Coastal Engineering Technical Note

METRIC (SI) STANDARD FOR DESIGN

PURPOSE: To provide a metric standard for use in design calculations and technical writing in the field of coastal engineering. This note describes the metric (SI) system and its proper usage; and provides conversion factors and metric equivalents for the water properties commonly used in coastal engineering.

BACKGROUND: In 1975, the Deputy Secretary of Defense established policies which encouraged a gradual changeover to the use of the metric system of measurement. At present, this impacts the Corps of Engineers primarily in the preparation of technical reports, feasibility studies, and design aids. The primary reference used in the preparation of this note is Engineering Design Handbook - Metric Conversion Guide (DARCOM, 1976). A more common reference is Petersen (1980).

INTRODUCTION: The metric system being adopted throughout the United States is the "International System of Units," commonly referred to as SI Units. This is the most widely used system for scientific and technical data and specifications. There are three classes of units in the SI system: base units, supplementary units, and derived units.

1. Base units are physical quantities of measurement which are considered dimensionally independent.
2. Supplementary units are measures of plane angle and solid angle.
3. Derived units are combinations of base units and/or supplementary units. Some derived units have special names.

The following SI standard includes only the units of measurements commonly used in coastal engineering applications. For other SI standards, see the references.

SI UNITS AND SYMBOLS: The standard SI units and symbols are given in Table 1. This table includes the base units, the supplementary units, and the commonly used derived units. Always be sure to use the SI symbols exactly as they are typed on the Table, i.e., upper or lower case.

Some of the derived units in Table 1 can be expressed in terms of other units as well as in terms of base units. It is best to use, and to become familiar with, the unit symbols as given in the Table. For example, pressure (or stress) could be expressed as newtons per square meter (N/m^2), but it is preferable to use pascals (Pa).

TABLE 1 - SI UNITS AND SYMBOLS

QUANTITY	UNIT NAME	UNIT SYMBOL	EXPRESSION IN TERMS OF OTHER UNITS	EXPRESSION IN TERMS OF SI BASE UNITS
		SI Base Units		
length	meter	m	—	m
mass	kilogram	kg	—	kg
time	second	s	—	s
		SI Supplementary Units		
plane angle	radian	rad	—	—
solid angle	steradian	sr	—	—
		Derived Units with Special Names		
frequency	hertz	Hz	—	1/s
force	newton	N	—	$kg \cdot m/s^2$
pressure, stress	pascal	Pa	N/m^2	$kg/(m \cdot s^2)$
energy, work, quantity of heat	joule	J	$N \cdot m$	$kg \cdot m^2/s^2$
power, radiant flux	watt	W	J/s	$kg \cdot m^2/s^3$
		Other Common Derived Units		
acceleration	meter per square second	m/s^2	—	m/s^2
angular acceleration	radian per square second	rad/s^2	—	rad/s^2
angular velocity	radian per second	rad/s	—	rad/s
area	square meter	m^2	—	m^2
density, mass density	kilogram per cubic meter	kg/m^3	—	kg/m^3
energy density	joule per cubic meter	J/m^3	N/m^2	$kg/(m \cdot s^2)$
moment of force	newton meter	$N \cdot m$	$N \cdot m$	$kg \cdot m^2/s^2$
specific energy	joule per kilogram	J/kg	J/kg	m^2/s^2
specific volume	cubic meter per kilogram	m^3/kg	—	m^3/kg
specific weight	newton per cubic meter	N/m^3	N/m^3	$kg/(m^2 \cdot s^2)$
speed, velocity	meter per second	m/s	—	m/s
surface tension	newton per meter	N/m	N/m	kg/s^2
viscosity, dynamic	pascal second	$Pa \cdot s$	$(N \cdot s)/m^2$	$kg/(m \cdot s)$
viscosity, kinematic	square meter per second	m^2/s	—	m^2/s
volume	cubic meter	m^3	—	m^3

UNITS ACCEPTED FOR LIMITED USE: Some units from different systems are accepted for limited use in the SI system. These are shown in Table 2. In certain applications these non-SI units have distinct advantages, such as degrees for plane angles, but their usage should be kept to a minimum with the preferred SI unit being used when possible. For example, liter is restricted to measurement of liquids and gases, and no prefix other than milli- should be used with liter. Likewise, the term hectare (square hectometer) is limited to measurement of land or water areas.

TABLE 2 - UNITS ACCEPTED FOR LIMITED USE

QUANTITY	UNIT NAME	UNIT SYMBOL	EXPRESSION IN TERMS OF OTHER UNITS	EXPRESSION IN TERMS OF SI BASE UNITS
		Accepted		
time	minute	min	—	60 s
time	hour	h	60 min	3 600 s
time	day	d	24 h	86 400 s
plane angle	degree	$^\circ$	—	$(\pi/180)$ rad
Celsius temperature	degree Celsius	$^\circ C$	—	—
volume	liter	ℓ	dm^3	$10^{-3}\ m^3$
mass	tonne	t	—	10^3 kg
		Accepted for Limited Use		
plane angle	minute	'	$(1/60)^\circ$	$(\pi/10\ 800)$ rad
plane angle	second	"	$(1/60)'$	$(\pi/648\ 000)$ rad
energy	kilowatthour	kWh	3.6 MJ	$3.6(10)^6\ kg{\cdot}m^2/s^2$
area	hectare	ha	—	$10^4\ m^2$
length	nautical mile	—	—	1 852 m
speed	knot	—	nautical mile/h	(1 852/3 600) m/s
pressure	bar	bar	10^5 Pa	$10^5\ kg/m{\cdot}s^2$
pressure	standard atmosphere	atm	101 325 Pa	$101\ 325\ kg/m{\cdot}s^2$

MASS, FORCE, AND WEIGHT: The main source of confusion in using SI units is the relationship between kilograms and newtons. The kilogram is a unit of *mass*, and the newton is a unit of *force*. Mass is a property of a body and remains constant for that body. When a body having a certain mass is accelerated, then it exerts a force which is given by Newton's Second Law as:

$$F = m\ a$$

where, F = force (newtons)

m = mass (kilograms)

a = acceleration (meters per second^2).

When the acceleration acting on the mass is the acceleration of gravity (9.80665 meters per second^2), then the resulting force is called *weight*. Since the acceleration of gravity can vary slightly from the standard value given above, the weight of a body can vary as much as 0.5% at different locations on the earth.

In the SI system it is technically incorrect to use kilograms as an expression of weight, but the engineer can expect to frequently encounter weights which are expressed in kilograms. This is a result of former metric systems which expressed weight as kilograms, and also due to the fact that most metric scales use units of kilograms. For example, a person who weighs 150 pounds in the English system will weigh about 68 kilograms on a metric scale. In the SI system, 68 kilograms is the person's *mass*, while the *weight* of this person is about 667 newtons (68 kg x 9.807 m/s^2). When the coastal engineer encounters units of kilograms for weight, he must first convert kilograms to newtons, using the conversion factor given in Table 4, before beginning any design calculations. Instances of when weight might be given in kilograms include: the weight of rubble-mound armor units, the unit weight of sand or fill material, or any other items which has been weighed on a metric scale.

SI PREFIXES: Table 3 lists the prefixes and associated SI symbols likely to be encountered by coastal engineers. When using the SI symbol it is very important to use the upper or lower case as indicated on the Table, since mega-(M) and milli-(m) both use the same letter.

These prefixes are attached to names or symbols of SI units to form powers-of-ten multiples. This helps to eliminate nonsignificant zeros. For example, a loading stress of 190 000 000 pascals (Pa) is better written as 190 mega-pascals (MPa). Never use more than one prefix with an SI symbol (example: 0.002 meters (m) = 2.0 millimeters instead of 2.0 decicentimeters). With the exception of the kilogram (kg), prefixes should not be used in the demoninator of compound units. For example, use millimeter per second (mm/s) for small velocities rather than meters per kilosecond (m/ks).

TABLE 3 - SI PREFIXES

Multiplication Factors	Prefix	SI Symbol
1 000 000 = 10^6	mega	M
1 000 = 10^3	kilo	k
100 = 10^2	hecto*	h
10 = 10^1	deka*	da
0.1 = 10^{-1}	deci*	d
0.01 = 10^{-2}	centi	c
0.001 = 10^{-3}	milli	m
0.000 001 = 10^{-6}	micro	μ

*To be avoided where possible.

Prefixes should be chosen so that the numerical value lies between 0.1 and 1000. For example, 12 200 m is written as 12.2 km. It is best to use prefixes in powers of 3 (i.e., mega-, kilo, milli-, micro-); however, centi- is in common use and often convenient in many cases.

USE OF SI UNITS IN TECHNICAL WRITING: Several style guidelines should be followed when using SI units, symbols, and prefixes.

1. Use lowercase letters for SI unit symbols unless the unit is derived from a proper name (Newton, Hertz, etc.).
2. When the unit name is spelled out in unabbreviated form, it is not capitalized. This is true for all cases (e.g., newtons, hertz).
3. The SI symbols for all prefixes in Table 3, with the exception of M for mega-, are written in lowercase letters.
4. SI symbols are always written in singular form (e.g., 14.2 kg). When spelling out units, form plurals in the usual manner (e.g., 14.2 kilograms).
5. Periods are used in SI symbols only at the end of sentences.
6. No space or hyphen is used between the prefix and the SI unit name (e.g., kilometer, millimeter).
7. A space is left between the numerical value and the unit (e.g., 0.26 kPa).
8. Multiplication of units is given by a raised dot (e.g., N·m), and division by a diagonal line or by a negative power (e.g., N/m or $N \cdot m^{-1}$).
9. In writing numbers having four or more digits, the digits should be placed in groups of three separated by a space and formed by counting both to the left and the right of the decimal point. In the case of exactly four digits the spacing is optional (e.g., 12 345.678 91; 1234 or 1 234; 0.123 456).

METRIC (SI) CONVERSION FACTORS: Table 4 contains conversion factors which are to be used when converting numerical values expressed in English units to their equivalent values expressed in metric (SI) units. The information contained in Table 4 has been condensed from the references and includes only those convertions most likely to occur in coastal engineering. The conversion factors have been given to an accuracy of six significant digits, except in cases when an exact value can be given. To find the metric equivalent of an English value, simply multiply the English value by the conversion factor. For example, to convert 30.4 cubic yards to cubic meters:

$$30.4 \text{ yd}^3 \times 0.764\ 555 = 23.2 \text{ m}^3.$$

TABLE 4 - CONVERSION FACTORS

Multiply	By	To Obtain
Length		
mil	25.4*	micrometers
inches	25.4*	millimeters
	2.54*	centimeters
feet	30.48*	centimeters
	0.304 8*	meters
yards	0.914 4*	meters
fathoms	1.828 8*	meters
statute miles (U.S.)	1 609.344*	meters
	1.609 344*	kilometers
nautical miles (internat.)	1 852.0*	meters
	1.852*	kilometers
Area		
square inches	6.451 6*	square centimeters
square feet	929.030	square centimeters
	0.092 903 0	square meters
square yards	0.836 127	square meters
acres	0.404 686	hectares
	4 046.86	square meters
square miles (U.S. statute)	2.589 99	square kilometers
Volume		
cubic inches	16.387 1	cubic centimeters
cubic feet	0.028 316 8	cubic meters
cubic yards	0.764 555	cubic meters
cubic yards per foot	2.508 38	cubic meters per meter
Liquid Capacity		
fluid ounces (U.S.)	29.573 5	cubic centimeters
	29.573 5	milliliters
liquid pints (U.S.)	0.473 176	liters
quarts (U.S.)	0.946 353	liters
gallons (U.S.)	3.785 41	liters
gallons (U.K.)	4.546 09	liters
cubic feet	28.316 8	liters
acre-feet	1 233.48	cubic meters

*Exact Conversion Value

TABLE 4 - CONVERSION FACTORS, CONTINUED

Multiply	By	To Obtain
Mass		
ounce-mass (avdp)	28.349 5	grams
pound-mass (avdp)	0.453 592 37*	kilograms
slugs	14.593 902 9*	kilograms
short tons (2 000 lbm)	907.185	kilograms
long tons (2 240 lbm)	1 016.05	kilograms
Mass/Time (Mass Flow)		
pound-mass per second	0.453 592	kilograms per second
Mass/Volume (Density)		
ounce-mass per cubic inch	1 729.99	kilograms per cubic meter
pound-mass per cubic foot	16.0185	kilograms per cubic meter
slugs per cubic foot	515.379	kilograms per cubic meter
long ton per cubic yard	1 328.94	kilograms per cubic meter
Force (or Weight)		
pound-force	4.448 22	newtons
kip (1 000 lbf)	4.448 22	kilonewtons
kilograms (weight) (1)	9.806 65	newtons
short tons (2 000 lbf) (1)	8.896 44	kilonewtons
long tons (2 240 lbf) (1)	9.964 01	kilonewtons
Force/Length		
pound-force per foot	14.593 9	newtons per meter
kips per foot	14.593 9	kilonewtons per meter
Force/Area (Pressure or Stress)		
millibar	100.0*	pascals
pound-force per square inch	6.894 76	kilopascals
pound-force per square foot	47.880 3	pascals
short tons per square foot (2)	95.760 5	kilopascals
kilograms per square meter (2)	9.806 65	pascals

*Exact Conversion Value

(1) Technically mass-to-force conversion

(2) Technically mass/area-to-force/area conversion

NOTE: pound-mass (or ounce-mass) refers to the British Type II system where mass is a base unit and force is given as pound-force. In the British Type I system mass is given in slugs and force is a base unit given in pounds. At sea level:

1 pound-mass	= 1 pound-force	= 1 pound
Type II	Type II	Type I

TABLE 4 - CONVERSION FACTORS, CONTINUED

Multiply	By	To Obtain
	Force/Volume (Specific Weight)	
pound-force per cubic inch. .	271.447	kilonewtons per cubic meter
pound-force per cubic foot. .	157.087	newtons per cubic meter
kilograms per cubic meter[3] . .	9.806 65 . . .	newtons per cubic meter
	Bending Moment or Torque	
inch-pounds-force	0.112 985 . .	newton meters
foot-pounds-force	1.355 82 . .	newton meters
	Velocity	
feet per second	0.304 8* . . .	meters per second
miles per hour (statute) . . .	0.447 04* . . .	meters per second
. . . .	1.609 344* . .	kilometers per hour
knots (international)	0.514 444 . .	meters per second
. . . .	1.852*	kilometers per hour
	Acceleration	
feet per second^2	0.3048*	meters per second^2
	Volume/Time (Discharge)	
cubic feet per second	0.028 317* . .	cubic meters per second
cubic yards per year.	0.764 555 . .	cubic meters per year
	Energy or Work	
foot-pounds-force	1.355 82 . . .	joules
kilowatt hours	3.60*	megajoules
British thermal units (Btu)	1 055.06	joules
	Power	
horsepower	745.700	watts
Btu per hour	0.293 071 . .	watts
foot-pound-force per second . .	1.355 82 . . .	watts

*Exact Conversion Value

(3) Technically density-to-specific weight conversion

NOTE: pound-mass (or ounce-mass) refers to the British Type II system where mass is a base unit and force is given as pound-force. In the British Type I system mass is given in slugs and force is a base unit given in pounds. At sea level:

1 pound-mass = 1 pound-force = 1 pound

Type II Type II Type I

TEMPERATURE CONVERSION: The conversion from degrees Fahrenheit to degrees Celsius is given by

$$^{o}C = \frac{5}{9}(^{o}F - 32^{o}) \ ,$$

which can be arranged to give the conversion from degrees Celsius to degrees Fahrenheit as

$$^{o}F = \frac{9}{5}(^{o}C) + 32^{o}$$

SIGNIFICANT DIGITS: When converting quantities from English to SI units, care must be taken to retain a sufficient number of significant digits to reflect the accuracy of the original quantity. Accurate conversions obtained by using conversion factors, generally imply a greater accuracy than the original value. Thus the converted number should be rounded to the proper degree of accuracy. For example, a linear measurement of 14.3 feet converts to 4.358 64 meters, but the measurement is obviously not this accurate. Therefore the result should be rounded to 4.36 meters since 0.1 feet is about 0.03 meters. In other words, linear measurements made to the accuracy of 0.1 feet in the English system could be made to an accuracy of about 0.03 meters in the SI system. The same consideration should be made when converting approximate quantities. For instance, 300 000 cubic yards of fill material converts to about 230 000 cubic meters instead of 229 366 cubic meters.

METRIC VALUES FOR PHYSICAL CONSTANTS: The primary physical constants used in coastal engineering are the properties of water. The metric equivalents of these properties are given in Table 5.

TABLE 5 - PHYSICAL PROPERTIES OF WATER

Property	Freshwater		Saltwater (35 $^{o}/oo$)	
	$10^{o}C$ ($50^{o}F$)	$20^{o}C$ ($68^{o}F$)	$10^{o}C$ ($50^{o}F$)	$20^{o}C$ ($68^{o}F$)
Density, ρ	999.63 kg/m^3	998.13 kg/m^3	1026.84 kg/m^3	1024.68 kg/m^3
Specific Weight, γ ($\gamma = \rho g$)	9.8030 kN/m^3	9.7883 kN/m^3	10.070 kN/m^3	10.0487 kN/m^3
Dynamic Viscosity, μ	$1.3076(10)^{-3}$ Pa·s	$1.0048(10)^{-3}$ Pa·s	$1.3927(10)^{-3}$ Pa.s	$1.0826(10)^{-3}$ Pa·s
Kinematic Viscosity, ν ($\nu = \mu/\rho$)	$1.3081(10)^{-6}$ m^2/s	$1.0067(10)^{-6}$ m^2/s	$1.3563(10)^{-6}$ m^2/s	$1.0565(10)^{-6}$ m^2/s

Additional physical constants which may be helpful are given in Table 6. Any other necessary constants can be easily converted from their English system value by using the conversion factors given in Table 4.

RULES OF THUMB: All engineers through their experience, develop a *feel* for what the magnitude of certain quantities should be. For example, the maximum flow velocity through a tidal inlet is probably between 1 to 4 feet per second. This experience, and the ability to estimate the probable order of magnitude, serves as a valuable check on the engineer's work. For instance, if a calculation revealed that the inlet tidal flow was 18 feet per second, or a calculated wave height for average conditions was 62 feet, the engineer would suspect an error in the analysis.

TABLE 6 - MISCELLANEOUS CONSTANTS

Gravitational Acceleration, g	9.8067 m/s^2
Atmospheric Pressure, P (standard)	101.33 kPa
Pressure of 1 inch of mercury at 15.6°C (60°F)	3.3769 kPa
Pressure of 1 foot of water at 15.6°C (60°F)	2.9861 kPa
Pressure of 1 meter of water at 15.6°C (60°F)	9.7969 kPa

In making the changeover to the metric system the engineer loses all of his *feel*. For this reason, the coastal engineer must be particularly careful when first starting out using the SI system. One way to check metric quantities is to convert them into the familiar English units to see if the answer is in the expected range. However, this often would not be necessary if a few simple approximate conversions are committed to memory. These allow the engineer to mentally convert from SI to English units to get an approximate result which can then be judged according to the engineer's *feel* for what the value should be. This method is particularly useful in the field, where conversion factors may not be readily available.

As an example of an approximate conversion, most people remember that 1 meter is a little more than 3 feet. Therefore, a 5-meter-high wave is about 5 x 3 = 15 feet high. While the error of this approximation is about 9%, it still provides a *feel* for the height of a 5-meter-high wave.

Table 7 provides similar "rules of thumb" which can be used to mentally convert metric values to English values. The coastal engineer may develop other approximations to suit his individual use of the SI system.

TABLE 7 - RULES OF THUMB

Multiply	By	To Approx.	Error
meters	3	feet	9%
kilometers	0.6	miles	3%
square meters	10	square feet	7%
cubic meters	35	cubic feet	1%
cubic meters	1.3	cubic yards	1%
meters/second	3	feet/second	9%
kilometers/hour	0.6	miles/hour	3%
newtons	0.2	pounds	11%
kilopascals	0.15	pounds/$inch^2$	3%
kilopascals	20	pounds/$feet^2$	4%
kilonewtons/$meter^3$	6	pounds/$feet^3$	6%

Acceleration of gravity ≈ 9.81 m/s^2
Density of freshwater ≈ 1 000 kg/m^3
Unit weight of freshwater ≈ 9.80 kN/m^3
Unit weight of saltwater ≈ 10.05 kN/m^3
3 000 psi concrete ≈ 20 MPa concrete

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The following examples illustrate the use of the metric (SI) conversion factors:

EXAMPLE 1

REQUIRED: Convert a force of 551 pounds to SI units.

SOLUTION: From Table 4, multiply pounds by 4.448 22 to obtain force in newtons.

$$(551\ \cancel{lb})\quad\left(\frac{4.448\ 22\ N}{1\ \cancel{lb}}\right) = 2\ 450 \text{ newtons} = 2.45 \text{ kN}$$

EXAMPLE 2

REQUIRED: Find the force exerted by a rubble-mound armor unit whose "weight" (mass) is given in non-SI units of 7 224 kilograms.

SOLUTION: From Table 4, multiply kilograms by 9.806 65 to obtain force in newtons.

$$(7\ 224\ \cancel{kg})\quad\left(\frac{9.806\ 65\ N}{1\ \cancel{kg}}\right) = 70\ 840 \text{ newtons} = 70.84 \text{ kN}$$

EXAMPLE 3

REQUIRED: Convert 15 Megapascals to pounds per square inch.

SOLUTION: Making conversions from metric (SI) units can be done by dividing the metric value by the appropriate conversion factor given in Table 4. For this example, 1 lb/inch^2 = 6.894 76 kilopascals, and the conversion is (noting 1 MPa = 1 000 kPa):

$$(15\ \cancel{MPa})\quad\left(\frac{1\ 000\ \cancel{kPa}}{1\ \cancel{MPa}}\right)\quad\left(\frac{1\ lb/in^2}{6.894\ 76\ \cancel{kPa}}\right) = 2\ 175\ lb/in^2$$

EXAMPLE 4

REQUIRED: Derive a conversion factor for converting energy per unit area (i.e., wave energy density in lb-ft/ft^2) to SI units.

SOLUTION: This can be done using the conversion factors from Table 4 by setting up the conversion equation so that the units cross-cancel. This is illustrated below.

$$\left(\frac{\cancel{lb\text{-}ft}}{\cancel{ft^2}}\right)\quad\left(\frac{1.355\ 82\ J}{1\ \cancel{lb\text{-}ft}}\right)\quad\left(\frac{1\ \cancel{ft^2}}{0.092\ 903\ m^2}\right) = J/m^2$$

or multiply lb-ft/ft^2 by 14.593 9 to obtain J/m^2.

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ADDITIONAL INFORMATION:
Call CEREN-CD at (202) 325-7172 for further information on the correct usage of the metric (SI) system.

REFERENCES:

PETERSEN, M.S., "Recommendations for Use of SI Units in Hydraulics," *Proceedings of the American Society of Civil Engineers, Journal of the Hydraulic Division*, ASCE, Vol. 106, No. HY 12, Dec. 1980, pp. 1981-1993.

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