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ENGINEERING AND DESIGN
Additional Guidance for Riprap Channel Protection

1. Purpose. The purpose of this ETL is to discuss detailed factors which must be considered in the application of criteria presented in paragraph 14 of EM 1110-2-1601, "Hydraulic Design of Flood Control Channels", to the design of graded stone riprap channel protection, present additional hydraulic design guidance, and suggest a coordinated office design procedure which should be adopted.

2. Applicability. This letter is applicable to all divisions and districts having the responsibility for the design and construction of Civil Works projects.

3. Discussion.

a. Riprap Physical Characteristics - Design Phase. The stone shape *(paragraph 14c), gradation limits (paragraph 14h) and layer thickness (paragraph 14i) are riprap material parameters for which equations (33) and (34), using 0.040 for coefficient "a" indicate the ability of the riprap to resist boundary shear. The criteria are sufficiently broad to encompass the usual riprap material produced from many acceptable quarries. A grizzly or similar type processing operation may be required to obtain acceptable riprap material from some quarries. Riprap material which fails to meet the criteria for gradation limits or stone shape is not capable of resisting the same amount of shear as indicated by the value of 0.04 for "a" in equation (33). As sufficient information is not available on which to base an adjustment of "a" for such material, sufficient samples should be tested during the design stage to determine its strength, gradation, and stone-shape limits within which material can be produced without undue waste. Sample test installations should be made in varying layer thicknesses to establish the layer thickness required to produce an acceptable protective blanket, giving consideration to the following:

(1) All stones should be contained reasonably well within the layer thickness.

(2) Surface irregularities should be minimal.

*Subparagraphs and equations indicated in the text, unless otherwise noted, are found in paragraph 14, EM 1110-2-1601.

(3) If pockets of smaller stones are present, the strength of the riprap material in these pockets may be determined by using the spherical diameter of the average size stones in equation (33).

(4) A gradation which is deficient in smaller stones will have an excessively irregular surface and openings may traverse the layer from top to bottom. In this case, an increase in layer thickness and coarser bedding material which would not pass through the voids should be used. The strength of the riprap material may be determined by using a stone size diameter somewhat less than the average size, based on judgment, in equation (33).

(5) Careful examination should be made of the in place position of elongated and/or slabby stones which fail to meet the shape criteria. If these stones are well keyed rather than lying loosely on the surface and the provisions of subparagraphs (1) and (2) above are satisfactory, the material should be acceptable. Elongated and/or slabby stones which lie on the surface should not be considered as contributing to riprap strength.

(6) Other reasonable assumptions should be made based on experience and judgment. For example, if riprap material from a quarry can be correlated with previously tested and accepted materials from similar type quarries, it may be possible to establish reasonable design strength and specification requirements for the material.

In summary, the discussion in this paragraph emphasizes the need to supplement the guidance given in EM 1110-2-1601 with the considerations, outlined above, in order to specify riprap shape factors, gradation limits and layer thickness, as well as to determine riprap strength. This discussion also applies to the use of "quarry run" material for riprap protection.

b. Design Aids. Inclosures 1 through 3 are tables showing riprap gradation limits for various specific weights (SSD), layer thicknesses and design factors as follows:

(1) Inclosure 1 corresponds to design factors indicated in paragraphs 14h and i, except 14i(3).

(2) Inclosure 2 corresponds to the design factors indicated in subparagraph 14i(3).

(3) Inclosure 3 duplicates inclosure 2 except that the W_{50} maximum theoretical stone diameter is one-half the increased layer thickness and the W_{15} maximum limit is increased correspondingly. Riprap material corresponding to these gradation limits should be considered when placed in the dry at locations subject to turbulent flow

caused by energy dissipators, bridge piers and abutments, etc. This table modifies instructions contained in USWES, HDC, SHEET 712-1, Rev. 9-70.

The tables show stone weights to the nearest pound which may be rounded for design and specification purposes.

c. Riprap Physical Characteristics - Construction Stage. During construction, the riprap material should be inspected using paragraph 14m for guidance. The specifications should include provisions for sample testing by the Contractor. Payment for testing should be made only for those samples which meet the specification requirements. In spite of extreme care in the design of riprap protection, the Contractor may experience difficulty in meeting the specifications for gradation limits and/or stone shape due to particular quarry and/or production problems. If the Contracting Officer should desire to negotiate a change in the riprap specifications a careful review of the specifications, considering the additional guidance given in paragraph 3a above, should be made by District design personnel.

d. Additional Hydraulic Design Guidance. The following additional guidance, which supplements the guidance presented in EM 1110-2-1601 is applicable to the hydraulic design of riprap channel protection:

(1) Initially water surface computations involving the determination of design flow depths and velocities should be made on the basis of friction coefficients which correspond to a trial riprap installation. Appendix IV of EM 1110-2-1601 and USWES, HDC, SHEETS 631-4 and 631-4/1 describe procedures and provide design aids for determining composite channel roughness coefficients.

(2) As roughness coefficients cannot be determined precisely, somewhat low rather than high roughness values will produce conservative riprap protection. Accordingly, the effective or equivalent riprap roughness, k, corresponding to the minimum D_{50} stone size should be used in Hydraulic Design Chart 631-1 to determine roughness coefficients for use in water surface computations. Similarly, expansion, contraction, bend and other losses which are included in the water surface computations should be estimated conservatively low.

(3) Next, the design flow depths and velocities resulting from the trial riprap installation should be used in equation (32) to determine local boundary shear values. The boundary roughness should be based on the maximum limit D_{50} stone size to obtain conservative local boundary shear values for design. When velocities near the riprap boundaries are available from model tests, prototype measurements or other means, the following equation 8-13 from Chow's "Open Channel

Hydraulics", 1959 edition, may be used to determine the local boundary shear:

$$\tau_o = \gamma \left[\frac{v}{32.6 \, \mathrm{Log}_{10} \frac{30\,y}{k}} \right]^2$$

where:

τ_o = local boundary shear, lbs per sq ft

~~ρ = density, 1.94 slugs~~ γ = Sp. wt. of water in lbs per cu. ft.

v = local velocity, fps

y = depth above boundary corresponding to v

k = equivalent roughness, ft

Inclosure 4 is a graphical aid for solution of this equation.

(4) Equation (32) is based on the assumptions of fully rough flow conditions and normal logarithmic vertical velocity distribution produced by uniform channel flow. Fully rough flow conditions, in the range indicated on Hydraulic Design Chart 631, normally occur in channels which require riprap protection, but significant deviations from the normal logarithmic vertical velocity distribution occur in channels which have non-uniform cross sections, varying slopes and different bed and bank roughness coefficients. Thus, unless a uniform channel cross section with identical bed and bank riprap material occurs on a constant slope over a sufficient distance to produce uniform channel flow at normal depth and velocity, maximum local boundary shear values will be greater than indicated by equation (32), due to greater localized velocities and pressure pulsations. As the effects of contributing factors to deviations from normal logarithmic vertical velocity distribution have not been established, values of local boundary shear computed from equation (32) should be increased by a factor of 1.5, except when flow is at or near normal depth in a channel with uniform cross section and equal bed and side roughness. The local boundary shear should be increased additionally in bends as indicated in EM 1110-2-1601, Plate 34.

(5) Finally, the amount of shear that the trial riprap protection can withstand, called the riprap design shear, should be determined by equations (33) and (34) for the minimum D_{50} size stone. If the local boundary shear is within a reasonable range of being equal to this design shear, the trial riprap stone sizes are satisfactory for design. However, if the local boundary shear is appreciably greater or less

than the design shear, then the computations should be repeated for a second trial riprap installation, with the stone sizes being greater or smaller, respectively, than the sizes used in the first trial computations. The trial-and-error computations should be repeated until local boundary and design shears are reasonably equal and further refinements would not result in a significant change in stone sizes and riprap layer thickness. Trial-and-error stone sizes should correspond to 3-inch modules in riprap layer thickness, such as 12, 15, 18, 21, etc. inches.

4. Suggested District Office Procedure. OCE review of the design of riprap protection, submitted in accordance with EM 1110-2-1601 guidance, has in some instances indicated that proper distribution of the design effort between engineering disciplines was not accomplished. In general, the following procedure should be adopted:

(1) Hydraulic design personnel should make sufficient preliminary hydraulic computations and analyses to determine areas which may require riprap protection and establish preliminary riprap material requirements.

(2) Foundation and materials personnel should assess the physical characteristics of available material, as discussed in subparagraph 3a above.

(3) Hydraulic design personnel should check the adequacy of the available material for use in providing the required riprap protection.

(4) Finally, a coordinated review of the riprap design should be made by both hydraulic design and foundation and materials personnel and modifications accomplished in the riprap design where indicated.

5. Design Example. A trapezoidal channel with 50 ft bottom width and 1 on 2.5 side slopes for a design discharge of 7,500 cfs is to be provided in natural sand and gravel materials having an estimated effective roughness range of 0.5 to 0.8 ft. As a first trial, it is assumed that the sides only will be riprapped and the following riprap material (Sp. wt. = 165 lbs per cu ft SSD) will be placed in an 18 inch layer.

PERCENT LIGHTER BY WEIGHT (SSD)	LIMITS OF STONE WEIGHT-LBS
100	290 - 120
50	90 - 60
15	50 - 20

From EM 1110-2-1601, Plate 30, the D_{50} size of the trial riprap material ranges from 0.88 to 1.0 ft. Friction coefficients for use in the water surface computations should be determined for the range of expected design depths by the procedures described in EM 1110-2-1601, Appendix IV. Inclosure 5 illustrates the computational procedure for the determination of the friction coefficient based on boundary roughness for a 10 ft depth. Assuming that the water surface computations, based on the determined friction coefficients and conservative estimates of other losses, result in a depth of 10 ft for the design discharge of 7,500 cfs, the corresponding average velocity in the channel section is 10 fps. As the channel bed is smoother than the riprapped sides, the average velocity in that part of the channel section vertically above the bed, which will be greater than the average velocity in the entire section, should be used in determining the local boundary shear at the toe of the riprap revetment. The computations in Inclosure 5 indicate that this velocity is 11.5 fps. From equation (32) and Plate 32 for the maximum D_{50} stone size equal to 1.0 ft and applying the 1.5 non-uniform flow factor, the local boundary shear at the toe of the riprap revetment is computed as follows:

$$y/D_{50} = 10/1 = 10 \text{ and } K_2 = 0.0135$$

$$\tau_o = 1.5 \times 0.0135 \times (11.5)^2 = 2.68 \text{ lbs per sq ft}$$

The design shear, using the minimum D_{50} stone size = 0.88 ft, for the trial riprap gradation, as determined from Plates 35 and 36, is:

$$\tau = 3.60 \text{ lbs for sq ft and } K_1 = 0.82$$

$$\tau' = 0.82 \times 3.60 = 2.95 \text{ lbs per sq ft}$$

As the design shear exceeds the local boundary shear by a significant amount, the possibility of using a 15-inch riprap layer thickness should be checked. In accordance with paragraphs 14h and i of EM 1110-2-1601, the 15-inch layer thickness would require the following riprap gradation:

PERCENT LIGHTER BY WEIGHT (SSD)	LIMITS OF STONE WEIGHT-LBS
100	170 - 70
50	50 - 35
15	25 - 10

For this gradation, the minimum D_{50} stone size is 0.74 ft and the corresponding design shear is 0.82 x 3.0 = 2.46 lbs per sq ft. As this value is less than the local boundary shear determined for the first trial riprap gradation and the smaller size stone in the 15-inch layer

would result in the local boundary shear being increased somewhat, the 18-inch layer thickness and first trial riprap gradation should be adopted. If by model measurement or otherwise it is known that a velocity of 10 fps will occur 1.0 ft above the riprap toe, then from Inclosure 4, the local boundary shear equals 2.70 lbs per sq ft. Thus, the 18-inch riprap layer is satisfactory as the design shear for the corresponding riprap gradation is 2.68 lbs per sq ft.

6. Requested Actions. In general, as evidenced by inordinate emergency repair costs after major floods in some riprap protected channels, the design, specifications, construction and inspection of riprap protection needs to be upgraded. The design of riprap protection resulting from the guidance contained in EM 1110-2-1601 and this ETL should always be reviewed in the light of experience and judgment gained with riprap protection projects in particular areas. In arriving at experience and judgment conclusions, careful consideration should be given to whether or not design flow conditions have occurred in the channel protection projects. In design memoranda, letter reports and other media, design considerations and computations should be presented in sufficient detail to reflect compliance with EM 1110-2-1601 and ETL guidance or use of procedures which have been proven by long-time experience to provide adequate riprap protection in particular localities. If procedures which differ from those presented in EM 1110-2-1601 and the ETL are used, the riprap design should be checked against EM 1110-2-1601 and ETL guidance, and the results of this comparison should be presented. If significant differences occur, revisions should be made in the design as experience, judgment and ETL considerations dictate. Surveillance provisions, as discussed in EM 1110-2-1601, paragraph 14n, which will be made during project construction should also be presented in design memoranda, letter reports, etc.

FOR THE CHIEF OF ENGINEERS:

Homer B. Willis

5 Incls
As stated

JOSEPH M. CALDWELL
for Chief, Engineering Division
Civil Works Directorate

SPECIFIC WEIGHT = 145 LBS/CU FT T=1.0'D(100)MAX;1.50D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNES =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	76	30	148	59	256	102	407	163
50	22	15	44	30	76	51	121	81
15	11	5	22	9	38	16	60	25
THICKNES =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	607	243	865	346	1186	475	1579	632
50	180	121	256	173	351	237	468	316
15	90	38	128	54	176	74	234	99
THICKNES =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	2050	820	3255	1302	4859	1944	6918	2767
50	607	410	964	651	1440	972	2050	1384
15	304	128	482	203	720	304	1025	432

SPECIFIC WEIGHT = 150 LBS/CU FT T=1.0'D(100)MAX;1.50D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNES =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	79	31	153	61	265	106	421	168
50	23	16	45	31	79	53	125	84
15	12	5	23	10	39	17	62	26
THICKNES =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	628	251	895	358	1227	491	1633	653
50	186	126	265	179	364	245	484	327
15	93	39	133	56	182	77	242	102
THICKNES =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	2121	848	3367	1347	5027	2011	7157	2863
50	628	424	998	673	1489	1005	2121	1431
15	314	133	499	210	745	314	1060	447

SPECIFIC WEIGHT = 155 LBS/CU FT T=1.00D(100)MAX;1.50D(50)MAX

LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
10	81	32	159	63	274	110	435	174
15	24	16	47	32	81	55	129	87
15	12	5	23	10	41	17	64	27
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
10	649	260	924	370	1268	507	1688	675
15	192	130	274	185	376	254	500	338
15	96	41	137	58	189	79	250	105
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
10	2191	87[illegible]	3480	1392	5194	2078	7396	2958
15	649	438	1031	696	1539	1039	2191	1479
15	325	137	516	217	769	325	1096	462

SPECIFIC WEIGHT = 160 LBS/CU FT T=1.00D(100)MAX;1.50D(50)MAX

LIGHTER WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNES =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
10	84	34	164	65	283	113	449	180
15	25	17	48	33	84	57	133	90
15	12	5	24	10	42	18	67	28
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
10	670	268	954	382	1309	524	1742	697
15	199	134	283	191	388	262	516	348
15	99	42	141	60	194	82	258	109
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
10	2 62	905	3592	1437	5362	2145	7634	3054
15	670	45[illegible]	1064	718	1589	1072	2262	1527
15	335	141	532	224	794	335	1131	477

SPECIFIC WEIGHT = 165 LBS/CU FT T=1.00D(100)MAX;1.50D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	86	35	169	67	292	117	463	185
50	26	17	50	34	86	58	137	93
15	13	5	25	11	43	18	69	29
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	691	276	984	394	1350	540	1797	719
50	205	138	292	197	400	270	532	359
15	102	43	146	62	200	84	266	112
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	2333	933	3704	1482	5529	2212	7873	3149
50	691	467	1098	741	1638	1106	2333	1575
15	346	146	549	232	819	346	1166	492

SPECIFIC WEIGHT = 170 LBS/CU FT T=1.00D(100)MAX;1.50D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNE =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	89	36	174	70	300	120	477	191
50	26	18	52	35	89	60	141	95
15	13	6	26	11	45	19	71	30
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	712	285	1014	406	1391	556	1851	740
50	211	142	300	203	412	278	548	370
15	105	45	150	63	206	87	274	116
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	2403	961	3816	1527	5697	2279	8111	3244
50	712	481	1131	763	1688	1139	2403	1622
15	356	150	565	239	844	356	1202	507

SPECIFIC WEIGHT = 175 LBS/CU FT T=1.00D(100)MAX;1.50D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	92	37	179	72	309	124	491	196
50	27	18	53	36	92	62	146	98
15	14	6	27	11	46	19	73	31
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	733	293	1044	417	1432	573	1906	762
50	217	147	309	209	424	286	565	381
15	109	46	155	65	212	89	282	119
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	2474	990	3929	1571	5864	2346	8350	3340
50	733	495	1164	786	1738	1173	2474	1670
15	367	155	582	246	869	367	1237	522

SPECIFIC WEIGHT = 180 LBS/CU FT T=1.00D(100)MAX;1.50D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	94	38	184	74	318	127	505	202
50	28	19	55	37	94	64	150	101
15	14	6	27	12	47	20	75	32
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	754	302	1074	429	1473	589	1960	784
50	223	151	318	215	436	295	581	392
15	112	47	159	67	218	92	290	123
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	2545	1018	4041	1616	6032	2413	8588	3435
50	754	509	1197	808	1787	1206	2545	1718
15	377	159	599	253	894	377	1272	537

SPECIFIC WEIGHT = 185 LBS/CU FT T=1.00D(100)MAX;1.50D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
10	97	39	189	76	327	131	519	208
50	29	19	56	38	97	65	154	104
15	14	6	28	12	48	20	77	32
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
10	775	310	1103	441	1514	605	2015	806
50	230	155	327	221	448	303	597	403
15	115	48	163	69	224	95	298	126
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
10	2615	1046	4153	1661	6199	2480	8827	3531
50	775	523	1231	831	1837	1240	2615	1765
15	387	163	615	260	918	387	1308	552

SPECIFIC WEIGHT = 190 LBS/CU FT T=1.00D(100)MAX;1.50D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
10	99	40	194	78	336	134	533	213
50	29	20	58	39	99	67	158	107
15	15	6	29	12	50	21	79	33
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
10	796	318	1133	453	1554	622	2069	828
50	236	159	336	227	461	311	613	414
15	118	50	168	71	230	97	307	129
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
10	2686	1074	4265	1706	6367	2547	9065	3626
50	796	537	1264	853	1887	1273	2686	1813
15	398	168	632	267	943	398	1343	567

SPECIFIC WEIGHT = 195 LBS/CU FT T=1.00D(100)MAX;1.50D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
10	102	41	199	80	345	138	547	219
50	30	20	59	40	102	69	162	109
15	15	6	30	12	51	22	81	34
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
10	817	327	1163	465	1595	638	2123	849
50	242	163	345	233	473	319	629	425
15	121	51	172	73	236	100	315	133
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
10	2757	1103	4378	1751	6535	2614	9304	3722
50	817	551	1297	876	1936	1307	2757	1861
15	408	172	649	274	968	408	1378	582

SPECIFIC WEIGHT = 200 LBS/CU FT T=1.00D(100)MAX;1.50D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
10	105	42	205	82	353	141	561	224
50	31	21	61	41	105	71	166	112
15	16	7	30	13	52	22	83	35
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
10	838	335	1193	477	1636	654	2178	871
50	248	168	353	239	485	327	645	436
15	124	52	177	75	242	102	323	136
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
10	2827	1131	4490	1796	6702	2681	9543	3817
50	838	565	1330	898	1986	1340	2827	1909
15	419	177	665	281	993	419	1414	596

SPECIFIC WEIGHT = 205 LBS/CU FT-RT=1.00D(100)MAX;1.50D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	107	43	210	84	362	145	575	230
50	32	21	62	42	107	72	170	115
15	16	7	31	13	54	23	85	36
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	859	343	1223	489	1677	671	2232	893
50	254	172	362	245	497	335	661	446
15	127	54	181	76	248	105	331	140
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	2898	1159	4602	1841	6870	2748	9781	3912
50	859	580	1364	920	2035	1374	2898	1956
15	429	181	682	288	1018	429	1449	611

SPECIFIC WEIGHT = 145 LBS/CU FT T=1.50D(100)MAX;2.25D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	22	9	44	18	76	30	121	48
50	7	4	13	9	22	15	36	24
15	3	1	7	3	11	5	18	8
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	180	72	256	102	351	141	468	187
50	53	36	76	51	104	70	139	94
15	27	11	38	16	52	22	69	29
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	607	243	964	386	1440	576	2050	820
50	180	121	286	193	427	288	607	410
15	90	38	143	60	213	90	304	128

SPECIFIC WEIGHT = 150 LBS/CU FT T=1.50D(100)MAX;2.25D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	23	9	45	18	79	31	125	50
50	7	5	13	9	23	16	37	25
15	3	1	7	3	12	5	18	8
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	186	74	265	106	364	145	484	194
50	55	37	79	53	108	73	143	97
15	28	12	39	17	54	23	72	30
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	628	251	998	399	1489	596	2121	848
50	186	126	296	200	441	298	628	424
15	93	39	148	62	221	93	314	133

SPECIFIC WEIGHT = 155 LBS/CU FT T=1.50D(100)MAX;2.25D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	24	10	47	19	81	32	129	52
50	7	5	14	9	24	16	38	26
15	4	2	7	3	12	5	19	8
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	192	77	274	110	376	150	500	200
50	57	38	81	55	111	75	148	100
15	28	12	41	17	56	23	74	31
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	649	260	1031	412	1539	616	2191	877
50	192	130	305	206	456	308	640	438
15	96	41	153	64	228	96	325	137

SPECIFIC WEIGHT = 160 LBS/CU FT T=1.50D(100)MAX;2.25D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	25	10	48	19	84	34	133	53
50	7	5	14	10	25	17	39	27
15	4	2	7	3	12	5	20	8
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	199	79	283	113	388	155	516	206
50	59	40	84	57	115	78	153	103
15	29	12	42	18	57	24	76	32
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	670	268	1064	426	1589	635	2262	905
50	199	134	315	213	471	318	670	452
15	99	42	158	67	235	99	335	141

SPECIFIC WEIGHT = 165 LBS/CU FT T=1.50D(100)MAX;2.25D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	26	10	50	20	86	35	137	55
50	8	5	15	10	26	17	41	27
15	4	2	7	3	13	5	20	9
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	205	82	292	117	400	160	532	213
50	61	41	86	58	119	80	158	106
15	30	13	43	18	59	25	79	33
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	691	276	1098	439	1638	655	2333	933
50	205	138	325	220	485	328	691	467
15	102	43	163	69	243	102	346	146

SPECIFIC WEIGHT = 170 LBS/CU FT T=1.50D(100)MAX;2.25D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	26	11	52	21	89	36	141	57
50	8	5	15	10	26	18	42	28
15	4	2	8	3	13	6	21	9
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	211	84	300	120	412	165	548	219
50	63	42	89	60	122	82	163	110
15	31	13	45	19	61	26	81	34
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	712	285	1131	452	1688	675	2403	961
50	211	142	335	226	500	338	712	481
15	105	45	168	71	250	105	356	150

SPECIFIC WEIGHT = 175 LBS/CU FT T=1.50D(100)MAX;2.25D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	27	11	53	21	92	37	146	58
50	8	5	16	11	27	18	43	29
15	4	2	8	3	14	6	22	9
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	217	87	309	124	424	170	565	226
50	64	43	92	62	126	85	167	113
15	32	14	46	19	63	27	84	35
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	733	293	1164	466	1738	695	2474	990
50	217	147	345	233	515	348	733	495
15	109	46	172	73	257	109	367	155

SPECIFIC WEIGHT = 180 LBS/CU FT T=1.50D(100)MAX;2.25D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	28	11	55	22	94	38	150	60
50	8	6	16	11	28	19	44	30
15	4	2	8	3	14	6	22	9
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	223	89	318	127	436	175	581	232
50	66	45	94	64	129	87	172	116
15	33	14	47	20	65	27	86	36
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	754	302	1197	479	1787	715	2545	1018
50	223	151	355	239	530	357	754	509
15	112	47	177	75	265	112	377	159

SPECIFIC WEIGHT = 185 LBS/CU FT T=1.50D(100)MAX;2.25D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	29	11	56	22	97	39	154	62
50	9	6	17	11	29	19	46	31
15	4	2	8	4	14	6	23	10
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	230	92	327	131	448	179	597	239
50	68	46	97	65	133	90	177	119
15	34	14	48	20	66	28	88	37
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	775	310	1231	492	1837	735	2615	1046
50	230	155	365	246	544	367	775	523
15	115	48	182	77	272	115	387	163

SPECIFIC WEIGHT = 190 LBS/CU FT T=1.50D(100)MAX;2.25D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	29	12	58	23	99	40	158	63
50	9	6	17	12	29	20	47	32
15	4	2	9	4	15	6	23	10
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	236	94	336	134	461	184	613	245
50	70	47	99	67	136	92	182	123
15	35	15	50	21	68	29	91	38
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	796	318	1264	506	1887	755	2686	1074
50	236	159	374	253	559	377	796	537
15	118	50	187	79	279	118	398	168

14 May 1971

SPECIFIC WEIGHT = 195 LBS/CU FT T=1.50D(100)MAX;2.25D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	30	12	59	24	102	41	162	65
50	9	6	18	12	30	20	48	32
15	4	2	9	4	15	6	24	10
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	242	97	345	138	473	189	629	252
50	72	48	102	69	140	95	186	126
15	36	15	51	22	70	30	93	39
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	817	327	1297	519	1936	774	2757	1103
50	242	163	384	259	574	387	817	551
15	121	51	192	81	287	121	408	172

SPECIFIC WEIGHT = 200 LBS/CU FT T=1.50D(100)MAX;2.25D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	31	12	61	24	105	42	166	67
50	9	6	18	12	31	21	49	33
15	5	2	9	4	16	7	25	10
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	248	99	353	141	485	194	645	258
50	74	50	105	71	144	97	191	129
15	37	16	52	22	72	30	96	40
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	838	335	1330	532	1986	794	2827	1131
50	248	168	394	266	588	397	838	565
15	124	52	197	83	294	124	419	177

SPECIFIC WEIGHT = 205 LBS/CU FT T=1.50D(100)MAX;2.25D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	32	13	62	25	107	43	170	68
50	9	6	18	12	32	21	51	34
15	5	2	9	4	16	7	25	11
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	254	102	362	145	497	199	661	265
50	75	51	107	72	147	99	196	132
15	38	16	54	23	74	31	98	41
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	859	343	1364	545	2035	814	2898	1159
50	254	172	404	273	603	407	859	580
15	127	54	202	85	302	127	429	181

SPECIFIC WEIGHT = 145 LBS/CU FT T=1.50D(100)MAX;2.00D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	22	9	44	18	76	30	121	48
50	9	4	19	9	32	15	51	24
15	5	1	9	3	16	5	25	8
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	180	72	256	102	351	141	468	187
50	76	36	108	51	148	70	197	94
15	38	11	54	16	74	22	99	29
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	607	243	964	386	1440	576	2050	820
50	256	121	407	193	607	288	865	410
15	128	38	203	60	304	90	432	128

SPECIFIC WEIGHT = 150 LBS/CU FT T=1.50D(100)MAX;2.00D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	23	9	45	18	79	31	125	50
50	10	5	19	9	33	16	53	25
15	5	1	10	3	17	5	26	8
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	186	74	265	106	364	145	484	194
50	79	37	112	53	153	73	204	97
15	39	12	56	17	77	23	102	30
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	628	251	998	399	1489	596	2121	848
50	265	126	421	200	628	298	895	424
15	133	39	210	62	314	93	447	133

SPECIFIC WEIGHT = 155 LBS/CU FT T=1.50D(100)MAX;2.00D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	24	10	47	19	81	32	129	52
50	10	5	20	9	34	16	54	26
15	5	2	10	3	17	5	27	8
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	192	77	274	110	376	150	500	200
50	81	38	116	55	159	75	211	100
15	41	12	58	17	79	23	105	31
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	649	260	1031	412	1539	616	2191	877
50	274	130	435	206	649	308	924	438
15	137	41	217	64	325	96	462	137

SPECIFIC WEIGHT = 160 LBS/CU FT T=1.50D(100)MAX;2.00D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	25	10	48	19	84	34	133	53
50	10	5	20	10	35	17	56	27
15	5	2	10	3	18	5	28	8
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	199	79	283	113	388	155	516	206
50	84	40	119	57	164	78	218	103
15	42	12	60	18	82	24	109	32
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	670	268	1064	426	1589	635	2262	905
50	283	134	449	213	670	318	954	452
15	141	42	224	67	335	99	477	141

SPECIFIC WEIGHT = 165 LBS/CU FT T=1.50D(100)MAX;2.00D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	26	10	50	20	86	35	137	55
50	11	5	21	10	36	17	58	27
15	5	2	11	3	18	5	29	9
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	205	82	292	117	400	160	532	213
50	86	41	123	58	169	80	225	106
15	43	13	62	18	84	25	112	33
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	691	276	1098	439	1638	655	2333	933
50	292	138	463	220	691	328	984	467
15	146	43	232	69	346	102	492	146

SPECIFIC WEIGHT = 170 LBS/CU FT T=1.50D(100)MAX;2.00D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	26	11	52	21	89	36	141	57
50	11	5	22	10	38	18	60	28
15	6	2	11	3	19	6	30	9
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	211	84	300	120	412	165	548	219
50	89	42	127	60	174	82	231	110
15	45	13	63	19	87	26	116	34
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	712	285	1131	452	1688	675	2403	961
50	300	142	477	226	712	338	1014	481
15	150	45	239	71	356	105	507	150

SPECIFIC WEIGHT = 175 LBS/CU FT T=1.50D(100)MAX;2.00D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	27	11	53	21	92	37	146	58
50	11	5	22	11	39	18	61	29
15	6	2	11	3	19	6	31	9
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	217	87	309	124	424	170	565	226
50	92	43	130	62	179	85	238	113
15	46	14	65	19	89	27	119	35
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	733	293	1164	466	1738	695	2474	990
50	309	147	491	233	733	348	1044	495
15	155	46	246	73	367	109	522	155

SPECIFIC WEIGHT = 180 LBS/CU FT T=1.50D(100)MAX;2.00D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	28	11	55	22	94	38	150	60
50	12	6	23	11	40	19	63	30
15	6	2	12	3	20	6	32	9
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	223	89	318	127	436	175	581	232
50	94	45	134	64	184	87	245	116
15	47	14	67	20	92	27	123	36
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	754	302	1197	479	1787	715	2545	1018
50	318	151	505	239	754	357	1074	509
15	159	47	253	75	377	112	537	159

SPECIFIC WEIGHT = 185 LBS/CU FT T=1.50D(100)MAX;2.00D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	29	11	56	22	97	39	154	62
50	12	6	24	11	41	19	65	31
15	6	2	12	4	20	6	32	10
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	230	92	327	131	448	179	597	239
50	97	46	138	65	189	90	252	119
15	48	14	69	20	95	28	126	37
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	775	310	1231	492	1837	735	2615	1046
50	327	155	519	246	775	367	1103	523
15	163	48	260	77	387	115	552	163

SPECIFIC WEIGHT = 190 LBS/CU FT T=1.50D(100)MAX;2.00D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	29	12	58	23	99	40	158	63
50	12	6	24	12	42	20	67	32
15	6	2	12	4	21	6	33	10
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	236	94	336	134	461	184	613	245
50	99	47	142	67	194	92	259	123
15	50	15	71	21	97	29	129	38
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	796	318	1264	506	1887	755	2686	1074
50	336	159	533	253	796	377	1133	537
15	168	50	267	79	398	118	567	168

SPECIFIC WEIGHT = 195 LBS/CU FT T=1.50D(100)MAX;2.00D(50)MAX

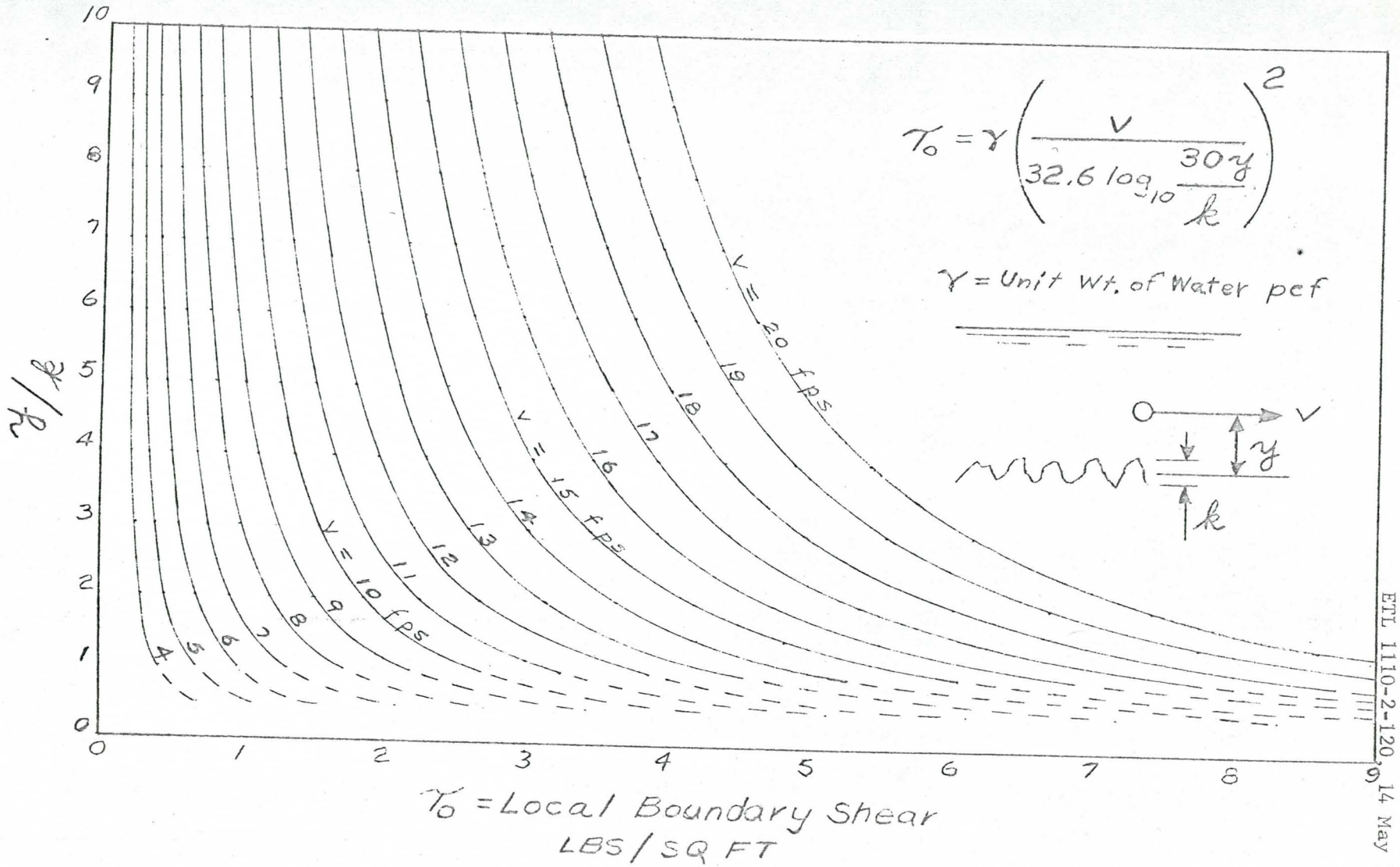
% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	30	12	59	24	102	41	162	65
50	13	6	25	12	43	20	68	32
15	6	2	12	4	22	6	34	10
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	242	97	345	138	473	189	629	252
50	102	48	145	69	199	95	265	126
15	51	15	73	22	100	30	133	39
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	817	327	1297	519	1936	774	2757	1103
50	345	163	547	259	817	387	1163	551
15	172	51	274	81	408	121	582	172

SPECIFIC WEIGHT = 200 LBS/CU FT T=1.50D(100)MAX;2.00D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	31	12	61	24	105	42	166	67
50	13	6	26	12	44	21	70	33
15	7	2	13	4	22	7	35	10
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	248	99	353	141	485	194	645	258
50	105	50	149	71	205	97	272	129
15	52	16	75	22	102	30	136	40
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	838	335	1330	532	1986	794	2827	1131
50	353	168	561	266	838	397	1193	565
15	177	52	281	83	419	124	596	177

SPECIFIC WEIGHT = 205 LBS/CU FT T=1.50D(100)MAX;2.00D(50)MAX

% LIGHTER BY WEIGHT	LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS		LIMITS OF STONE WEIGHT IN POUNDS	
THICKNESS =	12 INCHES		15 INCHES		18 INCHES		21 INCHES	
100	32	13	62	25	107	43	170	68
50	13	6	26	12	45	21	72	34
15	7	2	13	4	23	7	36	11
THICKNESS =	24 INCHES		27 INCHES		30 INCHES		33 INCHES	
100	254	102	362	145	497	199	661	265
50	107	51	153	72	210	99	279	132
15	54	16	76	23	105	31	140	41
THICKNESS =	36 INCHES		42 INCHES		48 INCHES		54 INCHES	
100	859	343	1364	545	2035	814	2898	1159
50	362	172	575	273	859	407	1223	580
15	181	54	288	85	429	127	611	181


$\tau_0 = \gamma \left(\frac{V}{32.6 \log_{10} \frac{30y}{k}} \right)^2$
γ = Unit Wt. of Water pcf
V
y
k
V = 20 fps
19
18
17
16
V = 15 fps
14
13
12
11
V = 10 fps
9
8
7
6
5
4
y/k
0
1
2
3
4
5
6
7
8
9
10
τ_0 = Local Boundary Shear
LBS / SQ FT

S B Powell

Ref. App. IV, EM 1110-2-1601 "HYDRAULIC DESIGN OF FLOOD CONTROL CHANNELS"

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Project	Sect. No.	Water Surface Elevation	Distance X From Base Line	Bottom Elevation	Depth Y in Feet	ΔX	ΔY	A_x	WP_x	R_x	Subsection k or D_{50}	Subsection C_x (Chart A1)	$(CR^{\frac{1}{2}})_x$	$(CR^{\frac{1}{2}})_x A_x$ X10^{-3}	$(CR^{\frac{1}{2}})^3_x A_x$ X10^{-9}	$R_x (CR^{\frac{1}{2}})_x A_x$ X10^{-6}
		10	0	10	0											
						12.5	5	31.25	13.45	2.32	.88	49	74.5	2.33	.013	.005
		10	12.5	5	5											
						12.5	5	93.8	13.45	6.97	.88	65	172	16.1	.477	.112
		10	25	0	10											
						50	0	500	50	10	.50	78	247	123.5	7.535	1.235
		10	75	0	10											
						12.5	5	93.8	13.45	6.97	.88	65	172	16.1	.477	.112
		10	87.5	5	5											
						12.5	5	31.25	13.45	2.32	.88	49	74.5	2.33	.013	.005
		10	100	10	0											
							$\Sigma =$	750						160.4	8.515	1.469

FOR X = 25 to 75

& Q = 7,500 CFS

$$Q_x = \frac{7500 \times 123.5 \times 10^3}{160.4 \times 10^3} = 5,760 \text{ CFS}$$

$$V_x = 5,760 / 500 = 11.5 \text{ fps}$$

$$R(\text{mean}) = \frac{\Sigma(17)}{\Sigma(15)} = \frac{1.469 \times 10^6}{160.4 \times 10^3} = 9.15$$

$$(C\sqrt{R})\text{mean} = \frac{\Sigma(15)}{\Sigma(9)} = \frac{160.4 \times 10^3}{750} = 214$$

$$\text{CHEZY } C = 214 / \sqrt{9.15} = 71$$

$$\text{MANNING'S } n = \frac{1.486\, R(\text{mean})^{1/6}}{C} = \frac{1.486 \times 1.447}{71} = 0.032$$