APPENDIX 1 -- METRIC (SI) SYSTEM ADAPTATION

A1.1 Procedures outlined in this standard practice have been presented using inch-pound units of measurement. The principles are equally applicable in SI system with proper adaptation of units. This Appendix provides all of the information necessary to apply the proportioning procedure using SI measurements. Table A1.1 gives relevant conversion factors. A numerical example is presented in Appendix 2.

TABLE A1.1-CONVERSION FACTORS, in.-lb TO SI UNITS*

Quantity	in-lb unit	SI† unit	Conversion factor (Ratio: in.-lb/SI)
Length	inch (in.)	millimeter (mm'	25.40
Volume	cubic foot (ft^3) cubic yard (yd^3)	cubic meter (m^3 cubic meter (m^3	0.02832 0.7646
Mass	pound (lb)	kilogram (kg)	0.4536
Stress	pounds per square inch (psi)	megapascal (MPa)	6.895 x 10^{-2}
Density	pounds per cubic foot (lb/ft^3) pounds per cubic yard (lb/yd^3)	kilograms per cubic meter (kg/m') kilograms per cubic meter (kg/m^3)	16.02 0.5933
Temperature	degrees Fahrenheit (F)	degrees Celsius (C)	‡

*Gives names (and abbreviations) of measurement units in the inch-pound system as used in the body of this report and in the SI (metric) system, along with multipliers for converting the former to the latter. From ASTM E 380.
†Systéme International d'Unites
‡C = (F – 32)/1.8

Al.2 For convenience of reference, numbering of subsequent paragraphs in this Appendix corresponds to the body of the report except that the designation "Al" is prefixed. All tables have been converted and reproduced. Descriptive portions are included only where use of the SI system requires a change in procedure or formula. To the extent practicable, conversions to metric units have been made in such a way that values are realistic in terms of usual practice and significance of numbers. For example, aggregate and sieve sixes in the metric tables are ones commonly used in Europe. Thus, there is not always a precise mathematical correspondence between inch-pound and SI values in corresponding tables.

A1.5.3 S*teps in calculating proportions* -- Except as discussed below, the methods for arriving at quantities of ingredients for a unit volume of concrete are essentially the same when SI units are employed as when inch-pound units are employed. The main difference is that the unit volume of concrete becomes the cubic meter and numerical values must be taken from the proper "A1" table instead of the one referred to in the text.

A1.5.3.1 ***Step 1. Choice of slump -- See*** Table A1.5.3.1.

TABLE A1.5.3.1 — RECOMMENDED SLUMPS FOR VARIOUS TYPES OF CONSTRUCTION (SI)

Types of construction	Slump, mm	
	Maximum*	Minimum
Reinforced foundation walls and footings	75	25
Plain footings, caissons, and substructure walls	75	25
Beams and reinforced walls	100	25
Building columns	100	25
Pavements and slabs	75	25
Mass concrete	75	25

*May be increased 25 mm for methods of consolidation other than vibration

A1.5.3.2 *Step 2. Choice of nominal maximum size of aggregate.*

A1.5.3.3 *Step 3. Estimation of mixing water and air content* -- See Table A1.5.3.3.

A1.5.3.4 *Step 4. Selection of water-cement ratio* -- See Table A1.5.3.4.

A1.5.3.5 *Step 5. Calculation of cement content.*

A1.5.3.6 *Step 6. Estimation of coarse aggregate content* -- The dry mass of coarse aggregate required for a cubic meter of concrete is equal to the value from Table A1.5.3.6 multiplied by the dry-rodded unit mass of the aggregate in kilograms per cubic meter.

A1.5.3.7 *Step 7. Estimation of fine aggregate content* -- In the SI, the formula for calculation of fresh concrete mass per cubic meter is:

$$U_M = 10G_a(100 - A) + C_M(1 - G_a/G_c) - W_M(G_a - 1)$$

where

U_M = unit mass of fresh concrete, kg/m^3
G_a = weighted average specific gravity of combined fine and coarse aggregate, bulk, SSD
G_c = specific gravity of cement (generally 3.15)
A = air content, percent
W_M = mixing water requirement, kg/m^3
C_M = cement requirement, kg/m^3

A1.5.3.9 *Step 9. Trial batch adjustments* -- The following "rules of thumb" may be used to arrive at closer approximations of unit batch quantities based on results for a trial batch:

A1.5.3.9.1 The estimated mixing water to produce the same slump as the trial batch will be equal to the net amount of mixing water used divided by the yield of the trial batch in m^3. If slump of the trial batch was not correct, increase or decrease the re-estimated water content by 2 kg/m^3 of concrete for each increase or decrease of 10 mm in slump desired.

A1.5.3.9.2 To adjust for the effect of

TABLE A1.5.3.3 — APPROXIMATE MIXING WATER AND AIR CONTENT REQUIREMENTS FOR DIFFERENT SLUMPS AND NOMINAL MAXIMUM SIZES OF AGGREGATES (SI)

Slump, mm	Water, Kg/m³ of concrete for indicated nominal maximum sizes of aggregate: 9.5*	12.5*	19*	25*	37.5*	50†*	75†‡	150†‡
Non-air-entrained concrete								
25 to 50	207	199	190	179	166	154	130	113
75 to 100	228	216	205	193	181	169	145	124
150 to 175	243	228	216	202	190	178	160	—
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-entrained concrete								
25 to 50	181	175	168	160	150	142	122	107
75 to 100	202	193	184	175	165	157	133	119
150 to 175	216	205	197	184	174	166	154	—
Recommended average§ total air content, percent for level of exposure:								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5**††	1.0**††
Moderate exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5**††	3.0**††
Extreme exposure‡‡	7.5	7.0	6.0	6.0	5.5	5.0	4.5**††	4.0**††

*The quantities of mixing water given for air-entrained concrete are based on typical total air content requirements as shown for "moderate exposure" in the Table above. These quantities of mixing water are for use in computing cement contents for trial batches at 20 to 25 C. They are maximum for reasonably well-shaped angular aggregates graded within limits of accepted specifications. Rounded coarse aggregate will generally require l8 kg less water for non-air-entrained and 15 kg less for air-entrained concretes. The use of water-reducing chemcial admixtures. ASTM C 494, may also reduce mixing water by 5 percent or more. The volume of the liquid admixtures is included as part of the total volume of the mixing water.

†The slump values for concrete containing aggregate larger than 40 mm are based on slump tests made after removal of particles larger than 40 mm by wet-screenmg.

‡These quantities of mixing water are for use in computing cement factors for trial batches when 75 mm or 150 mm normal maximum size aggregate is used. They are average for reasonably well-shaped coarse aggregates, well-graded from coarse to fine.

§Additional recommendations for air-content and necessary tolerances on air content for control in the field are given in a number of ACI documents, including ACI 201, 345, 3 18, 301, and 302. ASTM C 94 for ready-mixed concrete also gives air content limits. The requirements in other documents may not always agree exactly so in proportioning concrete consideration must be given to selecting an air content that will meet the needs of the job and also meet the applicable specifications.

**For concrete containing large aggregates which will be wet-screened over the 40 mm sieve prior to testing for air content, the percentage of air expected in the 40 mm minus material should be as tabulated in the 40 mm column. However, initial proportioning calculations should include the air content as a percent of the whole.

††When using large aggregate in low cement factor concrete, air entrainment need not be detrimental to strength. In most cases mixing water requirement is reduced sufficiently to improve the water-cement ratio and to thus compensate for the strength reducing effect of entrained air concrete. Generally, therefore, for these large nominal maximum sizes of aggregate. air contents recommended for extreme exposure should be considered even though there may be little or no exposure to moisture and freezing.

‡‡These values are based on the criteria that 9 percent air is needed in the mortar phase of the concrete. If the mortar volume will be substantially different from that determined in this recommended practice, it may be desirable to calculate the needed air content by taking 9 percent of the actual mortar volume.

TABLE A1.5.3.4(a) — RELATIONSHIPS BETWEEN WATER-CEMENT RATIO AND COMPRESSIVE STRENGTH OF CONCRETE (SI)

Compressive strength at 28 days, MPa*	Water-cement ratio, by mass: Non-air-entrained concrete	Air-entrained concrete
40	0.42	—
35	0.47	0.39
30	0.54	0.45
25	0.61	0.52
20	0.69	0.60
15	0.79	0.70

*Values are estimated average strengths for concrete containing not more than 2 percent air for non-air-entrained concrete and 6 percent total air content for air-entrained concrete. For a constant water-cement ratio, the strength of concrete is reduced as the air content is increased.

Strength is based on 152 X 305 mm cylinders moist-cured for 28 days in accordance with the sections on "Initial Curing" and "Curing of Cylinders for Checking the Adequacy of Laboratory Mixture Proportions for Strength or as the Basis for Acceptance or for Quality Control" of ASTM Method C 3 l for Making and Curmg Concrete Specimens in the Field. These are cylinders cured moist at 23 ± 1.7 C prior to testing.

The relationship in this Table assumes a nominal maximum aggregate size of about l9 to 25 mm. For a given source of aggregate, strength produced at a given water-cement ratio will increase as nominal maximum size of aggregate decreases; see Sections 3.4 and 5.3.2.

incorrect air content in a trial batch of air-entrained concrete on slump, reduce or increase the mixing water content of A1.5.3.9.1 by 3 kg/m³ of concrete for each 1 percent by which the air content is to be increased or decreased from that of the trial batch.

A1.5.3.9.3 The re-estimated unit mass of the fresh concrete for adjustment of trial batch proportions is equal to the unit mass in kg/m³ measured on the trial batch, reduced or increased by the percentage increase or decrease in air content of the adjusted batch from the first trial batch.

TABLE A1.5.3.4(b) — MAXIMUM PERMISSIBLE WATER-CEMENT RATIOS FOR CONCRETE IN SEVERE EXPOSURES (SI)*

Type of structure	Structure wet continuously or frequently and exposed to freezing and thawing†	Structure exposed to sea water or sulfates
Thin sections (railings, curbs, sills, ledges, ornamental work) and sections with less than 5 mm cover over stee	0.45	0.40‡
All other structures	0.50	0.45‡

*Based on ACI 201.2R.

†Concrete should also be air-entrained.

‡If sulfate resisting cement (Type II or Type V of ASTM C 150) is used, permissible water-cement ratio may be Increased by 0.05.

TABLE A1.5.3.6 — VOLUME OF COARSE AGGREGATE PER UNIT OF VOLUME OF CONCRETE (SI)

Nominal maximum size of aggregate, mm	Volume of dry-rodded coarse aggregate* per unit volume of concrete for different fineness moduli† of fine aggregate			
	2.40	2.60	2.80	3.00
9.5	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
19	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
37.5	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
75	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

*Volumes are based on aggregates in dry-rodded condition as described in ASTM C 29.

These volumes are selected from empirical relationships to produce concrete with a degree of workability suitable for usual reinforced construction. For less workable concrete such as required for concrete pavement construction they may be increased about 10 percent. For more workable concrete. such as may sometimes be required when placement is to be by pumping, they may be reduced up to 10 percent.

†See ASTM Method 136 for calculation of fineness modulus.

TABLE A1.5.3.7.1 — FIRST ESTIMATE OF MASS OF FRESH CONCRETE (SI)

Nominal maximum size of aggregate, mm	First estimate of concrete unit mass, kg/m³*	
	Non-air-entrained concrete	Air-entrained concrete
9.5	2280	2200
12.5	2310	2230
19	2345	2275
25	2380	2290
37.5	2410	2350
50	2445	2345
75	2490	2405
150	2530	2435

*Values calculated by Eq. (A1.5.3.7) for concrete of medium richness (330 kg of cement per m3) and medium slump with aggregate specific gravity of 2.7. Water requirements based on values for 75 to 100 mm slump in Table A1.5.3.3. If desired, the estimate of unit mass may be refined as follows if necessary information is available: for each 5 kg difference in mixing water from the Table A1.5. 3.3 values for 75 to 100 mm slump, correct the mass per m^3 8 kg in the opposite direction; for each 20 kg difference in cement content from 330 kg, correct the mass per m^3 3 kg in the same direction; for each 0.1 by which aggregate specific gravity deviates from 2.7, correct the concrete mass 60 kg in the same direction. For air-entrained concrete the air content for severe exposure from Table A.1.5.3.3 was used. The mass can be increased 1 percent for each percent reduction in air content from that amount.

APPENDIX 2 -- EXAMPLE PROBLEM IN METRIC (SI) SYSTEM

A2.1 *Example 1* -- Example 1 presented in Section 6.2 will be solved here using metric units of measure. Required average strength will be 24 MPa with slump of 75 to 100 mm. The coarse aggregate has a nominal maximum size of 37.5 mm and dry-rodded mass of 1600 kg/m³. As stated in Section 6.1, other properties of the ingredients are: cement -- Type I with specific gravity of 3.15; coarse aggregate -- bulk specific gravity 2.68 and absorption 0.5 percent; fine aggregate -- bulk specific gravity 2.64, absorption 0.7 percent, and fineness modulus 2.8.

A2.2 All steps of Section 5.3 should be followed in sequence to avoid confusion, even though they sometimes merely restate information already given.

A2.2.1 *Step 1* -- The slump is required to be 75 to 100 mm.

A2.2.2 *Step* 2 -- The aggregate to be used has a nominal maximum size of 37.5 mm.

A2.2.3 *Step* 3 -- The concrete will be non-air-entrained since the structure is not exposed to severe weathering. From Table A1.5.3.3, the estimated mixing water for a slump of 75 to 100 mm in non-air-entrained concrete made with 37.5 mm aggregate is found to be 181 kg/m³.

A2.2.4 *Step 4* -- The water-cement ratio for non-air-entrained concrete with a strength of 24 MPa is found from Table Al.5.3.4(a) to be 0.62.

A2.2.5 *Step 5* -- From the information developed in Steps 3 and 4, the required cement content is found to be 181/0.62 = 292 kg/m³.

A2.2.6 *Step 6* -- The quantity of coarse aggregate is estimated from Table A 1.5.3.6. For a fine aggregate having a fineness modulus of 2.8 and a 37.5 mm nominal maximum size of coarse aggregate, the table indicates that 0.71 m³ of coarse aggregate, on a dry-rodded basis, may be used in each cubic meter of concrete. The required dry mass is, therefore, 0.71 x 1600 = 1136 kg.

A2.2.7 *Step* 7 -- With the quantities of water, cement and coarse aggregate established, the remaining material comprising the cubic meter of concrete must consist of fine aggregate and whatever air will be entrapped. The required fine aggregate may be determined on the basis of either mass or absolute volume as shown below:

A2.2.7.1 *Mass basis* -- From Table A1.5.3.7.1, the mass of a cubic meter of non-air-entrained concrete made with aggregate having a nominal maximum size of 37.5 mm is estimated to be 2410 kg. (For a first trial batch, exact adjustments of this value for usual differences in slump, cement factor, and aggregate specific gravity are not critical.) Masses already known are:

Water (net mixing)	181 kg
Cement	292 kg
Coarse aggregate	1136 kg
Total	1609 kg

The mass of fine aggregate, therefore, is estimated to be

$$2410 - 1609 = 801 \text{ kg}$$

A2.2.7.2 *Absolute volume basis* -- With the quantities of cement, water, and coarse aggregate established, and the approximate entrapped air content (as opposed to purposely entrained air) of 1 percent determined from Table Al.5.3.3, the sand content can be calculated as follows:

$$\text{Volume of water} = \frac{181}{1000} \quad 0.181 \text{ m}^3$$

$$\text{Solid volume of cement} = \frac{292}{3.15 \times 1000} \quad 0.093 \text{ m}^3$$

Solid volume of coarse aggregate =	$\frac{1136}{2.68 \times 1000}$	0.424 m^3
Volume of entrapped air =	0.01 x 1.000	0.010 m^3
Total solid volume of ingredients except fine aggregate		0.708 m^3
Solid volume of fine aggregate required =	1.000 - 0.705	0.292 m^3
Required weight of dry fiie aggregate =	0.292 x 2.64 x 1000	771 kg

A2.2.7.3 Batch masses per cubic meter of concrete calculated on the two bases are compared below:

	Based on estimated concrete mass, kg	Based on absolute volume of ingredients, kg
Water (net mixing)	181	181
Cement	292	292
Coarse aggregate (dry)	1136	1136
Sand (dry)	801	771

A2.2.8 *Step 8* -- Tests indicate total moisture of 2 percent in the coarse aggregate and 6 percent in the fine aggregate. If the trial batch proportions based on assumed concrete mass are used, the adjusted aggregate masses become

Coarse aggregate (wet) = 1136(1.02) = 1159 kg
Fine aggregates (wet) = 801(1.06) = 849kg

Absorbed water does not become part of the mixing water and must be excluded from the adjustment in added water. Thus, surface water contributed by the coarse aggregate amounts to 2 - 0.5 = 1.5 percent; by the fine aggregate 6 - 0.7 = 5.3 percent. The estimated requirement for added water, therefore, becomes

$$181 - 1136(0.015) - 801(0.053) = 122 \text{ kg}$$

The estimated batch masses for a cubic meter of concrete are:

Water (to be added)	122 kg
Cement	292 kg
Coarse aggregate (wet)	1159 kg
Fine aggregate (wet)	849 kg
Total	2422 kg

A2.2.9 *Step 9* -- For the laboratory trial batch, it is found convenient to scale the masses down to produce 0.02 m3 of concrete. Although the calculated quantity of water to be added was 2.44 kg, the amount actually used in an effort to obtain the desired 75 to 100 mm slump is 2.70 kg. The batch as mixed, therefore, consists of

Water (added)	2.70 kg
Cement	5.84 kg
Coarse aggregate (wet)	23.18 kg
Fine aggregate (wet)	16.98 kg
Total	48.70 kg

The concrete has a measured slump of 50 mm and unit mass of 2390 kg/m? It is judged to be satisfactory from the standpoint of workability and finishing properties. To provide proper yield and other characteristics for future batches, the following adjustments are made:

A2.2.9.1 Since the yield of the trial batch was

$$48.70/2390 = 0.0204 \text{ m}^3$$

and the mixing water content was 2.70 (added) + 0.34 (on coarse aggregate) + 0.84 (on fine aggregate) = 3.88 kg, the mixing water required for a cubic meter of concrete with the same slump as the trial batch should be

$$3.88/0.0204 = 190 \text{ kg}$$

As indicated in A1.5.3.9.1, this amount must be increased another 8 kg to raise the slump from the measured 50 mm to the desired 75 to 100 mm range, bringing the total mixing water to 198 kg.

A2.2.9.2 With the increased mixing water, additional cement will be required to provide the desired water-cement ratio of 0.62. The new cement content becomes

$$198/0.62 = 319 \text{ kg}$$

A2.2.9.3 Since workability was found to be satisfactory, the quantity of coarse aggregate per unit volume of concrete will be maintained the same as in the trial batch. The amount of coarse aggregate per cubic meter becomes

$$\frac{23.18}{0.0204} = 1136 \text{ kg wet}$$

which is