CHAPTER 2 METRIC UNITS

CHAPTER 2. - METRIC UNITS, TERMS, & CONVERSION FACTORS

2.1 INTRODUCTION

Over the years, there have been several "metric" systems. The current **SI** metric system was preceded by the **cgs** (centimeter-gram-second) system and the **mks** (meter-kilogram-second) system. Beware of using old metric reference material, since some of the elements may not agree with current practice.

ASTM E380, Standard Practice for Use of the International System of Units (SI), has been designated by the FHWA, the Department of Defense, and other federal agencies as their chosen metric conversion document. An equivalent standard is AASHTO R1, Standard Metric Practice Guide. R1 is found in the AASHTO Specifications for Transportation Materials and Methods of Sampling and Testing, Part I, Specifications. The Alaska DOT&PF has also adopted these standards. Note, however, that we have used the spellings of meter and liter which are preferred in the United States.

2.2 BASE UNITS

There are seven base metric units, six of which are used in design and construction. (the seventh, mole, is mainly used in physics.)

BASE UNITS		
QUANTITY	**NAME**	**SYMBOL**
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
temperature*	Kelvin	K
luminous intensity	candela	cd

*Celsius temperature(^{O}C) will be used more commonly than Kelvin.

2.3 DECIMAL PREFIXES

The four prefixes most common in DOT&PF work are shown below.

PREFIXES					
Submultiples			Multiples		
milli	m	10^{-3}	kilo	k	10^{3}
micro	μ	10^{-6}	mega	M	10^{6}

Decimal prefixes to the tertiary power of 10 are preferred. The prefixes deci (d) for one tenth (10^{-1}), centi (c) for one hundredth (10^{-2}), deca (da) for ten (10^{1}), and hecto (h) for one hundred (10^{2}) have limited application in construction.

2.4 DERIVED UNITS

Derived units are formed by combining base units and other derived units. For example, velocity (m/s), slope (m/m), and density (kg/m^3) are derived measures. Some derived units have their own special names. Most of those are shown in the following table.

DERIVED UNITS			
Quantity	Name	Symbol	Expression
frequency	hertz	Hz	$Hz = s^{-1}$
force	Newton	N	$N = kg \cdot m/s^2$
pressure(stress, etc.)	pascal	Pa	$Pa = N/m^2$
energy (work, heat, etc.)	joule	J	$J = N \cdot m$
power (radiant flux, etc.)	watt	W	$W = J/s$
electric charge, quantity	coulomb	C	$C = A \cdot s$
electric potential	volt	V	$V = W/A$
capacitance	farad	F	$F = C/V$
electric resistance	ohm	Ω	$\Omega = V/A$
electric conductance	siemens	S	$S = A/V$
magnetic flux	weber	Wb	$Wb = V \cdot s$
magnetic flux density	tesla	T	$T = Wb/m^2$
inductance	henry	H	$H = Wb/A$
luminous flux	lumen	lm	$lm = cd \cdot sr$
illuminance	lux	lx	$lx = lm/m^2$

2.5 CONVERSION FACTORS

Length, Area, and Volume Conversion Factors

Quantity	From Inch-Pound Units	To Metric Units	Multiply by
Length	mile	km	1.609 344
	yard	m	0.914 4
	foot	m	0.304 8
	foot	mm	304.8
	inch	mm	25.4
Area	square mile	km^2	2.590
	acre	m^2	4 047
	acre	ha (10 000 m^2)	0.404 7
	square yard	m^2	0.836 127 36
	square foot	m^2	0.092 903 04
	square inch	mm^2	645.15
Volume	acre foot	m^3	1 233
	cubic yard	m^3	0.764 6
	cubic foot	m^3	0.028 32
	cubic foot	cm^3	28 32
	cubic foot	L(1000 cm^3)	28.32
	100 board feet	m^3	0.236
	gallon	L(1000 cm^3)	3.785
	cubic inch	cm^3	16.387 064
	cubic inch	mm^3	16 387.064

NOTE: Underline denotes exact number.

Civil and Structural Engineering Conversion Factors

Quantity	From Inch-Pound Units	To Metric Units	Multiply by
Mass	lb kip (1000 lb)	kg metric ton (1000 kg)	0.453 6 0.453 6
Mass/unit length	plf	kg/m	1.488
Mass/unit area	psf	kg/m^2	4.882
Mass density	pcf	kg/m^3	16.019
Force	Ib kip	N kN	4.448 4.448
Force/unit length	plf klf	N/m kN/m	14.59 14.59
Pressure, stress, modulus of elasticity	psf ksf psi ksi	Pa kPa kPa MPa	47.88 47.88 6.895 6.895
Bending moment, torque, moment of force	ft-lb ft-kip	N•m kN•m	1.356 1.356
Moment of mass	Ib-ft	kg•m	0.138 3
Moment of inertia	$Ib\text{-}ft^2$	$kg•m^2$	0.042 14
Second moment of area	in^4	mm^4	416 2
Section modulus	in^3	mm^3	16 387.064

NOTE: Underline denotes exact number.

Electrical & Illumination Engineering Conversion Factors

Quantity	From Inch-Pound Units	To Metric Units	Multiply by
Power, radiant flux	W	W	1 (same unit)
Radiant intensity	W/sr	W/sr	1(same units)
Radiance	$W/(sr \cdot m^2)$	$W/(sr \cdot m^2)$	1(same units)
Irradiance	W/m^2	W/m^2	1(same units)
Frequency	Hz	Hz	1(same value)
Electric current	A	A	1 (same unit)
Electric charge	A•hr	C	3600
Electric potential	V	V	1 (same unit)
Capacitance	F	F	1 (same unit)
Inductance	H	H	1 (same unit)
Resistance	Ω	Ω	1 (same unit)
Conductance	mho	S	l00
Magnetic flux	l maxwell	Wb	10^{-8}
Magnetic flux density	gamma	T	10^{-9}
Luminous intensity	cd	I cd	1 (same unit)
Luminance	lambert cd/ft^2 footlambert	kcd/m^2 cd/m^2 cd/m^2	3.183 10.76 3.426
Luminous flux	Im	m	1 (same unit)
Illuminance	footcandle	Ix	10.76

NOTE: Underline denotes exact number.

2.6 PROCEDURAL RULES

Rules for Writing Metric Symbols and Names

Print unit symbols in upright type and in lower case except for liter (L) and when the unit name is derived from a proper name.

Print unit names in lower case, even those derived from a proper name. (newton, pascal, ampere)

Print decimal prefixes in lower case for magnitudes 10^3 and lower (that is, k for kilo, m for milli, μ for micro, and n for nano), and print the prefixes in upper case for magnitudes 10^6 and higher (that is, M for mega and G for giga).

Leave a space between a numeral and symbol (write 45 kg or 37 ˚C, not 45kg or 37˚C or 37˚ C).

Do not use a degree mark (˚) with kelvin temperature (write K, not ˚K).

Do not leave a space between a unit symbol and its prefix (write kg, not k g).

Do not use the plural of unit symbols (write 45 kg, not 45 kgs), but you may use the plural of written unit names (several kilograms).

For technical writing, use symbols in conjunction with numerals (the area is 10 m^2); write out unit names if numerals are not used (carpet is measured in square meters). Numerals may be combined with written unit names in non-technical writing (10 meters).

Indicate the product of two or more units in symbolic form by using a dot positioned above the line ($kg \cdot m \cdot s^{-2}$).

Do not mix names and symbols (write N•m or newton meter, not N•meter or newton•m).

Do not use a period after a symbol (write 12 g, not 12 g.) except when it occurs at the end of a sentence.

Rules for Writing Numbers

Always write decimals, not fractions (write 0.75 g, not 3/4 g).

Use a zero before the decimal marker for values less than one (write 0.45 g, not .45 g).

In the United States, the preferred decimal marker is a period; in other countries a comma usually is used.

Use spaces instead of commas to separate blocks of three digits for any number over four digits (write 45 138 kg, 0.004 46 kg, or 4371 kg). This does not apply to the expression of amounts of money.

Pronunciation

candela	Accent the second syllable: can-**dell**-ah.
hectare	Accent the first syllable: **heck**-tare. The second syllable rhymes with **care**.
joule	Rhymes with **pool**.
kilometer	Accent the first syllable: **kill**-o-meter.
pascal	Rhymes with **rascal**.
siemens	Sounds like **seamen's**.

Rules for Linear Measurement (Length)

Use only the meter and millimeter in design and construction.

Use the kilometer for long distances.

Avoid use of the centimeter in technical work.

Use only the meter and the kilometer for survey measurement.

Rules for Area Measurement

The square meter is preferred.

Very large areas may be expressed in square kilometers and very small areas in square millimeters.

Use the hectare (10 000 square meters) for land and water measurement only.

Avoid use of the square centimeter.

Rules for Volume and Fluid Capacity Measurement

Cubic meter is preferred for volumes in construction and for large storage tanks.

Use liter (L) and milliliter (mL) for fluid capacity (liquid volume). One liter is 1/1000 of a m^3, 1 dm^3, or 1000 cm^3.

Since a cubic meter equals one billion cubic millimeters, the cubic decimeter and cubic centimeter may be used. They are multiples of 1000 in volume measurement.

Rules for Civil and Structural Engineering

The kilogram (kg) is the base unit for mass.
The newton (N) is the derived unit for force (mass times acceleration, or $kg \cdot m/s^2$).

The joule is not used in structural design. Moments and torque are always expressed in terms of newton meters ($N \cdot m$), or the multiple $kN \cdot m$.

The pascal (Pa) is the unit for pressure and stress ($Pa = N/m^2$). The term "bar" or "millibar" is not an SI unit and should not be used.

Structural calculations should be shown in MPa or kPa.

The radian (rad) and steradian (sr) denote plane and solid angles. They are used in lighting work and in various engineering calculations.

In surveying, plane angles will continue to be measured in degrees, minutes, and seconds rather than in radians.

Slope is expressed in non-dimensional ratios. The vertical component is shown first and then the horizontal. For instance, a rise of one meter in four meters is expressed as 1:4. The units that are compared must be the same (meters to meters, millimeters to millimeters).

For slopes less than 45°, the vertical component should be unitary (for example, 1:20). For slopes 45° and over, the horizontal component should be unitary (for example, 5:1).

Rules for Electrical and Illumination Engineering

There are no unit changes for electrical engineering except for the renaming of conductance from "mho" to siemens (S).

The candela (cd) is the unit for luminous intensity and is already in common use; it replaces candle and candlepower.

The lux (lx) is the unit for illuminance and replaces lumen per square foot and footcandle.

Luminance is expressed in candela per square meter (cd/m^2) and replaces candela per square foot, footlambert, and lambert.

2.7 CONVERSION AND ROUNDING RULES

When converting numbers from inch-pound to metric, round the metric value to the same number of digits as there were in the inch-pound number (11 miles at 1.609 km/mi equals 17.699 km, which rounds to 18 km). (Not to be used where exact conversions are needed, such as for stationing, elevations, or coordinates.)

Convert mixed inch-pound units (feet and inches, pounds and ounces) to the smaller inch-pound unit before converting to metric and rounding (10 feet, 3 inches = 123 inches; 123 inches x 25.4 mm = 3124.2 mm; round to 3120 mm.

2.7.1 HARD VS. SOFT CONVERSION

One concept which confuses many people, due to the fact that the intent is not intuitively obvious, is the question of hard versus soft conversion. A soft conversion is an exact re-stating of a conventional English measurement in metric terms. This is often undesirable because the metric terms may have odd values (i.e., a traffic lane may be 3.658 meters wide).

"Soft" conversions are used primarily to convert dimensions of proprietary products which would require an extensive retooling expenditure if dimensional changes were made. In a "soft" conversion, an inch-pound measurement is mathematically converted to its exact (or nearly exact) metric equivalent.

A hard conversion is a statement of a previous dimension in convenient, rounded metric units. For example, it would be easier for lane widths to be stated as 3.6 meters

or 3.7 meters. These convenient units are much easier to remember. In general, highway standards lend themselves readily to hard conversion.

With "hard" conversion, a new rounded, rationalized metric number is created that is in harmony with established worldwide metric practice and is convenient to work with and remember. Use hard metric for a design dimension (one that the designer has control over) or for a known metric product that is readily and economically available.

The Rachet: 100 - 50 - 10 - 5 - 1

The rachet is a five level priority system, 100 being the highest level. It requires justification to move down one level. (eg., to move from 100 to 50)

Thus, design dimensions, created in ones mind, should be in increments of 100 mm, unless solid reasons exist to move down a rachet to design in 50 mm increments.

Critics have indicated this is not always possible, which we know. But increments of 100 and 50 mm should now become the baseline for project design, with 10 and 5 mm increments used only as required.

Rules of Thumb

Rule of 3's For Meters Many say, no matter how many classes attended, they will never have a feel for meters as they have for feet. The rule of 3's can help, and is fairly accurate.

Feet times three, move decimal left one digit. Here are two examples:

50 feet, times 3 = 150, move decimal, 15 m
20 feet times 3 = 60, yields 6 m

Rule of 4 s For Hectares This rule can help develop a feel for converting acres to hectares (ha), or "hecters", as many pronounce it.

Acres times 4, move decimal left one digit. Here are two examples:
30 acres times 4 = 120. move decimal, yields 12 hectares.
10 acres times 4 = 40, move decimal, yields 4 ha.

Rule of 10's For Square Meters This rule can help estimate the conversion from square feet to square meters. Move the decimal left one digit. For example:

Square Feet divided by 10 = Square Meters

500,000 s.f. divided by 10 = 50 000 m^2

2.8 COMMON USAGE

Pressure/ Stress. The pascal is only now becoming accepted as the unit of stress worldwide. Since steel section properties are expressed in millimeters, it is more convenient to express stress in a derivative of pascals - newtons per square millimeter.

Note that (1 N/mm^2 = 1 MPa).

Force vs. mass

In order to perform metric calculations properly it is important that the distinction between gravity "force" and "mass" be understood.

When working in the "inch-pound" system, weight can mean gravity force as well as mass. A block of concrete weighing 1000 pounds of mass when placed on a beam causes 1000 pounds of gravity force.

In the SI system, there are separate units for mass (kg) and force (N). The familiar law of physics applies: $F=MA$, or force equals mass times acceleration, due to gravity, in this case.

Since the acceleration of gravity is 32.2 ft/sec^2, and there are 0.3048 m/ft, the metric expression is 32.2 times 0.3048 = 9.807 or 9.81 m/s^2

The 1000 lb block has a **mass** of 1000 lb times 0.4536 kg/lb = 453.6 kg

but exerts a **force** of 453.6 kg times 9.81 m/s^2 = 4450 N

Metric Slang

Slang is part of our vibrant culture. From the Alcan to the Keys, from the Lone Star, the Bay Area, and the Beltway, Americans are efficient and we like things fast. People everywhere will brand the SI system with their personality and make it their own.

While perhaps controversial, we do not discourage this, as we feel a verbally modified system will be more quickly accepted in society-at-large. Smooth and catchy words such as nada are easily incorporated into our daily speech. The critical issue is that SI be implemented, and that everyone is clear what the new expressions mean. Few are confused when five kilos, a non-SI term, instead of five kilograms, are referred to. This information shows techniques from daily usage, but is not represented as preferred metric practice.

mmoc We have seen the term "mmoc" on drawings, to mean mm-on-center. (i.e., Fasten every 600 mmoc)

The "x" can verbally represent "hundred millimeters". (i.e., "five x", vs. "five hundred millimeters", 2 vs. 7 syllables). This can be very efficient for lengths up to 10 meters (i.e., 5x, 12x, 52x, 78x). Even decimals can be verbally faster using x. (i.e., "point five x", vs. "fifty millimeters") This also helps people to use 100 mm increments. The use of "x" does not conflict with any other SI symbol.

Modular Products such as ceiling tiles, access floor, light fixtures, and carpet tiles, have few standard sizes. We often use shortened names for 100 mm increments. 5 x 5 is 500 x 500, 6 x 6 is 600 x 600, etc.

Centimeters While not used in drawings and specs, they are used in other countries in day-to-day life. We sometimes call them "c's" (pronounced "seas"). (i.e., the report was about 2 seas thick) This technique was used earlier with cc's for volume.

Pascals "k-p-a" is often said instead of kilopascals, and "m-p-a" instead of megapascals.

Mass Megagram (Mg), equal to 1000 kg or one metric ton, is often used for large masses. (i.e., rebar, steel, gravel). In daily use, the term megagram is shortened to "meg". (i.e., eighty meg of rebar). This is already used by people in daily speech, such as a 25 meg hard drive. We hear metric ton used, but we find it slow, and it can be confusing, since people often drop metric and say only tons, even when metric tons are meant.

Characters

Micrometers are often shown as "um" since the micro character (μ) can be hard to use on many keyboards. (i.e., 25 um means 25 micrometers)

Superscripts can be cumbersome, and are often avoided in correspondence, using only the number.

2500 m3 means 2500 cubic meters.
1100 g/m2 means 1100 grams per square meter.