WEIGHT, SWELL, VOLUME OF MATERIALS

Table compiled from many sources provides useful information on how the weight per cu. yd. of materials changes with excavation and compaction.

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For 100 years, authoritative sources in America have been publishing tables on the characteristics of materials. Generally, these tables include specific gravities, weights in natural bed, swell factors from natural bed or cut to loose condition, weights in loose condition, swell and shrinkage factors from natural bed or cut to uncompacted and compacted embankments or fills, and weights in uncompacted and compacted embankments or fills.

Engineering organizations both public and private contractors, mining companies, machinery manufacturers, and writers of handbooks have contributed to this array of data.

However, these tables lack completeness, uniformity of treatment, and modernity because of today's excavation and embankment construction methods. California, for example, is letting contracts in terms of tons instead of yards of excavation, thereby calling for a knowledge of weights per cubic yard, bank-measure of materials in natural bed.

The writer has been unable to find a single all-inclusive table giving the desired characteristics of the common materials encountered in construction. The accompanying table is a summary of existing tables commencing with Trautwine's pioneering work in his "Civil Engineer's Pocketbook" of 1882 and ending with personal data gathered during the past thirty years.

The table is necessarily based on properly interpreted and weighed averages. It is therefore not absolute for a specific case. Engineering experience and judgement will guide the user in its proper application. The following explanatory notes apply:

Cubic yards in cut, loose and in the fill.

Weight is in natural bed and contains natural moisture. The average weight is subject to about plus or minus 5% variation.

Percent swell from natural bed to loose condition is an average subject to about plus or minus 33% variation in both earthy and rock materials. Variations are multipliers and are not percentages to be added to or subtracted from the factors. The swell factor of 67%, given for several rocks, is an average figure obtained from existing data for solid rock, and it has been applied to solidly bedded rocks for which no swell factors are available specifically.

Weights in the loose condition are averages, except when calculated on the basis of the average 67% swell factor. All weights are subject to any adjusted value of swell factor.

Percent swell or shrink from natural bed to fill is an average, subject to about plus or minus 33% variation for earthy materials, and 33% variation for rock materials. Percentage is a multiplier.

In the case of rock materials, it is essential to distinguish between two methods of fill construction.

1. Natural or gravity compaction. This method, common years ago, is little used presently except in private construction as in the case of waste fills. The swell and shrinkage factors from natural bed to fill vary from -10% for earthy materials to +67% for rock materials. Because of different degrees of fragmentation from cut to fill and because of the wide latitude of fill construction methods in natural or gravity compaction, no figures are tabulated.

2. Mechanical compaction by rolling and wetting is today's accepted method, and swell and shrinkage factors and weights are tabulated for today's methods of full compaction.

Two other influences affect factors and resultant weights. First, tractor-mounted rippers are producing better fragmentation and better grading of both earthy and rock formations. Second, the average so-called rock job really consists of an earth-rock mixture which in itself is pretty well graded.

These three factors, nature of material, use of rippers, and modern compaction methods, have made possible the prevalent high densities of fill, densities not in accordance with hitherto tabulated data on swell and shrinkage factors. The writer has used swell and shrinkage factors and weights, including moisture, resulting from average compaction methods.

It is a fact that certain friable rocks in weathered and parent rock zones have low swell factors from cut to fill. These rocks are really equivalent to rock-earth mixtures in their behavior. Rock swell factors are in terms of solid natural bed formations, and do not include allowances for overlain residual and weathered deposits or earthy and friable materials, which would reduce greatly the swell factors from cut to fill.

CHARACTERISTICS OF WESTERN MATERIALS

Material	In Place	Loose		In Fill	
	lb./c.y.	Swell %	lb./c.y.	Shrink or Swell %	lb./c.y.
Adobe	3,230	50	2,140	-10	3,570
Andesite	4,950	67	2,970	43	3,460
Asbestos	4,040	67	2,420		
Ashes, coal	1,030	33	800		
Asphaltum	2,150	67	1,390		
Asphalt rock	4,050	62	2,500		
Aragonite					
Calcium ore	5,050	67	3,020		
Argentite					
Silver ore	12,300	67	7,360		
Barite					
Barium ore	7,560	67	4,520		
Basalt	4,950	64	3,020	36	3,640
Bauxite					
Aluminum ore	4,420	50	2,940		
Bentonite	2,700	35	2,000		
Biotite					
Mica ore	4,850	67	2,900		
Borax	2,920	75	1,670		
Breccia	4.050	33	3,040	27	3,190
Calcite					
Calcium ore	4,500	67	2,700		
Caliche	2,430	16	2,100	-25	3,200
Carnotite					
Uranium ore	4,150	50	2,770		
Cement			2,700		
Cerrusite					
Lead ore	10,970	67	6,560		
Chalcocite					
Copper ore	9,600	67	5,750		
Chalcopyrite					
Copper ore	7,060	67	4,220		
Chalk	4,060	50	2,710	33	3,050
Charcoal			1,030		
Chat					
Mine tailings			2,700		
Cinders	1,280	33	960	-10	1,420
Cinnabar					
Mercury ore	13,630	67	8,170		
Clay					
Dry	3,220	50	2,150	-10	3,570
Damp	3,350	67	2,010	-10	3,720
Clinker			2,570		

CHARACTERISTICS OF WESTERN MATERIALS
(Continued)

Material	In Place	Loose		In Fill	
	lb./c.y.	Swell %	lb./c.y.	Shrink or Swell %	lb./c.y.
Colemanite					
Borax ore	2,920	75	1,670		
Concrete					
Stone	3,960	72	2,310	43	2,770
Cyclopean	4,180	72	2,430	43	2,930
Cinder	2,970	72	1,730	43	2,080
Conglomerate	3,720	33	2,800		
Decomposed rock					
75% R. 25% E.	4,120	31	3,140	12	3,680
50% R. 50% E.	3,750	38	2,710	-6	4,000
25% R. 75% E.	3,380	43	2,370	-9	3,720
Diabase	5,050	67	3,010	43	3,530
Diorite	5,220	67	3,130	43	3,650
Diatomite					
Diotomaceous earth	1,470	62	910		
Dolomite	4,870	67	2,910	43	3,400
ırth, loam					
Dry	3,030	50	2,070	-12	3,520
Damp	3,370	43	2,360	-4	3,520
Wet, mud	2,940	0	2,940	-20	3,520
Earth, rock mixtures					
75% E. 25% R.	3,380	43	2,370	-9	3,720
50% E. 50% R.	3,750	38	2,710	-6	4,000
25% E. 75% R.	4,120	31	3,140	12	3,680
Feldspar	4,410	67	2,640	43	3,080
Gabbro	5,220	67	3,130	43	3,650
Galena					
Lead ore	12,630	67	7,570		
Gneiss	4,550	67	2,720	43	3,180
Gravel					
Dry					
Bad Gradation	2,980	10	2,700	-5	3,150
Average G.	3,280	20	2,730	-8	3,570
Good G.	3,680	33	2,770	-11	4,130
Wet					
Bad G.	3,310	5	3,150	-5	3,150
Average G.	3,640	10	3,290	-2	3,570
Good G.	4,090	16	3,520	1	4,130
Granite	4,540	72	2,640	43	3,170
Gumbo					
Dry	3,230	50	2,150	-10	3,570
Wet	3,350	67	2,020	-10	3,720

CHARACTERISTICS OF WESTERN MATERIALS
(Continued)

Material	In Place	Loose		In Fill	
	lb./c.y.	Swell %	lb./c.y.	Shrink or Swell %	lb./c.y.
Gypsum	4,080	72	2,380		
Hematite					
Iron ore	8,560	75	4,880		
Hessite					
Silver ore	14,300	67	8,560		
Ice	1,560	67	930		
Limonite					
Titanium ore	8,000	69	4,730		
Kaolinite					
Dry	3,230	50	2,150		
Wet	3,350	67	2,010		
Lignite	2,100	65	1,270		
Lime			2,220		
Limestone	4,380	63	2,690	36	3,220
Limonite					
Iron ore	6,400	55	4,140		
Loam, earth					
Dry	3,090	50	2,070	-12	3,520
Damp	3,370	43	2,360	-4	3,520
Wet, mud	2,940	0	2,940	-20	3,520
Loess					
Dry	3,220	50	2,150	-10	3,570
Wet	3,350	67	2,010	-10	3,720
Magnesite					
Magnesium ore	5,050	50	3,360		
Magnetite					
Iron ore	8,470	54	5,520		
Marble	4,520	67	2,700	43	3,160
Marl	2,740	67	2,240	43	2,620
Masonry, rubble	3,920	67	2,350	43	2,750
Millerite					
Nickel ore	9,530	67	5,710		
Molybdenite					
Molybdenum ore	7,910	67	4,750		
Mud	2,940	0	2,940	-20	3,520
Muscovite					
Mica ore	4,860	67	2,910		
Niccolite					
Nickel ore	12,600	67	7,550		
Pavement					
Asphalt	3,240	50	1,940	0	3,240
Brick	4,050	67	2,430	43	2,840
Concrete	3,960	67	2,370	43	2,770
Macadam	2,840	67	1,700	0	2,840
Wood Block	1,630	72	950	43	1,140

CHARACTERISTICS OF WESTERN MATERIALS
(Continued)

Material	In Place	Loose		In Fill	
	lb./c.y.	Swell %	lb./c.y.	Shrink or Swell %	lb./c.y.
Peat	1,180	33	890		
Phosphorite					
Phosphate rock	5,400	50	3,600		
Phorphyry	4,630	67	2,770	43	3,240
Potash	3,700	50	2,470		
Pumice	1,080	67	650		
Pyrites					
Iron ore	8,540	67	5,110		
Pyrolusite					
Manganese ore	7,560	50	5,050		
Quartz	4,360	67	2,610	43	3,000
Quartzite	4,520	67	2,710	43	3,160
Rhyolite	4,050	67	2,420	43	2,870
Riprap rock					
Average	4,500	72	2,610	43	3,150
Rock-earth mixtures					
75% R. 25% E.	4,120	31	3,140	12	3,680
50% R. 50% E.	3,750	38	2,710	-6	4,000
25% R. 75% E.	3,380	43	2,370	-9	3,720
Salt, rock	3,670	67	2,200		
Sand					
Dry	2,880	11	2,590	-11	3,240
Wet	3,090	5	3,230	-11	3,460
Sandstone	4,070	61	2,520	34	3,030
Scheelite					
Tungsten ore	10,100	67	6,050		
Schist	4,530	67	2,710	43	3,170
Shale	4,450	79	2,480	49	2,990
Silt	3,240	36	2,380	-17	3,890
Siltstone	4,070	61	2,520	-11	4,560
Slag					
Furnace	4,840	98	2,690	65	2,930
Sand	1,400	11	1,260	-11	1,570
Slate	4,500	77	2,600	43	3,150
Snow					
Dry	220	0	220		
Wet	860	0	860		
Soapstone					
Talc ore	4,550	67	2,720		
Sodium niter					
Chile salt peter	2,710	50	2,470		
Sulphur	3,450	50	2,310		
Syenite	4,460	67	2,670	43	

CHARACTERISTICS OF WESTERN MATERIALS
(Continued)

Material	In Place	Loose		In Fill	
	lb./c.y.	Swell %	lb./c.y.	Shrink or Swell %	lb./c.y.
Taconite					
Iron ore	5,370	60	3,360		
Talc	4,640	67	2,780	43	3,250
Topsoil	2,430	56	1,620	-26	3,280
Trachyte	4,050	67	2,420	43	2,870
Trap rock					
Igneous rocks	4,710	67	2,820	43	3,300
Trash			400	-50	800
Tuff	4,050	50	2,700	33	3,050
Witherite					
Barium ore	7,230	67	4,320		
Wolframite					
Tungsten ore	12,280	67	7,350		
Zinc Blende					
Zinc ore	6,780	67	4,060		
Zincite					
Zinc ore	9,550	67	5,710		

Weights per cubic yard in cut are subject to average plus or minus 5% variation.

Swell and shrinkage factors for loose condition and embankment are subject to average plus or minus 33% variation.

Weights in loose condition and in embankment are subject to adjustments in accordance with modified swell and shrinkage factors.

All ores are in the mineral state, with no gangue.

EXAMPLES OF USE OF TABLE

Determination of pay load prior to job figure

This Caterpillar DW20 tractor--Shepherd 456S Long Haul scraper is being push loaded by two Caterpillar D9 tractors in damp mixture of sand-clay--50% sand and 50% clay. Loose load capacity is 27.3 cu. yd. at 3:1 slope. Table gives sand at 3,090 lb. in cut with 5% swell factor in loose condition, and clay at 3,350 lb. in cut with 50% swell factor. Average for the mixture is then 3,220 lb. in cut with 28% swell factor.

Calculated pay load is 27.3 divided by 1.28 or 21.3 cu. yd. in cut weighing 68,700 lb. for 3,220 lb. per cu. yd. mixture in the cut.

NOTE: during the job, pay loads were weighed, and results were:

Average pay load, 69,800 lb.
Weight per cu. yd. in cut (engineers), 3,190 lb.
Average pay load, bank measurement, 21.0 cu. yd.

Determination of pay load in advance of job figure

Caterpillar DW20 tractor -- Athey PW20 Bottom Dump trailer units are set to work hauling fairly dry gravel of good gradation. Loose capacity is 31.2 yd. with 3:1 sloped load.

Table gives 3,680 lb. per yd. in cut, swell factor from cut to loose of 33%, and 2,770 lb. per yd. loose. Accordingly, pay load will be 86,500 lb., and 23.5 yd. bank measure.

Pay loads were weighed subsequently and showed: Average pay load of 91,600 lb., and weight per yd. (engineers) was 3,750 lb., with average pay load, bank measurement, of 24.4 yd.

Determination of body dimensions for desired capacity

Capacity of 40 tons of limestone is desired in side dump bodies, as pictured. The Caterpillar DW20 tractor -- Athey PD 20 Side Dump trailer regularly has 20.5 yd. struck capacity and about 24.6 yd. loose capacity based on 2:1 sloped load. Table gave limestone loose weight at 2,690 lb., the swell factor being 63%. Required sloped capacity is 29.7 cu. yd.

It is felt that the particular limestone weighs slightly more than 4,380 lb. per yd. in place and a 12-in. lip is added to standard body giving sloped capacity of about 27 yd. An average pay load of 40.5 tons is carried.

It is probable that the limestone is more dense than was estimated and that swell factor is less than 63%.

Determination of pay load in rock

Caterpillar DW21 -- Athey PR21 Rear Dump trailers are moving in on a rock excavation job of a mixture of breccia and solid basalt, both requiring blasting. Loose capacity at 2:1 slope is 22.5 yd. Table gives 33% swell for breccia and 64% swell for basalt, averaging 48% for the mixture from cut to loose condition. Pay load therefore is 15.2 yd. bank measurement. Upon completion of job, contractor felt that job average was about 15 yd.

Determination of ripper production in tons per hour

It is known that the 4-yd. shovel will load out 350 yd. bank measure hourly of 50% rock and 50% earth mixture, and that the D9 tractor with two-shank ripper can rip 600 yd. comfortably. The basis of payment is tons and the tonnage production of both shovel and ripper are desired to determine highway haulage unit requirements and excess D9 time available for bulldozing assistance.

For rock-earth mixture of 50% proportion, table gives weight in cut of 3,750 lb. per yd. Shovel production is then 657 tons hourly. Conservative ripper capacity is 1,120 tons hourly, thus allowing 41% of total time available for bulldozing.

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