PROCEDURE FOR DETERMINING ROCK WEIGHTS, SIZES AND GRADATIONS

Note: The gradation required for rock-lined chutes is determined differently. See Chapter 6 of the Engineering Field Handbook (EFH) for details.

Rock gradations are required for several conservation practices in Wisconsin. Gradations are usually determined by finding the percent of material by weight that is smaller than a certain size. The gradations will usually allow a percentage range, or envelope, for a specific weight or equivalent size ("d").

Designs are based on the weight and shape of a particle. Particles which have the same weight may be a sphere, a cube, or some intermediate shape between the two. Design weight is a critical factor for the stability of individual rock particles. Therefore, it is also a critical factor for stability of the entire structure. Weighing is not practical for rocks that exceed 100 pounds. Weight definitely cannot be determined by observation. The procedure for NRCS in Wisconsin uses an equivalent "d" for the gradation parameter.

Visual observation to determine an equivalent "d" or rock gradation is not acceptable. Once a proper gradation has been determined by physically measuring or weighing the rock particles, visual observation may be used as a construction inspection tool. Visual observation of the complete rock layer (not just the surface) should approximate the appearance of a gradation sample pile that can be prepared. Apparent variations in the visual observation will usually require physically measuring or weighing another sample area to determine gradation adequacy.

Joe Calder, construction engineer at the former Midwest National Technical Center, developed a procedure to estimate the weight and equivalent "d" of rock. The procedure requires measuring the major and minor circumferences or perimeters of the rock in feet. See Figures 1 and 2. The sum of the perimeters can be sued to: 1) graphically read the rock weight in pounds and equivalent "d" in inches from Figure 3; or 2) calculate the rock weight and equivalent "d" by using the formulas shown on Figure 3.

The perimeter measurement method provides a close approximation of the rock weight. It appears to provide a more accurate weight than obtained by measuring a "d". A "d" error of 1 inch while measuring a 12-inch rock can yield an error of approximately 25 percent in theoretical weight. Averaging the "d" of oblong shaped rocks can also produce a significant error.

The perimeter measurement method produces an error of approximately ±10 percent when compared to actual scale weights. The weight and "d" lines on Figure 3 are based on the average of a perfect sphere and a perfect cube. The perimeter measurement compensates for other than "perfect" shapes. The theoretical errors for the perimeter measurement method for a perfectly shaped sphere and cube, respectively, are: 1) weight, -3 percent and +5 percent; and 2) "d", -12 percent and +11 percent. These errors are expected to be less for shapes other than perfect spheres and cubes. Because the weight is a critical factor in design and "d" dimensions are used only for a visual check, the error in this procedure is considered to be tolerable.

Some measurement precautions are necessary to obtain the best results from this procedure. They are as follows:

1. The graph in Figure 3 and formulas are for rock that has a specific gravity of 2.65 (165 pounds per cubic foot). Use this graph or formula unless the actual specific gravity (G_{sa}) is known and varies more than 5 percent (±0.13) from 2.65.

   To correct to the actual weight (W_a) use this formula:

   $$W_a = (W \text{ from Figure } 3/2.65) \times G_{sa}$$

2. When measuring the major and minor perimeters, do not measure sharp peaks, protrusions, or valleys. Move the tape slightly off the 90º angle or adjust the measurement to represent the rock's general shape.

3. The approximate formula, $0.335(P_1 + P_2)^3$ = Weight of rock (W) in pounds can be used. To obtain the equivalent "d", use this formula:

   $$\text{"d" inches} = 2.4 \times (W)^{1/3}$$

Use the following procedure for the perimeter measurement method:

1. Place the rock in its most probable "at rest" laying position.

2. Imagine two vertical cutting planes passing through the rock at nearly right angles to each other. Measure the two resulting perimeters in feet and add them together.

3. Enter the graph in Figure 3 at the measured $P_1 + P_2$ and follow horizontally to the intersection with the line labeled Weight of Rock (W). Follow down the chart and read the approximate weight in pounds on the bottom scale.

4. To determine the equivalent "d", enter the graph at weight at the bottom of the chart. Proceed vertically to the intersection of the line labeled Size of Rock "d" and move horizontally to the right to read "d".

5. To determine the weight of small rock and sand-gravel, determine the volume in cubic feet and multiply by 100 pounds. See Figure 4.

   Note: The volume of a cone is: $V = \frac{3.14\ b^2 h}{12}$

   Where V = Volume in cubic feet
   b = Base in feet
   h = Height in feet

After the weight and "d" of each rock (except small rock, gravel) are determined, they need to be accumulated into sizes that would be held on a particular screen size such as 1.5 D_{50}, D_{50}, etc. The weights of the rocks that have a "d" greater than the screen size are accumulated and considered retained on the screen. The cumulative percentage is subtracted from 100 percent to obtain the percent passing. See Examples 1 and 2.

Comments on Example 1 are: D_{50} = 6 inches; D_{max} = 12 inches. Note: 3 rocks which have a "d" greater than 9 inches (1.5 x D_{50}) weigh 244 pounds (106 + 80 + 58); 8 rocks which have a "d" greater than 6 inches (D_{50}) weigh 214 pounds (82 + 81 + 51); 27 rocks which have a "d" greater than 3 inches (0.5 x D_{50}) weigh 123 pounds (60 + 35 + 28); 52 rocks that have a "d" greater than 1 inch (0.2 x D_{50}) weigh 31 pounds. Note the increase in number of rocks as the size decreases. Also note that the gradation is at the lower limit of the envelope for a D_{50} = 6 inches. The material 3 inches and smaller could be counted and the weight estimated. The expected volume of the total sample in cubic feet (ft^3) is:

$$VOL = 612 \text{ lbs} / (165 \text{ lbs/ft}^3 \times 0.7) = 5.3 \text{ ft}^3$$

To check rock in place, the cumulative weight of the rocks larger than 9 inches must not exceed 40 percent of the total weight; the cumulative weight of the rocks larger than 6 inches must not exceed 75 percent of the total weight; etc.

Comments on Example 2: D_{50} = 6 inches; D_{max} = 12 inches. Use the same method as in Example 1 to calculate the gradation. Note that this gradation is the upper limit of the gradation for D_{50} = 6 inches. The expected volume of the total sample in cubic feet (ft^3) is:

$$VOL = 1562 \text{ lbs} / (165 \text{ lbs/ft}^3 \times 0.7) = 13.5 \text{ ft}^3$$

Comments on both examples: The number of rock (and weight) larger than 1.5 x D_{50} remained equal to keep the sample size at a minimum. Note that a 9+ inch, 10+ inch, and 11+ inch rock were used for the part of the sample larger than 1.5 x D_{50}. Three rocks which have a "d" of 10.3 inches weigh approximately 240 pounds; 20 rocks which have a "d" of 7.3 inches weigh approximately 550 pounds, etc., to less than 0.2 x D_{50}. These weights would meet the percent passing criteria. However, this would be considered a poorly graded material because there would be no sizes between 7.3 inches and 10.3 inches, etc. All sizes should be represented in the total sample to have a proper gradation. Variation in the size allows for better filling of voids, interlocking of the rock and stability of the rock structure. Because the examples are near the upper and lower limits of the gradation envelope, the number of rock with equivalent dimensions (or weight) could be piled as a "sample" in the quarry or on the construction site. These sample piles could be used for training personnel who are involved in construction inspection.

Tables 1 through 5 have gradation guidelines for D_{50}s of 4 inches through 12 inches. The smaller (i.e., 1 and 2 inch) diameters shown should be considered as "weight of material" rather than "number of rock." The tables can be used to produce gradation sample piles showing the upper and lower limits of the desired gradation. These piles can be used in the rock quarry to provide the contractor with a visual model of the rock gradation needed.

Example 1

D_{50} = 6 inches; D_{max} = 12 inches

P_1 P_2 (feet)	"d" (inches)	Weight per Rock (pounds)	Number of Rocks	Weight Retained (pounds)	Percent Retained	Percent Retained Subtotal	Percent Passing	Spec. Limits
	12	0	0	0	0	0	100	100
6.8	11.4	106	1	106				
6.2	10.3	80	1	80				
5.6	9.3	58	1	58	39.9	39.9		
	9.0						60.1	60-85
5.0	8.3	41	2	82				
4.3	7.3	27	3	81				
3.7	6.2	17	3	51	35	74.8		
	6.0						25.2	25-50
3.1	5.2	10	6	60				
2.5	4.2	5	7	35				
1.9	3.1	2	14	28	20.1	94.9		
	3.0						5.1	5-20
1.21*	>2	0.6	52	31				
	1		0	0	4.9	100	0.0	0-5
Total Weight: 612								

*calculated

Example 2

D_{50} = 6 inches; D_{max} = 12 inches

P_1 P_2 (feet)	"d" (inches)	Weight per Rock (pounds)	Number of Rocks	Weight Retained (pounds)	Percent Retained	Percent Retained Subtotal	Percent Passing	Spec. Limits
	12	0	0	0	0	0	100	100
6.8	11.4	106	1	106				
6.2	10.3	80	1	80				
5.6	9.3	58	1	58	15.6	15.6		
	9.0						84.4	60-85
5.0	8.3	41	3	123				
4.3	7.3	27	7	189				
3.7	6.2	17	14	238	35.2	50.8		
	6.0						49.2	25-50
3.1	5.2	10	19	190				
2.5	4.2	5	30	150				
1.9	3.1	2	64	128	30	80.8		
	3.0						19.2	5-20
1.21*	>2	0.6	250	150				
	>1			75				
	1.0				14.4	95.2	4.8	0-5
	<1			75	4.8	100	0	
Total Weight:				1562				

*calculated

Table 1

D_{50} = 4 inches Rock Gradation Envelope Limits

D (inches)	Weight per Rock (pounds)	Number of Rocks and Weight			
		Lower Limit		Upper Limit	
		Number	Weight	Number	Weight
7.5	31	1	31	1	31
6.5	20	1	20	1	20
5.5	12	2	24	4	48
4.5	7	3	21	10	70
3.5	3	5	15	18	54
2.5	1.1	10	11	44	48
<2			7		51
<1			0		16
		Total Weight:	129		338

Resulting Gradation

D (inches)	Specification Percent Passing	Lower Limit Percent Passing by Weight	Upper Limit Percent Passing by Weight
8	100	100	100
6	60-85	60.5	84.9
4	25-50	25.6	50.0
2	5-20	5.4	19.8
1	0-5	0	4.7

Table 2

D_{50} = 6 inches Rock Gradation Envelope Limits

D (inches)	Weight per Rock (pounds)	Number of Rocks and Weight			
		Lower Limit		Upper Limit	
		Number	Weight	Number	Weight
11.5	110	1	110	1	110
10.5	84	1	84	1	84
9.5	62	1	62	1	62
8.5	44	2	88	4	176
7.5	31	2	62	7	217
6.5	20	4	80	10	200
5.5	12	5	60	15	180
4.5	7	6	42	25	175
3.5	3	9	27	50	150
2.5	1.1	17	19	150	165
<2			14		87
<1			0		85
		Total Weight:	648		1691

Resulting Gradation

D (inches)	Specification Percent Passing	Lower Limit Percent Passing by Weight	Upper Limit Percent Passing by Weight
12	100	100	100
9	60-85	60.5	84.9
6	25-50	25.0	49.8
3	5-20	5.1	19.9
1	0-5	0	5.0

Table 3

D_{50} = 8 inches Rock Gradation Envelope Limits

D (inches)	Weight per Rock (pounds)	Number of Rocks and Weight			
		Lower Limit		Upper Limit	
		Number	Weight	Number	Weight
15.5	269	1	269	1	269
13.5	178	1	178	1	178
11.5	110	2	220	4	440
9.5	62	3	186	10	620
7.5	31	4	124	16	496
5.5	12	9	108	33	396
3.5	3	19	57	147	441
<2			0		147
Total Weight:			1142		2987

Resulting Gradation

D (inches)	Specification Percent Passing	Lower Limit Percent Passing by Weight	Upper Limit Percent Passing by Weight
16	100	100	100
12	60-85	60.8	85.0
8	25-50	25.3	49.5
4	5-20	5.0	19.7
2	0-5	0	4.9

Table 4

D_{50} = 10 inches Rock Gradation Envelope Limits

D (inches)	Weight per Rock (pounds)	Number of Rocks and Weight			
		Lower Limit		Upper Limit	
		Number	Weight	Number	Weight
19.5	536	1	536	1	536
17.5	388	1	388	1	388
15.5	269	1	269	1	269
13.5	178	3	534	7	1246
11.5	110	5	550	14	1540
9.5	62	4	248	14	992
7.5	31	7	217	28	868
5.5	13	12	144	44	528
3.5	3	51	153	398	1194
<2			0		397
		Total Weight:	3039		7958

Resulting Gradation

D (inches)	Specification Percent Passing	Lower Limit Percent Passing by Weight	Upper Limit Percent Passing by Weight
20	100	100	100
15	60-85	60.7	85.0
10	25-50	25.1	50.0
5	5-20	5.0	20.0
2	0-5	0	5.0

Table 5

D_{50} = 12 inches Rock Gradation Envelope Limits

D (inches)	Weight per Rock (pounds)	Number of Rocks and Weight			
		Lower Limit		Upper Limit	
		Number	Weight	Number	Weight
23.5	939	1	939	1	939
21.5	719	1	719	1	719
19.5	536	1	536	1	536
17.5	388	1	388	4	1552
15.5	269	3	807	6	1614
13.5	178	4	712	11	1958
11.5	110	4	440	15	1650
9.5	62	6	372	23	1426
7.5	31	10	310	42	1302
5.5	12	15	180	110	1320
3.5	3	34	102	292	876
<2			0		731
		Total Weight:	5505		14,623

Resulting Gradation

D (inches)	Specification Percent Passing	Lower Limit Percent Passing by Weight	Upper Limit Percent Passing by Weight
24	100	100	100
18	60-85	60.1	85.0
12	25-50	25.5	50.0
6	5-20	5.1	20.0
2	0-5	0	5.0

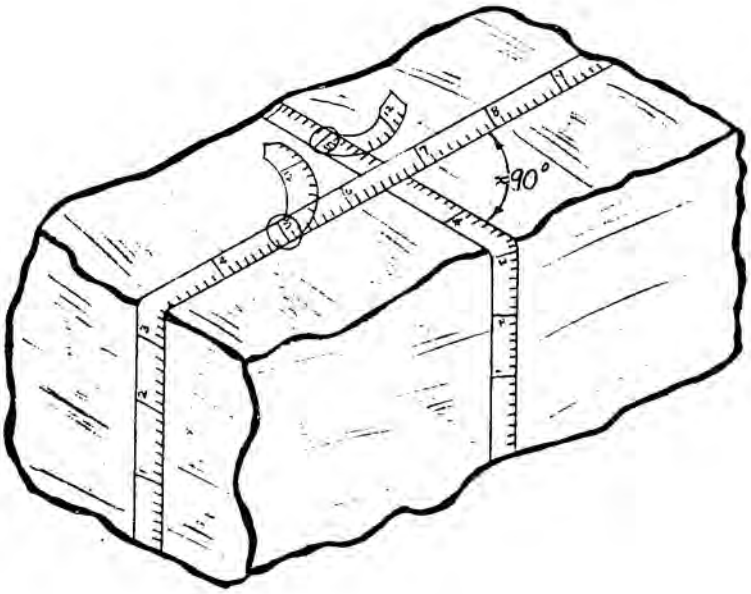

Figure 1

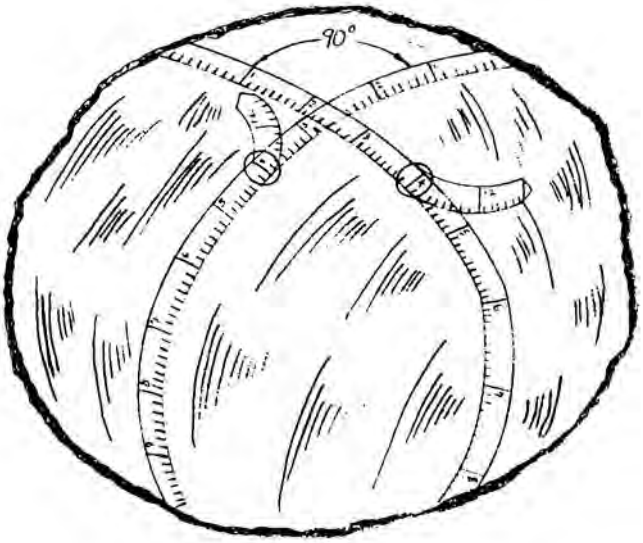

Figure 2

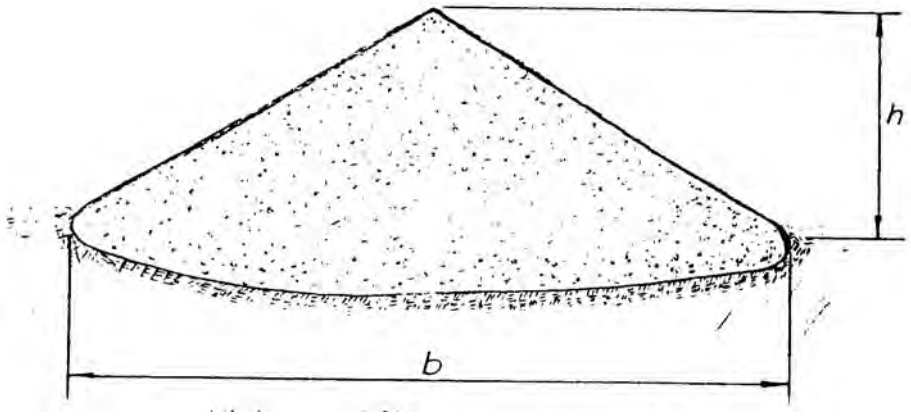

Figure 4

$$Volume\ (ft^3) = \frac{3.14 \times b^2 \times h}{12}$$

(b and h in feet)

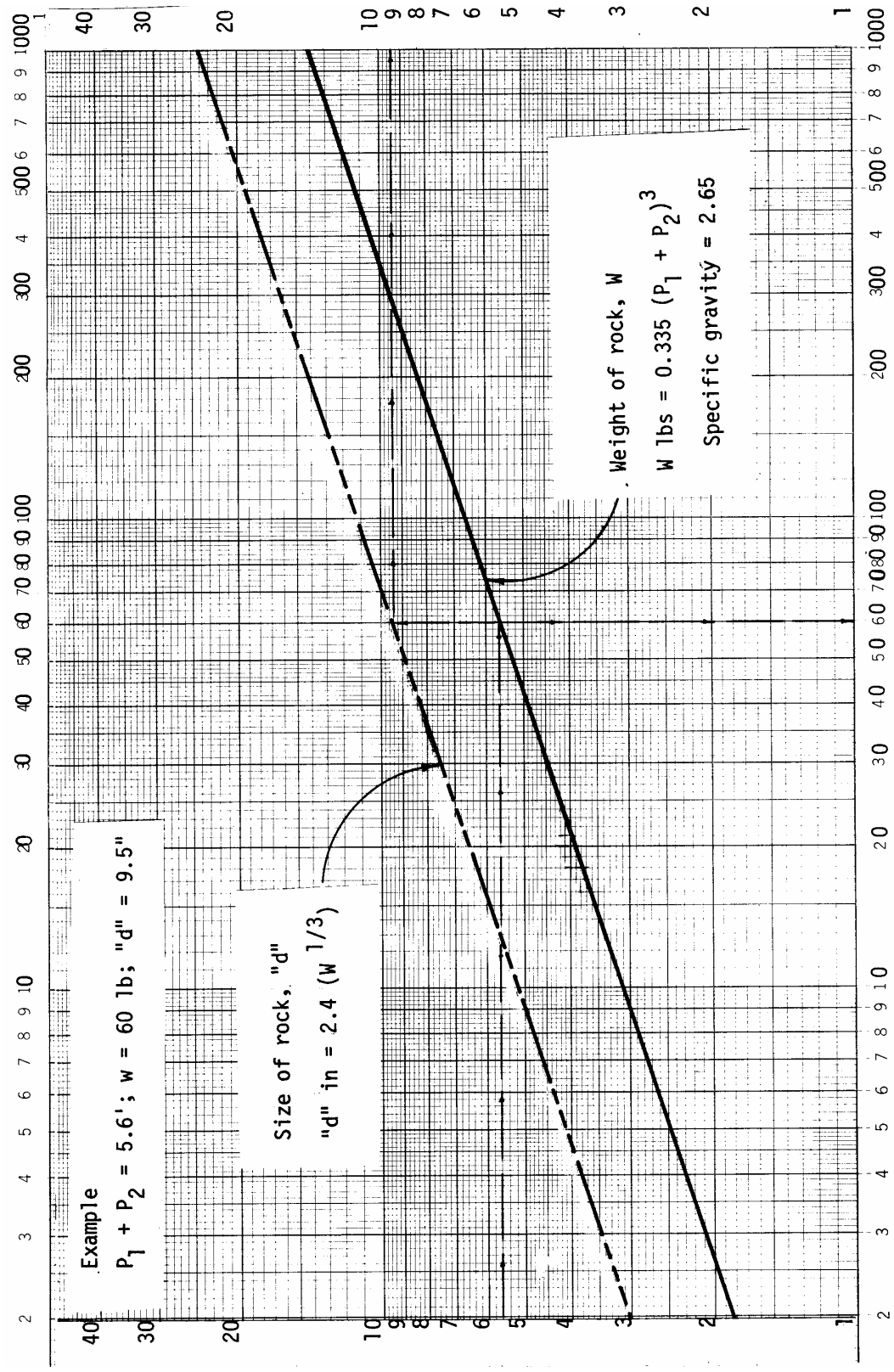

Figure 3 – Rock weight vs. (p1 + P2) and "d"

ROCK WEIGHT AND DIAM. VS (P_1 + P_2)

(Specific Gravity 2.65)

P_1+ P_2	Weight.	Diam.	Weight	Diam.	Weight	Diam.	Weight	Diam.	Weight	Diam.	Weight	Diam.	Weight	Diam.	Weight	Diam.	Weight	Diam.	Weight	Diam.
	0.0		0.1		0.2		0.3		0.4		0.5		0.6		0.7		0.8		0.9	
2	2.7	3.3	3.1	3.5	3.6	3.7	4.1	3.8	4.6	4.0	5.2	4.2	5.9	4.3	6.6	4.5	7.4	4.7	8.2	4.8
3	9.0	5.0	10.0	5.2	11.0	5.3	12.0	5.5	13.2	5.7	14.4	5.8	15.6	6.0	17.0	6.2	18.4	6.3	19.9	6.5
4	21.4	6.7	23.1	6.8	24.8	7.0	26.6	7.2	28.5	7.3	30.5	7.5	32.6	7.7	34.8	7.8	37.0	8.0	39.4	8.2
5	41.9	8.3	44.4	8.5	47.1	8.7	49.9	8.8	52.8	9.0	55.7	9.2	58.8	9.3	62.0	9.5	65.4	9.7	68.8	9.8
6	72.4	10.0	76.0	10.2	79.8	10.3	83.8	10.5	87.8	10.7	92.0	10.8	96.3	11.0	100.8	11.2	105.3	11.3	110.0	11.5
7	114.9	11.7	119.9	11.8	125.0	12.0	130.3	12.2	135.8	12.3	141.3	12.5	147.0	12.7	152.9	12.8	159.0	13.0	165.2	13.2
8	171.5	13.3	178.0	13.5	184.7	13.7	191.5	13.8	198.6	14.0	205.7	14.2	213.1	14.3	220.6	14.5	228.3	14.7	236.2	14.8
9	244.2	15.0	252.4	15.2	260.9	15.3	269.4	15.5	278.2	15.7	287.2	15.8	296.4	16.0	305.7	16.2	315.3	16.3	325.0	16.5
10	335.0	16.7	345.2	16.8	355.5	17.0	366.1	17.2	376.8	17.3	387.8	17.5	399.0	17.7	410.4	17.8	422.0	18.0	433.8	18.2
11	445.9	18.3	458.2	18.5	470.6	18.7	483.4	18.8	496.3	19.0	509.5	19.2	522.9	19.3	536.5	19.5	550.4	19.7	564.5	19.8
12	578.9	20.0	593.5	20.2	608.3	20.3	623.4	20.5	638.7	20.7	654.3	20.8	670.1	21.0	686.2	21.2	702.5	21.3	719.1	21.5
13	736.0	21.7	753.1	21.8	770.5	22.0	788.1	22.2	806.0	22.3	824.2	22.5	842.7	22.7	861.4	22.8	880.4	23.0	899.7	23.2
14	919.2	23.3	939.1	23.5	959.2	23.7	979.6	23.8	1000.3	24.0	1021.3	24.2	1042.6	24.3	1064.1	24.5	1086.0	24.7	1108.2	24.8

Column Units

(P1 = P2) in feet
Weight in pounds
Diam. in inches

Example

P1 = P2 = 5.6 feet
Weight = 58.8 pounds
Diam. = 9.3 inches

TABULATION SHEET FOR ROCK GRADATION

P1 + P2 (ft)	"d" (inches)	Weight per Rock (pounds)	Number of Rock	Weight Retained (pounds)	Percent Retained	Subtotal Percent Retained	Percent Passing	Specification Limit

This page reserves pages 17-WI-45 through 17-WI-50 for future supplements.