APPENDIX D

Metrication Issues

Basic Metric Information

BACKGROUND

The modern metric system (Systeme Intenationale or SI system) has been the international standard of measurement since it was adopted by the 11th General Conference on Weights and Measures in 1960.

The Metric Usage Act of 1975, as amended by the Omnibus Trade and Competitiveness Act of 1988, requires that the metric system be used in all federal procurement, grants, and business-related activities to the extent feasible by September 30, 1992. The intent of the law is to make the United States more competitive in international trade by bringing its measurement system into line with that of the rest of the world. Executive Order 12770 of July 1991, Metric Usage in Government Programs, requires federal agencies to develop specific timetables and milestones for the transition to the metric system. Federal agencies involved in construction generally agreed to institute the use of metric measures in the design of all federal construction by January 1994.

The United States is the only industrialized country on earth that does not use the metric system.

The metric system is more than just the International System of Units (SI). In international trade, the metric system refers to the use of product standards and preferred sizes that are accepted by industries throughout the world. It is, therefore, essential that goods manufactured in the United States be built to metric specifications to be competitive in the international marketplace.

WHAT ARE SOME OF THE BASIC SI UNITS

Some of the fundamental items are:

Meter (m): The basic unit for the measurement of length in the metric system is the meter. It is slightly longer than a yard(39.37 Inches)and generally used for measuring short distances. The length of a football field is approximately 91 m.

Kilometer (km): The metric unit used to denote longer distances is the kilometer. The kilometer is equal to 1000 meters and is slightly longer than half of a mile.

Millimeter (mm): Applied to the measurement of small distances or thicknesses is the millimeter. The millimeter is equal to one thousandth of a meter, or 0.001 meter. An inch is approximately 25 mm.

Square meter (m^2): The unit commonly used for the measurement of area is the square meter. A square meter is approximately 20% larger in area than a square yard. A room ten feet long and ten feet wide has a floor area of approximately 9 m^2.

Hectare (ha): To express the area of land or bodies of water use the hectare. A hectare is equal to 10 000 m^2, which is approximately 2.5 acres.

Cubic Meter (m^3): The unit of volume in the metric system is the cubic meter. The cubic meter has approximately 30% more volume than a cubic yard.

Liter (L): The unit that is used for the measurement of liquids or gasses is the liter. A liter is slightly more than a quart. Ever purchased a soft drink in a 2 L bottle?

Kilogram (kg): The basic unit that is used to express the mass of large items is the kilogram. A kilogram is a little more than two pounds.

Gram (g): The unit used to express the mass of small items is the gram. A gram is equivalent to one thousandth of a kilogram (0.001 kg). The mass of a penny is about 3g.

Metric ton (t): Used to express the mass of very large items or quantities, the metric ton. The metric ton is equivalent to 1000 kg, or approximately 2200 pounds.
Second (s): The second is the fundamental unit of time and is the same unit as currently used in everyday terminology.

Temperature (C): Widely used in the measurement of temperature is the degree Celsius (C°). On a hot summer day when the temperature is 95 F (Fahrenheit scale), the metric equivalent would be 35 C°.

Velocity (km/h): Velocity, or speed, is expressed in kilometers per hour (km/h). A residential speed limit of 25 miles per hour (mph) is approximately 40 km/h.

SOFT METRIC CONVERSION VERSUS HARD METRIC CONVERSION

Soft conversion is the result of a mathematical conversion of inch-pounds to SI equivalents. ASTM defines soft conversion as the "process of changing the description of an existing measurement to acceptable metric units without a significant change in size or magnitude." Hard conversion, on the other hand, is the "process of changing the description of an existing measurement to acceptable metric units, but with a change in the size of an existing quantity to obtain standard, convenient, rounded or rationalized metric dimensions."

Simple mathematical dimensional conversions should be avoided when at all possible. If "soft conversions" are made a "rational equivalent" would be more appropriate. For example, 12 inches (exactly 304.8 mm) is not a clean, rational number. It should be rounded to 300 mm to facilitate the cleanest construction possible.

Other common measurements would be rounded to a rational equivalent. Consider the following:

- 1" = 25 mm

- 4" = 100 mm
- 6" = 150 mm
- 12" = 300 mm
- 16" = 400 mm
- 24" = 600 mm (a normal building planning grid)

Once conversions have been made many architects, engineers and contractors alike find the metric system easier, simpler and more efficient to use since it is a decimal based system. The steps necessary to compute the area of a floor 27' 8-5/8" wide x 32' 6-7/16" long versus one that is 8.45 m wide x 9.92 m long, demonstrates the complexity of our current system of measurement. The metric system also simplifies building design by using only one unit for each physical property. For example, our current system of measurement uses psi, psf, tons/SF, inches of water, inches of mercury, and kips/SF to measure pressure. The metric system greatly simplifies this measurement by establishing one unit of measurement for pressure, the Pascal (Pa). Depending upon how large the measurement, kilopascals (x 1000), kPa, or megapascals (x 1000000), MPa, can be used.

Conversion Factors*

Quanity	From English 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	acre	km^2	2.590
	square yard	ha (10 000 m^2)	0.404 685 6
	square foot	m^2	0.836 127 36
	square inch	m^2	0.092 903 04
		mm^2	645.16
Volume	cubic yard	m^3	0.764 555
	cubic foot	m^3	0.028 316 8
	cubic foot	L (1000 cm^3)	28.316 85
	gallon	L (1000 cm^3)	3.785 41
	cubic inch	mm^3	16 387.064
Mass	lb	Kg	0.453 592
	ton (2000 lb)	metric ton (1000 kg)	0.907 184
Force	lb	N	4.448 22
Pressure, stress	psi	kPa	6.894 76
Torque	in-lb	N·m	0.112 98
	ft-lb	N·m	1.355 82

NOTE: Underline denotes exact number

*(From the homepage of Montana Department of Transportation)

METRIC CONVERSION PITFALLS

One might think that metric conversion is as simple as a mathematical "soft" conversion. However as one soon discovers, metric conversion, unlike the "hard" metric design that some are accustomed to is full of pitfalls. The following are the general rules and guidelines to be used when converting existing designs, specifications and calculations from English units to SI units.

- Know which is the correct conversion factor, especially when converting weight, or mass, and force. The SI system has specific values for both.
- Be careful not to introduce accuracy into a value which did not have it to begin with, when converting from the English system to the SI system.
- Use common sense when rounding, and strive for consistency.
- When necessary, perform a soft metric conversion, however, wherever possible, make all conversions hard. Hard conversion will accelerate the learning process and acceptability of the metric system.
- Again, be careful not to introduce accuracy into a value which did not have it to begin with. This is probably the most common mistake when making metric conversions. Review what the original intent of the value was, before making the conversion. If possible, try to make hard metric conversions.

In almost every case, the products and material strengths are not changing, however the nomenclature used to specify these particular products is changing. This constantly changing criteria and nomenclature can turn even the simplest metric conversion project into a difficult one. Common sense and good engineering judgement must be used!

CONVERSION AND ROUNDING

- ♦ Always establish intended precision as a guide to how many digits to retain after conversion. The number 1.1875 may be a very accurate decimalization of a number that could have been expressed as 1.19. The value 2 may mean ”about 2,” or it may be a very accurate value of 2, expressed as ”2.0000”.
- ♦ The converted dimension should be rounded to a minimum number of significant digits so the unit of the last place is equal to or smaller than its conversion.

Example: Precision of a 6 inch stirring rod is estimated at about 1/2 in (±1/4 in) or, converted, 12.7 mm. The converted dimension, 152.4 mm, should be rounded to the nearest 10 mm and shown as 150 mm.

- ♦ Converted values should be rounded to the minimum number of significant digits in order to maintain the required accuracy.

Example: A length of 125 ft converts exactly to 38.1 m. But if the 125 ft length was obtained by rounding to the nearest 5 ft, the conversion should be given as 38 m; if it had been obtained by rounding to the nearest 25 ft, the result should be rounded to 40 m.

- ♦ A stated limit such as ”not more than” must be handled so the limit is not violated. ”At least 3 inches wide” requires a width of at least 76.2 mm, or at least 77 mm.
- ♦ When converting, multiply a value by a more accurate factor than required, then round appropriately afterward. Rounding before multiplying will reduce accuracy.

Example: When converting 3 feet 2 9/16 inches to meters (9/16” = 0.5625”):

(3 x 0.3048)+(2.5625 x 0.0254) = 0.979 487 5 m, rounds to 0.979 m

Significant Digits

- When converting integral values of units, consider the implied or required precision of the integral value to be converted.

Example: The value *4 in.* may represent 4, 4.0, 4.00, 4.000 or 4.0000 in.

- Any digit necessary to define the specific value or quantity is significant.

Example: Measured to the nearest 1 m, a recorded distance of 157 m would have three significant digits. Measured to the nearest 0.1 m, a distance of 157.4 m would have four significant digits.

- Zeros may indicate either a specific value or an order of magnitude. As an example, the population of the United States in 1970, rounded to thousands, was 203 185 000. The six left-hand digits are significant, each measuring a value. The three right hand zeros indicate that the number has been rounded to the nearest thousand.
- Identifying significant digits is only possible by knowing the circumstances by which they were originally arrived at. For example, if the number 1000 is rounded from 965, only one zero is significant. If it is rounded from 999.7, all three zeros are significant.
- When adding or subtracting, the answer must contain no significant digits to the right of the least precise number.

Example: For the problem: Round the numbers one significant digit to the right of the least precise number and take the sum as follows:

163 000 000	163 000 000
217 885 000	217 900 000
96 432 768	96 400 000
477 317 768	477 300 000

(Round the total to 477 000 000 as called for by the rule)

- When multiplying or dividing, the product or quotient must contain no more significant digits than the fewest significant digits used in the multiplication or division.

Example: 113.2 x 1.43 = 161.876 – round to 162 because 1.43 has three significant digits
113.2 ÷ 1.43 = 79.160 8 – round to 79.2 for same reason.

Rounding Values

When the first digit discarded is less than 5, the last digit retained is not changed.

Example: 3.463 25, rounded to four digits would be 3.463; if rounded to three digits, 3.46.

- When the first digit discarded is greater than 5 or is a 5 followed by at least one digit other than 0, add 1 to the last digit retained.

Example: 8.376 52, rounded to four digits would be 8.377; if rounded to three digits 8.38.

- When the first digit discarded is exactly 5 followed only by zeros, the last digit retained should be rounded upward if it is odd. No adjustment is made if it is an even number.

Example: 4.365, rounded to three digits becomes 4.36. The number 4.355 would round to the same value, 4.36, if rounded to three digits.

HOW WILL THIS EFFECT ENGINEERING?

Drawing units will change from feet and inches to millimeters for all building dimensions and to meters for large site plans and civil engineering drawings; meters are always carried to one, two or three decimal places depending on the accuracy required. Drawing scales will change from $1_{inch} = x_{feet}–y_{inch}$ (1"=1'-8") to true ratios (1:20). Drawing sizes will be changed to the standard ISO metric drawing sizes. Drawings should be presented with only metric units. Typically, all dimensions are shown in millimeters, however, the suffix mm is not used, nor needed. Currently, most products that go into concrete work can be accomplished with either soft or hard metric conversions. At this time, reinforcing steel is still specified using the bar number, however, bar diameters in millimeters may eventually be used. Metric design guides for concrete design are available through the American Concrete Institute. Most products associated with steel construction have undergone soft metric conversions. Metric steel shape tables and design guides are available through the American Institute of Steel Construction.

One obvious advantage to the metric system is that metric dimensions can easily be checked with a calculator. By eliminating the cumbersome feet and inches, addition and conversion errors can be reduced significantly. The use of dual dimensions is discouraged since dual dimensioning takes time, double the change for errors, makes drawings more confusing and the impedes the learning process. Plans are usually presented in meters with sections and details presented in millimeters. Specifications will require either soft or hard metric conversions. Units of measure from feet and inches should be converted to millimeters for linear dimensions, from square feet to square meters for area, and from cubic yards to cubic meters for volume (except use liters for fluid volumes). Again, dual units are discouraged except when the use of an inch-pound unit of measure serves to clarify an otherwise unfamiliar metric measure, then place the inch-pound unit in parentheses after the metric unit. Calculations should be performed solely in metric units. This will eliminate the possibility of conversion errors. Many technical manuals and codes are currently available in their metric equivalents. Cost estimates should also be prepared in metric units. Many cost estimating guides are now being prepared in both English and metric units of measure.

WHAT EFFECT WILL THIS HAVE ON CONSTRUCTION?

Recent construction awards indicate that there is no detectable cost premium for using metric units. Construction contractors find that the use of metric units eliminates most dimensional construction errors since it is easier to use. By substituting metric measuring tapes, some contractors have found that very little effort and training was required to make the conversion from English to metric units.

HOW WILL THIS EFFECT THE GENERAL PUBLIC?

Most people today purchase metric packaged products and don't even know it. Almost all soft drinks are sold in liter containers, and have been for several years. Items purchased in grocery stores have displayed a dual system of volume and weights measurements for nearly 10 years. School children are now being taught both systems of measurement in the public school system and will be the first to readily accept either form of measurement. Car speedometers have been provided in both miles per hour and kilometers per hour for several years. The metric system of measurements have been introduced in our daily lives without our even realizing it. Once a conscious effort is made to convert to the metric system of measurements, the more widely accepted the metric system will become. Many Americans each year travel abroad and are immersed not only in a foreign culture, but the metric system of measurements. Speed limits are given in kilometers per hour and weights are given in kilograms. Although it may take some getting used to, many of these travelers eventually feel that a system based on a simple decimal system is easier to understand and is easier to use. To visualize metric equivalents, visualize the following:

- 1 mm (millimeters) is the approximate thickness of a dime
- 10 mm is the approximate diameter of a ball point pen
- 30 mm is the approximate length of a standard paper clip
- 150 mm is the length of a dollar bill
- 2 m (meters) is the average height of a door
- 90 m is the length of a football field

WHAT'S NEXT?

One of the largest obstacles to overcome is the inherent dislike for anything different. Most practicing engineers and architects have a real dislike for metric units because they loose their intuition and don't have a "feel" for what a value means in another system of measurements. For example, many structural and civil engineers know, and have a good physical sense of what 100 psf or 4000 psi means. However, convert 4000 psi to 27.5 MPa, and engineers and architects are confronted with a system of measurement that is completely foreign to them. Education and practice is required in order for engineers and architects to feel comfortable with metric units and regain their sense of "feel" for what is right. One of the biggest pitfalls in metric conversion will be to rely on soft conversions and not hard conversions. The faster one can use metric units from beginning to end, the sooner one will achieve the confidence needed to work with metric units.

Much effort in needed in the area of education for engineers and architects. The federal government has made a concerted effort to bring metrication to fabrication and construction. However, if engineers and architects are unwilling or unable to perform the necessary calculations and contract drawings in metric units, it will take years before the metrication process can be completed. Metrication is important for our future economic survivability in an ever shrinking global economy. Engineers have been called upon time and time again to solve problems, this is not one that they should shy away from.

REFERENCES:

1. American Society of Civil Engineers. http://www.pilot.infi.net/~cstone/comindex.htm
2. ASCE Metric References. http://www.pilot.infi.net/~cstone/com_i_1.htm
3. Metric Conversion Pitfalls. http://www.pilot.infi.net/~cstone/asceref7.htm
4. Metrication - Who, What, When, Where and Why!. http://www.pilot.infi.net/~cstone/asceref0.htm
5. Metrics Facts and Figures. http://www.pilot.infi.net/~cstone/mfacts2.htm
6. Montana Metrics. http://www.mdt.mt.gov/metric/mtmetric.htm
7. U.S. Metric Association (USMA). http://lamar.ColoState.EDU/~hillger/
8. The 1-Step metric conversion calculator. http://www.shaban.com/