Piteau 1970). Caution is advised, however, in structural domains where joint set patterns are systematic because a survey line parallel with the trend of a dominant joint set may result in undersampling and data bias.

Procedure

The rock outcrop in the area of interest must be well exposed, clean, and accessible for measurement and study. Cleaning can be accomplished by whatever means is necessary and available, including power equipment, hand tools, or pressurized air or water.

To determine the average spacing of a systematic, persistent, high-angle joint set, orient a measuring tape perpendicular to the trend of the joint set. The length of the survey line depends on the spacing of the joints and the amount of exposed outcrop. The recommended length is 10 meters or 10 joints, whichever is greater. Widely spaced joints may require a longer survey line to obtain a meaningful average. In some instances, outcrop limitations require shorter lines. For each persistent joint set, determine average spacing by dividing the length of the survey line by the number of joints in the set that intersects the survey line.

To determine the average spacing of bedding plane partings or sheeting joints on steep outcrops, use a telescoping range pole or a weighted tape against the face to facilitate measurement. In situations where the vertical component is unexposed or inaccessible, use drilling logs or drill core samples of nearby test holes, if available, to estimate the spacing.

For complex structural domains with abundant unique (random) fractures, establish three mutually perpendicular axes for survey lines. Establish one axis parallel with and another perpendicular to the streamflow direction. The third axis, the vertical component, is handled as described above. Calculate mean block size by taking the cube root of the product of the average joint set spacings for the three surveyed directions.

To improve the determination of the average joint set spacing in a given dimension, survey more than one line. For example, consider using three parallel survey lines 5 meters apart and average the results. The number of lines needed is a function of the size and geologic complexity of the site.

For more details on the line survey method, refer to publications by International Society for Rock Mechanics (1981), Geological Society of London (1977), or F.G. Bell (1992).

Documentation

Plot the location of each survey line on a geologic evaluation map and record its orientation, elevation, and ground coordinates or stationing on data sheets. Measure the attributes of all structural discontinuities that intersect the fixed lines according to procedures described in this appendix and record the information on data sheets.

Appendix 52B Headcut Erodibility Index Flow Chart

The Headcut Erodibility Index of a material is represented as the scaler product of the indices for its constituent parameters in the form:

$$K_h = M_s \times K_b \times K_d \times J_s$$

Computation of the headcut erodibility index for any earth (geologic) material:

1. Use criteria in ASTM D 2488 to determine if the geologic material of interest is soil or rock.

2. If soil, use plasticity index (PI) to determine if it is cohesive (PI >10) or cohesionless (PI ≤10) soil.

The Headcut Erodibility Index is then determined separately for cohesive soil, cohesionless soil, and rock, as follows.

3. Material strength number (M_s)

cohesive soil	$M_s = 0.78\ (UCS)^{1.09}$	(use table 52–3)
cohesionless soil	$M_s = 1.7\ (IDM)^{0.832}$	(use table 52–2)
rock for which UCS ≤10	$M_s = 0.78\ (UCS)^{1.09}$	(use table 52–4)
rock for which UCS >10	$M_s = (UCS)$	(use table 52–4)

Note: If data are available, use coefficent of relative density times UCS to obtain M_s directly for any material for which UCS ≤10.

USC = Unconfined Compressive Strength.
IDM = In situ Deformation Modulus.

4. Particle size number of soils (K_b)

jointed cohesive soil $K_b = \frac{RQD}{J_n}$ (use tables 52–5 and 52–6)

where: $RQD = 115 - 3.3\ J_c$ and $5 \le RQD \le 100$

massive (unjointed) cohesive soil $K_b = 1$

cohesionless soil where D < 0.1 m $K_b = \frac{RQD}{J_n} = \frac{5}{5} = 1$

cohesionless soil where D ≥ 0.1 m $K_b = \frac{\left\{105 - \left(\frac{10}{D}\right)\right\}}{J_n}$

5. Block size number of rock (K_b)

RQD is known and D ≥0.1 m $K_b = \frac{RQD}{J_n}$ (use tables 52–5 and 52–6)

RQD is unknown $K_b = \frac{\left\{105 - \left(\frac{10}{D}\right)\right\}}{J_n}$

where: D is the cube root of the volume of the average block size determined by joint set spacings

6. For interparticle bond shear strength of soils, $K_d \cong \tan \phi'_r$, such that

for clay fraction (≤ 20%), $\phi'_r = 169.58\ (LL)^{-0.4925}$
for clay fraction (25 – 45%), $\phi'_r = 329.56\ (LL)^{-0.7100}$
for clay fraction (≥ 50%), $\phi'_r = 234.73\ (LL)^{-0.6655}$

where:
ϕ'_r = residual (minimum) friction angle (°)
effective normal stress = 100 kPa
clay fraction = percent finer than 0.002 mm
LL = liquid limit (%)

7. For discontinuity shear strength of rock $K_d = \frac{J_r}{J_a}$ (use tables 52–8 and 52–9)

8. Relative ground structure number (J_s)

The number is based on table 52–12, which is represented graphically as a curve in Kirsten (1988, ASTM, STP-984, p. 57). The curve used in the spreadsheet is taken as for r = 1, and is represented by the following mathematical expressions:

First, the effective dip, q, is calculated by converting the apparent dip of the least favorable joint set in the rock mass by using the following relationship expressing horizontal angles in degrees azimuth and vertical angles in degrees:

$$\tan a = (\tan b)(\sin c)$$

where:
a = apparent dip of discontinuity
b = true dip of discontinuity
c = (strike of discontinuity) – (spillway flow direction)

The effective dip is the apparent dip of the discontinuity adjusted for the slope of the spillway channel, α. Dip direction is measured perpendicular to the strike. If the absolute value of the dip direction (expressed in degrees azimuth) minus the spillway flow direction (expressed in degrees azimuth) is less than or equal to 90° (including 0°; i.e., north) or greater than or equal to 270°, the dip direction is considered to be with the direction of spillway flow; otherwise, it is considered against the flow.

If the spillway flow direction is with the apparent dip:

$$q = a - \alpha$$

If the spillway flow direction is against the apparent dip:

$$q = a + \alpha$$

Values for J_s can be interpolated from table 52–12 or can be calculated directly from the following curve-matching formulas that are used in the spreadsheet.

For dip direction with the flow:

$$J_s = 1.004 + 7.42132(q) - 56.25696(q)^2 + 156.64285(q)^3 - 226.16576(q)^4 + 179.69753(q)^5 - 74.43984(q)^6 + 12.57373(q)^7$$

For dip direction against the flow:

$$J_s = 0.99926 - 4.85356(q) + 25.54649(q)^2 - 78.44504(q)^3 + 135.73875(q)^4 - 129.63181(q)^5 + 63.81557(q)^6 - 12.57373(q)^7$$

Computation of hydraulic energy, E, as peak stream power (kW/m):

The energy head is calculated using the Bernoulli equation combined with the continuity equation:

1. $$H_L = \frac{V_1^2}{2g} + d_1 - 1.5\left(\frac{V_1^2 d_1^2}{g}\right)^{0.33} + H_O$$

where:
- V_1 = velocity of flow in the exit channel associated with peak discharge
- g = acceleration of gravity
- d_1 = depth of flow corresponding to V_1 in exit channel
- H_o = $(z_1 - z_2)$

where:
- z_1 = elevation of end of constructed exit channel
- z_2 = elevation of flood plain.

2. $$E = \left\{62.4\frac{(0.746043)}{550}\right\}V_1 d_1 H_L$$

Appendix 52C Field Data Sheets

Data Sheets for Headcut Erodibility Index, K_h

(Use one set of sheets for each material) Set ____ of ____

General Information

Watershed name: ______________________ Site number: ________ State: ______

Investigator: ______________________ Title: ______________________ Date: ______________

Type of investigation:
- Reconnaissance .... ______
- Preliminary .... ______
- Detailed/design .... ______
- As-built/construction .... ______
- Spillway performance .... ______

Intensity of investigation:
- Subjective survey .... ______
- Objective survey .... ______

Photograph numbers: ______________________

Earth Material (Soil/Rock) Unit Identification

Formal rock type name or alphanumeric designation: ______________________ Rock code from table 4: ______

Soil group name (ASTM D 2488): ______________________ Unified classification symbol: ______

Location (show on geol. map/sketch): Station __________ Offset (lt) ______ Offset (rt) ______ Elevation ______

Locality type (check one): Natural exposure______ Channel side slope ______ Channel floor ______

Earth Material Information

Table 1 Color (choose from up to three columns for selected material condition)

Condition: Fresh - dry .... ________
Condition: Fresh - wet .... ________
Condition: Altered - dry .... ________
Condition: Altered - wet .... ________

light _____				white	_____
dark _____	yellowish	_____		yellow	_____
	buff	_____		buff	_____
	orangish	_____		orange	_____
	brownish	_____		brown	_____
	pinkish	_____		pink	_____
	reddish	_____		red	_____
	bluish	_____		blue	_____
	purplish	_____		purple	_____
	olive	_____		olive	_____
	greyish	_____		gray	_____
				black	_____

Table 2 Summary of parameters determined for the headcut erodibility index, K_h

Parameter	Determination
MPa (table 5 or 6)	____________
RQD (table 7)	____________
J_n (table 8)	____________
J_s (use spreadsheet)	____________
J_r (table 9)	____________
J_a (table 10)	____________

Note: Use spreadsheet to calculate K_h.

Table 3 Dry density (unit weight)

lb/ft^3	Mg/m^3	Check one	lb/ft^3	Mg/m^3	Check one	lb/ft^3	Mg/m^3	Check one
< 60	< 0.96	___	90 - 100	1.44 - 1.60	___	130 - 140	2.08 - 2.24	___
60 - 70	0.96 - 1.12	___	100 - 110	1.60 - 1.76	___	140 - 150	2.24 - 2.40	___
70 - 80	1.12 - 1.28	___	110 - 120	1.76 - 1.92	___	150 - 160	2.40 - 2.56	___
80 - 90	1.28 - 1.44	___	120 - 130	1.92 - 2.08	___	> 160	> 2.56	___

Test method used (check one): Field estimate: ____ Laboratory test: ____ Lab value: ____

Note: 1.0 pound per cubic foot (lb/ft^3) approximately equals 0.0160 megagram per cubic meter (Mg/m^3).

Table 4 Rock type classification (code number in parentheses)

Genetic Group	Detrital Sedimentary	Detrital Sedimentary	Chemical Organic	Metamorphic	Metamorphic	Pyroclastic	Igneous	Igneous	Igneous	Igneous
Usual Structure	Bedded	Bedded	Bedded	Foliated	Massive	Bedded	Massive	Massive	Massive	Massive
Composition	Grains of rock, quartz, feldspar, and clay minerals	At least 50% of grains are of carbonate	Salts, carbonates, silica, carbonaceous	Quartz, feldspars, micas, dark minerals	Quartz, feldspars, micas, dark minerals, carbonates	At least 50% of grains are of igneous rock	Quartz, feldspars, micas, dark minerals: Acid	Quartz, feldspars, micas, dark minerals: Intermediate	Feldspar; dark minerals: Basic	Dark minerals: Ultrabasic
Very coarse-grained (Predominant grain size, mm (sieve no.): 75 (3"))	Rudaceous: Grains are of rock fragments. Rounded grains: CONGLOMERATE (11); Angular grains: BRECCIA (12)	LIMESTONE (undifferentiated) (21); CALCIRUDITE (23)	CLINKER (31); SALINE ROCKS: Halite (32), Anhydrite (33), Gypsum (34)	TECTONIC BRECCIA (41); MIGMATITE (42)	TECTONIC BRECCIA (41); METACONGLOMERATE (51)	Rounded grains: AGGLOMERATE (61); Angular grains: VOLCANIC BRECCIA (62)	PEGMATITE (71)	PEGMATITE (71)	PEGMATITE (71)	
Coarse-grained (4.75 (4))				GNEISS (43)	MARBLE (52); GRANULITE (53)		GRANITE (72)	DIORITE (81); GRANODIORITE (82)	GABBRO (91)	PYROXENITE (01)
Medium-grained (0.074 (200))	Arenaceous: Grains are mainly mineral fragments. SANDSTONE (13); ARKOSE (14); GRAYWACKE (Argillaceous ss) (15)	CALCARENITE (24)	CALCAREOUS ROCKS	SCHIST (44); Amphibolite (45)	QUARTZITE (54); Amphibolite (45)	TUFF (63)	SYENITE (73)	ANORTHOSITE (83)	DIABASE (92)	PERIDOTITE (02)
Fine-grained (0.005)	Argillaceous or Lutaceous: MUDSTONE (16); SHALE: fissile mudstone (17); SILTSTONE>50% fine-grained particles (18)	MARLSTONE (22); CALCISILTITE (25)	LIMESTONE (35)	PHYLLITE (46)	HORNFELS (55)	Fine-grained TUFF (64)	APLITE (74); RHYOLITE or FELSITE (75)	MONZONITE (84); Dacite (85)	BASALT (93)	DUNITE (03)
Very Fine-grained	CLAYSTONE>50% very fine grained particles (19)	MARLSTONE (22); CHALK (26); CALCILUTITE (27)	DOLOMITE (36)	Mylonite (47); SLATE (48)	Mylonite (47)	Very fine-grained TUFF (65)		ANDESITE (86)		NEPHELINE-BASALT (04)
Glassy Amorphous			SILICEOUS ROCKS: Chert (37), Flint (38); CARBONACEOUS ROCKS; LIGNITE/COAL (39)	Ultramylonite (49)	Ultramylonite (49)	Welded TUFF (66); PUMICE (67)	VOLCANIC GLASSES: OBSIDIAN (76)	VOLCANIC GLASSES: PITCHSTONE (87)	VOLCANIC GLASSES: TACHYLYTE (94)	

Determination Of Strength, MPa

Table 5 Consistency or hardness categories for rock material and cohesive soil

Consistency or hardness category	Field assessment tests	SPT (N)	Typical range in unconfined compressive strength (MPa)	Strength value selected (MPa)
Very soft soil*	Exudes between fingers when squeezed in hand. Easily penetrated several cm with fist.	< 2	< 0.04	______
Soft soil*	Easily molded with fingers. Head of geologic hammer easily pushed in to shaft of handle.	2 - 4	0.04 - 0.08	______
Firm soil*	Penetrated several cm. by thumb with moderate pressure. Molded by fingers with some pressure.	4 - 8	0.08 - 0.15	______
Stiff soil*	Indented by thumb with great effort. Point of geologic pick pushed in up to 1 cm. Very difficult to mold with fingers. Can be just penetrated with hand spade.	8 - 15	0.15 - 0.30	______
Very stiff soil*	Indented only by thumbnail. Slight indentation by pushing point of geologic pick into material. Requires hand pick for excavation.	15 - 30	0.30 - 0.60	______
Very soft rock or hard, soil-like material	Scratched with fingernail. Slight indentation by light blow of point of geologic pick. Requires power tools for excavation. Peels with pocket knife.	> 30	0.60 - 1.25	______
Soft rock	Handheld specimen crumbles under firm blows with point of geologic pick.		1.25 - 5.0	______
Moderately soft rock	Shallow indentations (1–3 mm) by firm blows with point of geologic pick. Peels with difficulty with pocket knife.		5.0 - 12.5	______
Moderately hard rock	Cannot be scraped or peeled with pocket knife. Intact hand-held specimen breaks with single blow of geologic hammer. Can be distinctly scratched with 20d common steel nail.		12.5 - 50	______
Hard rock	Intact handheld specimen requires more than one hammer blow to break it. Can be faintly scratched with 20d common steel nail.		50 - 100	______
Very hard rock	Intact specimen breaks only by repeated, heavy blows with geologic hammer. Cannot be scratched with 20d common steel nail.		100 - 250	______
Extremely hard rock	Intact specimen can only be chipped, not broken by repeated, heavy blows of geologic hammer.		> 250	______

Method used to determine consistency or hardness (check one):

Field assessment:	_____	Rebound hammer (ASTM D 5873):	_____	Pocket penetrometer:	_____
Uniaxial lab test:	_____	Pocket vane shear test:	_____	Other: ______________	_____

Notes:
(1) Cohesive soil is material with a plasticity index (PI) greater than 10. Use table 6 for cohesionless soils.
(2) Standard Penetration Test (SPT) refers to ASTM D 1586, where N equals blow count in blows per 0.3 meter.
(3) Consistency/hardness categories are based solely on physical characteristics, not geologic origin. For examples, a highly weathered shale may classify as Firm soil, and a partially lithified, Recent soil may classify as Moderately Soft Rock. The transition from soil to rock, however, usually occurs within the 0.60 to 1.25 MPa range.
(4) Materials marked with (*) must be evaluated for hardness in a saturated condition.
(5) 1.0 Megapascal (MPa) or 10 Kg/cm^2 equals 145.039 pounds per square inch (psi), or 10.443 tons per square foot (tsf).
(6) Correlation between SPT and UCS should be used as a guide only as results may vary in different geologic areas. Lab strength tests are recommended on soil materials to support SPT or field assessment tests. Vane shear strength values also are applicable in the lower strength ranges.

Determination Of Strength, MPa

Table 6 Relative density categories for cohesionless soil

Relative density category	Field assessment tests	SPT (N)	In situ deformation modulus (MPa)	Strength value selected (MPa)
Very loose	Particles loosely packed. High percentage of voids. Very easily dislodged by hand. Matrix crumbles easily when scraped with point of geological pick. Excavated faces often unravel.	< 5	< 0.005	________
Loose	Particles loosely packed. Some resistance to being dislodged by hand. Large number of voids. Matrix shows low resistance to penetration when pushed by point of geologic pick.	5 - 10	0.005 - 0.01	________
Medium dense	Particles closely packed. Difficult to dislodge individual particles by hand. Voids less apparent. Matrix has considerable resistance to penetration when struck by point of geologic pick.	10 - 30	0.01 - 0.03	________
Dense	Particles very closely packed and occasionally very weakly cemented. Cannot dislodge individual particles by hand. The mass has very high resistance to penetration when struck by point of geologic pick. Requires many blows of geologic pick to dislodge particles.	30 - 50	0.03 - 0.08	________
Very dense	Particles very densely packed and usually cemented together. Mass has high resistance to repeated blows of geologic pick. Requires power tools for excavation.	> 50	0.08 - 0.20	________

Notes: (1) Cohesionless soil is material with a plasticity index (PI) less than or equal to 10. Use table 5 for cohesive soils.

(2) Standard Penetration Test (SPT), where N equals blow count in blows per 0.3 m, is used for most sandy-type cohesionless soils. In situ Deformation Modulus is used for most gravel-type soils and coarse detritus.

(3) Cohesionless soils in which blow counts are greater than 50, or In situ Deformation Modulus is greater than 0.200 MPa, are to be taken as rock, for which the hardness may be obtained from table 5.

Determination Of Relative Ground Structure Number, J_s

1. Draw plan view sketch of spillway. Show north arrow.
2. Spillway flow direction at end of exit channel (or at headcut): __________° (azimuth).
3. Exit channel slope: __________°.
4. Strike: _______° (azimuth), and dip: ________° of bedrock (or least favorable joint set) at end of exit channel.
5. Bedrock dip direction: __________° (azimuth).
6. Enter data from items 2 through 5 into spreadsheet to calculate J_s factor.

Determination of Block Size Number, RQD/J_n

Determine RQD by method 1, 2, or 3 below, depending on the type of data available. Determine joint set number, J_n, using table 8. Then, determine block size number, RQD/J_n.

1. Determine RQD (rounded to nearest whole number between 5 and 100) from drilling logs. If no logs are available, use method 2 or 3 below. RQD: ___________
2. Determine mean block diameter, D, based on spacing of joint sets in rock mass. Use a line survey to measure average joint spacing within a set. Plot location of survey lines on a map/sketch.
   A. For systematic joint sets:
      — Lines 1 and 2 are for the two most persistent, high-angle, intersecting joint sets.
      — Line 3 is for bedding plane partings or sheeting joints.
   B. For apparently random fractures:
      — Line 1 is set perpendicular to channel flow direction (x axis).
      — Line 2 is set parallel to channel flow direction (y axis).
      — Line 3 is for bedding plane partings or sheeting joints in the vertical direction (z axis) .

Survey line (axis)	a Line trend (azim °)	b Line plunge (°)	c Line length (meters)	d Total number of joints	e Average spacing (c/d)
Line 1 (x)					
Line 2 (y)					
Line 3 (z)					

   C. Use values in column e above to calculate mean block diameter, $D = (ex\ ey\ ez)^{0.333}$ = _________ meters.
   D. Calculate RQD from mean block diameter, D, as follows:
      $RQD \approx [105 - (10/D)]$: ____________.
3. RQD also may be determined from joint count number, J_c (number of joints per m^3 of rock mass), by:
   A. A direct count of the joints in a cubic meter of rock mass and converting J_c to RQD according to table 7, or
   B. Estimating J_c from mean block diameter, D, where:
      $J_c \approx (3/D) + 3$ (for $D \geq 0.1$ m) ≈ ____________, and then calculate RQD from J_c by:
      $RQD \approx (115 - 3.3\ J_c)$: ____________, for $5 \leq RQD \leq 100$.

Table 7 Relationship between J_c and RQD

RQD	J_c	RQD	J_c
5	33	55	18
10	32	60	17
15	30	65	15
20	29	70	14
25	27	75	12
30	26	80	11
35	24	85	9
40	23	90	8
45	21	95	6
50	20	100	5

Table 8 Joint set number, J_n

Number of joint sets in rock mass	J_n	Check one
Intact; no or few joints	1.00	______
One joint set	1.22	______
One joint set plus random	1.50	______
Two joint sets	1.83	______
Two joint sets plus random	2.24	______
Three joint sets	2.73	______
Three joint sets plus random	3.34	______
Four joint sets	4.09	______
More than four joint sets	5.00	______

Determination of Shear Strength Number, J_r/J_a

Table 9 Joint roughness number, J_r

Joint separation	Joint roughness condition	J_r
Joints are tight or become closed during hydraulic flow.	Discontinuous joints; stepped	4.0
	Rough/irregular; undulating (e.g., tension joints, rough sheeting, and rough bedding)	3.0
	Smooth; undulating (e.g., smooth sheeting, nonplanar foliation, and bedding)	2.0
	Slickensided; undulating	1.5
	Rough/irregular; planar	1.5
	Smooth; planar (e.g., planar sheeting joints, planar foliation, and bedding)	1.0
	Slickensided; planar	0.5
Joints are open and remain open during hydraulic flow.	Joints are either open or contain soft gouge thick enough to prevent wall contact during flow	1.0
	Joints contain swelling clays	1.0

Note: Consider a joint open when aperture width exceeds the amplitude of the asperities of joint faces.

Table 10 Joint alteration number, J_a

Field identification of gouge (infilling)	J_a for aperture width < 1.0 mm 1/	J_a for aperture width 1.0 - 5.0 mm 2/	J_a for aperture width ≥ 5.0 mm 3/	Typical ϕ'_r °
Joint tightly healed with hard, nonsoftening, impermeable mineral filling, e.g., quartz, calcite, or epidote	0.75	1.0	1.5	- - -
Clean, open joint with fresh or discolored (unweathered) walls only; no infilling	1.0	1.5	2.0	- - -
Discolored to disintegrated joint walls; infilling is sand or gravel with < 15% cohesionless fines in matrix; with or without disintegrated or crushed rock fragments.	2.0	4.0	6.0	(25 – 30)
Discolored to disintegrated joint walls; cohesionless, nonswelling, low to nonplastic fines in matrix; with or without disintegrated or crushed rock fragments	3.0 4/	6.0 4/	10.0 4/	(15 – 24)
Disintegrated to decomposed joint walls; nonswelling, lean clay or clay matrix, or low friction clays, such as chlorite, talc, mica, serpentine, gypsum, graphite, kaolinite, or other sheet silicates; with or without disintegrated or crushed rock fragments	4.0 4/	8.0 4/ 5/	13.0 4/ 5/	(10 – 14)
Disintegrated to decomposed joint walls; fat clay, swelling clay, such as montmorillonite, or clay matrix, with or without disintegrated or crushed rock fragments	5.0 4/	10.0 4/ 5/	18.0 4/ 5/	(6 – 9)

1/ Joint walls effectively in contact.
2/ Joint walls come into contact after approximately 100 mm shear.
3/ Joint walls do not come into contact at all upon shear. Use this column to determine J_a for intact, cohesive granular materials, for which $J_r = 3.0$. Alternatively, tan ϕ'_r can be substituted for the quotient J_r/J_a where ϕ'_r is the equivalent residual (minimum) friction angle.
4/ Values added to Barton et al. (1974) data.
5/ Also applies when disintegrated or crushed rock fragments occur in clay matrix without wall contact.

Area Survey of Discontinuity Attributes

Instructions for classifying discontinuity attributes by an area survey:

1. Assign each discontinuity an ID number and record on the summary data sheet; show its location on geologic evaluation map or sketch.
2. Select appropriate code numbers from tables 11 through 15 and record on data sheet.
3. Classify infilling using ASTM D 2488 (USCS); record soil classification symbols on data sheet.
4. Determine strength of infilling using tables 5 or 6; record on data sheet.

Table 11 Joint set spacing categories

Bedding plane partings	Joint sets	Spacing (meters)	Category
Massive/ unstratified	Extremely wide	> 6.000	1
Very thick-bedded	Very wide	2.000 - 6.000	2
Thick-bedded	Wide	0.600 - 2.000	3
Medium bedded	Mod. wide	0.200 - 0.600	4
Thin-bedded	Mod. close	0.060 - 0.200	5
Very thin-bedded	Close	0.020 - 0.060	6
Laminated	Very close	0.006 - 0.020	7
Thinly laminated	Shattered	0.002 - 0.006	8
Fissile	Fissured	< 0.002	9

Table 12 Discontinuity types

Discontinuity type	Code
Stratigraphic	
lithosome (sharp contact)	1
unconformity	2
Structural	
Plastic deformation	
Foliation	
— schistosity	3
— gneissosity	4
Banded rock	5
Folded rock	6
Fracture deformation	
Random fracture	7
Systematic joint set	8
Bedding plane parting	9
Sheeting joint	10
Slaty cleavage	11
Fault	12
Other	13

Table 13 Joint persistence categories

Joint persistence category	Trace length (meters)	Code
Very low	< 1	1
Low	1 - 3	2
Medium	3 - 10	3
High	10 - 20	4
Very high	> 20	5

Table 14 Aperture categories

Aperture category	Range (mm)	Code
Wide	> 200	1
Moderately wide	60 - 200	2
Moderately narrow	20 - 60	3
Narrow	6 - 20	4
Very Narrow	2 - 6	5
Extremely narrow (hairline)	< 2	6

Table 15 Weathering condition categories for joint face material (to support table 10)

Category	Weathering condition of joint face material	Code
Fresh	No sign of weathering.	1
Discolored	Iron-stained or discolored, but otherwise unweathered.	2
Disintegrated	Physically disintegrated to a soil condition with original fabric still intact. Material is friable and mineral grains are not decomposed.	3
Decomposed	Chemically altered to a soil condition with original fabric still intact. Some or all mineral grains are decomposed.	4

Summary Data Sheet

Table #	12	Discontinuity measurements				13	14	15	D 2488	5, 6
Discon. ID #	Discon. type code	Trend (azim)	Dip (°)	Dip direction (azim)	Joint persis. (m)	Joint persis. code	Apert. categ. code	Joint weath. code	Infill. class (USCS)	Infill. strength (MPa)

Spillway Profile

1. In the space below sketch the spillway profile.
2. Label materials by ID (as given on page 1).
3. Show elevations of tops of materials, ground surface at major slope breaks, and flood plain.

** Notes on Using This Spreadsheet

1. Refer to NEH Part 628, Chapter 52, "Field Procedures Guide for the Headcut Erodibility Index," for details on how to collect the field information for the input parameters.
2. Use copies of the eight data sheets in appendix 52C for recording field data. The numbers of the tables on the data sheets agree with those in the spreadsheet.
3. Supplemental instructions on how to use this spreadsheet:

Cell	Parameter	Notes
B-7	Exit channel slope	For exit channels with more than one slope, use slope of exit section.
B-8	Spillway flow direction	For curved spillways, use the orientation of exit section.
B-9	Bedrock strike	If the strike of the bedrock varies within the exit channel, measure the strike as it occurs at the exit section.
B-10	Bedrock dip	If the dip of the bedrock varies within the exit channel, measure the dip as it occurs at the exit section.
B-11	Bedrock dip direction	Measure at right angles to the strike and express as an azimuth.
B-12	Apparent dip	The spreadsheet calculates this after all data above it are entered.
B-13	Effective dip	The spreadsheet calculates this after all data above it are entered.
B-14	Is dip direction against or with the flow?	The spreadsheet calculates this after all data above it are entered.
B-15	Ground structure number	The spreadsheet calculates this after all data above it are entered.
B-16	Unconfined compressive strength	If material is rock or cohesive soil, use table 5 to select best value.
B-18	Unconfined compressive strength	If material is cohesionless soil, use table 6 to select best value.
B-20		If table 5 is used, enter **yes**; if table 6 is used, enter **no**. This block must be filled in because it tells the spreadsheet which formula to use to calculate M_s.
B-21		If the material is rock or cohesive soil, the spreadsheet calculates M_s after cell B-16 is filled in.
B-22		If the material is cohesionless soil, the spreadsheet calculates M_s after cell B-18 is filled in. If nothing is entered into cell B-18, **0.000** is shown, indicating the cell is not in use.
B-23	RQD	The three ways to arrive at this value are described on sheet 5. Enter the value derived from either method 1 or 3. If the line survey method (2) is used to calculate mean block diameter, D, based on joint set spacing, enter the average spacing of each of the 3 sets into cells B-42, B-43, and B-44, respectively.

** Notes on Using This Spreadsheet—Continued

Cell	Parameter	Notes
B-24	Joint set number, J_n	Use table 8 to determine J_n.
B-25	Joint roughness number, J_r	If material is rock, use table 9.
B-26		If material is rock, use table 10. For field estimation of J_a for soil material, use column 3 of table 10 (for aperture width > 5 mm).
B-28		If a lab residual shear test is conducted, enter ϕ'_r in degrees in cell B-27. If a lab shear test is unavailable, ϕ'_r can be approximated from liquid limit. See alternative method, cell B-33.
B-30	Headcut erodibility index, K_h	Spreadsheet calculates K_h after all appropriate data above are entered.
B-32	Hydraulic energy, E (kilowatts)	Spreadsheet calculates E after cells B-52 through B-57 are entered.
B-37	Percent clay	Enter clay content (percent finer than 0.002 micron) of soil.
B-38	Liquid limit	Enter liquid limit of soil in percent.
B-39		Once data are entered in cells B-35 and B-36, the spreadsheet calculates residual friction angle. Enter the value obtained in cell B-37 into cell B-27.
B-44	Mean block diameter	Once data are entered into cells B-42, B-43, and B-44, the spreadsheet calculates mean block diameter. If nothing is entered into these cells, **0.000** is shown, indicating the cells are not in use.
B-45	Joint count	After data are entered into cells B-40, B-41, and B-42, the spreadsheet calculates J_c according to the relationship shown in table 7. If nothing is entered, **33** is shown, indicating the cell is not in use.
B-46	Equivalent RQD	Once the data are entered into cells B-42, B-43, and B-44, the spreadsheet calculates Equivalent RQD. Enter this figure into cell B-23. If this alternative method is not used, **6** is shown, indicating the cell is not in use.
B-52	Peak velocity in exit channel	Use the velocity of flow associated with the peak discharge in the exit channel reach containing the exit section and at a point where the flow is not at critical head.
B-53	Maximum depth of flow in exit channel	Use the maximum depth associated with the peak velocity (used in cell B-52) in the reach containing the exit section and at a point where the flow is not at critical head.
B-54	Elevation of end of exit channel	If the exit channel is constructed all the way to the flood plain, this methodology for calculating a headcut erodibility index does not apply. An overfall condition is one of the necessary assumptions.

**** Notes on Using This Spreadsheet—Continued**

Cell	Parameter	Notes
B-55	Elevation of flood plain	Use the elevation of the flood plain at the base of the hillside in which the spillway is constructed.
B-56	Energy head	The spreadsheet calculates this after cells B-52 through B-55 are filled in.
B-57	Hydraulic energy	The spreadsheet calculates this after cells B-52 through B-55 are filled in.

Notes on significance of chart 1:

1. If the calculated value for K_h plots above the erosion threshold, significant erosion can be anticipated.
2. If the calculated value for K_h plots below the erosion threshold, little to no erosion can be anticipated.
3. Erosion rates are not determined by this method.