SEAW's Handbook of a Rapid-Solutions Methodology™ for Wind Design

By Ed Huston, P.E., S.E.

Wind design, in the legacy codes between 1961 and 1982, generally consisted of using a table of pressures which varied with height. These tables were based on the American Standards Association's *ASA Standard A58-1955, Minimum Design Loads for Buildings and Other Structures*. This document later became American National Standards Institute's *ANSI A58.1-1972*. The problem with these simple tables of pressures was that they didn't account for wind uplift or higher design pressures for components and cladding. In the mid-1970s, writers of the legacy codes started to transition to more modern wind standards. ANSI A58.1 was further updated in 1982. The document then came under the purview of the American Society of Civil Engineers (ASCE) as *Minimum Design Loads for Buildings and Other Structures, ASCE 7*.

Structural engineers on the west coast wanted to maintain user-friendly wind design provisions, since for the majority of their designs, seismic forces for the overall lateral force resisting system were far greater than the wind forces predicted by ANSI A58.1. In other words, for the majority of structures designed on the west coast, "seismic governed." The 1982 *Uniform Building Code* (UBC) contained the first step in the transition from using a table of pressures that varied with height to the more modern, but simplified, wind provisions. These provisions were updated in the 1994 UBC. Structural engineers from the Structural Engineers Association of California (SEAOC), the Structural Engineers Association of Oregon (SEAO), and the Structural Engineers Association of Washington (SEAW) formed the Tri-States Wind Committee to help facilitate this work. The Tri-States Wind Committee prepared a code change proposal to the *2000 International Building Code* (IBC) to introduce a simplification of the American Society of Civil Engineer's ASCE 7-98 *Method 2 Analytical Procedure for Rigid Buildings of All Heights* (Method 2). This effort was unsuccessful.

Between 1999 and 2004, the SEAW Wind Engineering Committee worked on the *SEAW Commentary on Wind Code Provisions* (Commentary), which was published by the Applied Technology Council (ATC) as SEAW/ATC 60. This document was the first comprehensive commentary on wind code provisions written by and for practicing structural engineers. Published in two volumes, the first volume contains 17 chapters of explanations, illustrations, and commentaries. The second volume contains worked out examples of wind load calculations for the main wind force resisting system, and for components and cladding for six buildings which vary in height from one to seven stories; for a freestanding sign; and for an open frame tower. These example problems utilize every possible wind design option allowed in the 2000 or 2003 IBC or in ASCE 7-98 or 7-02, with the exception of the wind tunnel option. The wind tunnel option is, however, discussed in volume one of ATC 60.

Concurrently, the SEAW Wind Engineering Committee worked on *SEAW's Handbook of a Rapid-Solutions Methodology (RSM) for Wind Design*, which was also published by the Applied Technology Council as SEAW RSM-03. This companion document to SEAW's Commentary provides the same kind of simplification of ASCE 7-02 Method 2 that the UBC provided from 1982 to 1997 for the ANSI A58.1 documents. By basing the simplification on ASCE 7-02 Method 2, SEAW created a methodology that could be used for the vast majority of buildings being designed in the United States today.

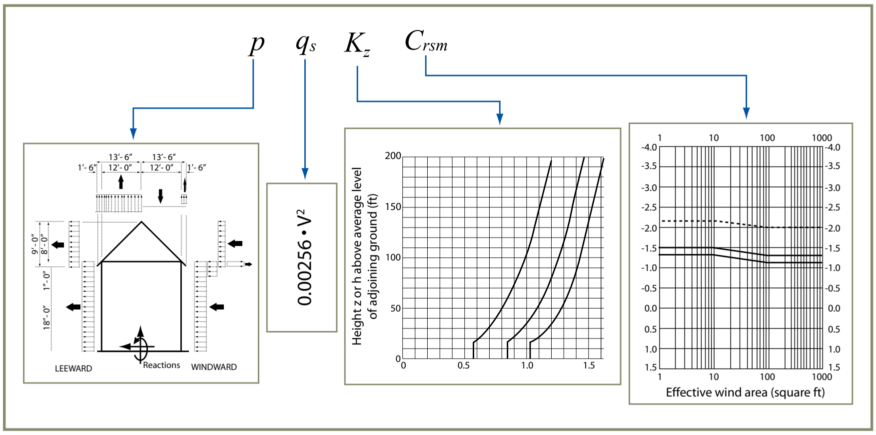


Figure 1: The road map for calculating wind pressures.

Basis of the Simplification

ASCE 7 Method 2 is built around two fundamental equations; the velocity pressure, q_z, equation and the design wind pressure, p, equation:

$$q_z = 0.00256\, K_z K_{zt} K_d V^2 I$$

$$p_{ASCE} = qGC_p - q_i(GC_{pi})$$

The velocity pressure equation has been modified over the years to introduce additional concepts, such as the height and exposure factor, K_z and the importance factor, I. More recent additions include the directionality factor, K_d, and the topographic factor, K_{zt}. These two equations, when combined, represent the Bernoulli Equation written for wind, which is an unwieldy equation as follows:

$$p_{ASCE} = 0.00256 V^2 K_d I\, [K_z K_{zt} GC_p - K_{zi} K_{zti}\,(GC_{pi})]$$

This expression is comparable to the seismic equivalent lateral force procedure. That is, it represents a conservative expression of wind forces for design of the structure and converts the chaotic nature of wind forces on a building to an elastic basis. In a similar way, the seismic equivalent lateral force procedure presents a generally conservative expression of the dynamic nature of a building's response to seismic inertial forces. Nonetheless, this expression for wind forces on a building can be confusing and needlessly cumbersome.

The RSM simplifies this cumbersome equation into:

$$p_{rsm} = q_s K_z C_{rsm} I_w K_t$$

where q_s is the wind velocity pressure $0.00256\ V^2$.

To make this simplification, the C_{rsm} term was derived as follows:

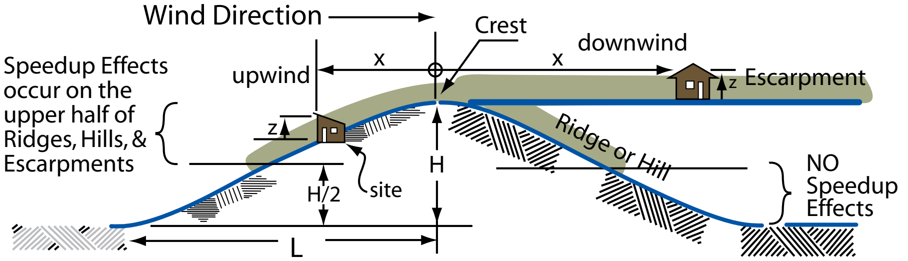
$C_{rsm} = K_d [GC_p – GC_{pi}] = (0.85) [0.85C_p - GC_{pi})]$

In making this simplification, the directionality factor, K_d, is taken as 0.85 which is appropriate for all buildings, signs, and towers according to ASCE-7 Table 6-4. The gust factor, G, is also taken as 0.85 per ASCE 7-02 Section 6.5.8.1 for rigid structures. Another manipulation involved in using C_{rsm} is to algebraically add internal and external pressures. Resulting charts and graphs of C_{rsm} values were adjusted to be generally conservative. Addition of internal and external pressures isn't new to the RSM. ASCE-7 *Method 1 – Simplified Procedure* (Method 1) also uses this formulation. Addition of internal and external pressures is appropriate for simple diaphragm type buildings where windward and leeward walls are tied together by members such that internal pressures on these surfaces cancel each other out. In fact, this condition exists in the vast majority of structures engineers design. A notable exception is a type of rigid frame building typically thought of as a pre-engineered metal building. This simplification allows for a rapid and easy determination of the net effect of combined external and internal pressures, and eliminates up to four possible load cases. It also saves time by eliminating two-way interpolation of values for C_p between various shape factors and roof angles.

There have been numerous calls for code simplification recently, and the RSM is a rational type of simplification. Some types of proposed simplifications penalize a design by increasing force levels or detailing provisions. In order to gain simplicity, the design must be made more robust. The RSM simplification is still in conformance with the more complex method in ASCE 7-05, and, being a reformatting of the ASCE 7 equations, provides virtually the same values as Method 2, thus not penalizing the design.

Natural Frequency

The RSM is limited to rigid structures because it utilizes a gust factor, G, of 0.85. ASCE 7 defines a rigid building as "A building or other structure whose fundamental frequency is greater than or equal to 1 Hz." The commentary of ASCE 7 goes on to state, "When buildings or other structures have a height exceeding four times the least horizontal dimension or when there is reason to believe that the natural frequency is less than 1 Hz (natural period greater than 1 s), the natural frequency for it should be investigated." The ASCE 7 commentary explains the difference between the natural frequency calculated by approximate methods for seismic design and appropriate estimates of natural frequency for wind design. Approximate equations of natural frequency developed for seismic design tend to give higher estimates of the natural frequency (lower estimates of the structure's period), as this gives conservative approximations of the seismic base shear. For



L is assumed to be twice the width at the midheight of the slope.

Elevation Section of a Shallow Ridge, Hill, or Escarpment
where 1/10 < H/L < 1/4

K_1 values for steep slope **H/L =1/4**					
Exposure Class	Continuous Ridge	Flat Topped Ridge	Hill	Flat Topped Hill	Continuous Escarpment
B	0.65	0.58	0.48	0.43	0.38
C	0.73	0.63	0.53	0.48	0.43
D	0.78	0.68	0.58	0.53	0.48

For shallow upwind slopes where H/L < 1/4 the speedup effect is reduced from the steep slope values above, in proportion to its steepness, and the appropriate K_1 value is obtained by multiplying the steep slope values above by 4(H/L).

Examples:

for 1/5 slope, K_1 = 80% of the values above
for 1/6 slope, K_1 = 67% of the values above
for 1/7 slope, K_1 = 57% of the values above
for 1/8 slope, K_1 = 50% of the values above
for 1/9 slope, K_1 = 44% of the values above
for 1/10 slope, K_1 = 40% of the values above

Expressed as an angle, this modifying coefficient would be 4(tan Φ), where "Φ" represents the angle of the slopefrom the horizontal.

Length "L" is very important for shallow slopes.
Height "H" is of minor importance, since it only influences the K_1 coefficient.

K_2 Multiplier			K^3 Multiplier			
$\frac{x}{L}$	Ridges or Hills	Contiuous Escarpment	$\frac{z}{L}$	Continuous Ridge	Hill	Continuous Escarpment
0	1	1	1	0	0	0.01
0.02	0.97	0.99	0.75	0.01	0	0.02
0.05	0.93	0.98	0.5	0.05	0.02	0.08
0.1	0.87	0.95	0.4	0.09	0.04	0.14
0.2	0.73	0.9	0.3	0.17	0.09	0.22
0.3	0.6	0.85	0.2	0.3	0.2	0.37
0.4	0.47	0.8	0.18	0.34	0.24	0.41
0.5	0.33	0.75	0.16	0.38	0.28	0.45
0.6	0.2	0.7	0.14	0.43	0.33	0.5
0.7	0.07	0.65	0.12	0.49	0.38	0.55
0.8	0	0.6	0.1	0.55	0.45	0.61
1		0.5	0.08	0.62	0.53	0.68
1.2		0.4	0.06	0.7	0.62	0.74
1.4		0.3	0.04	0.79	0.73	0.82
1.6		0.2	0.02	0.89	0.85	0.9
1.8		0.1	0.01	0.94	0.92	0.95
2		0	0	1	1	1
$\frac{x}{L}$	$K_2 = 1 - \frac{4x}{3L}$	$K_2 = 1 - \frac{x}{2L}$	$\frac{z}{L}$	$K_3 = e^{-6z/L}$	$K_3 = e^{-8z/L}$	$K_3 = e^{-5z/L}$

$K_T = [1 + K_1 \bullet K_2 \bullet K_3]^2$ *Equation 2-3*

Figure 2: The simplified topographic factor for features with a slope of 5.7 through 14 degrees.

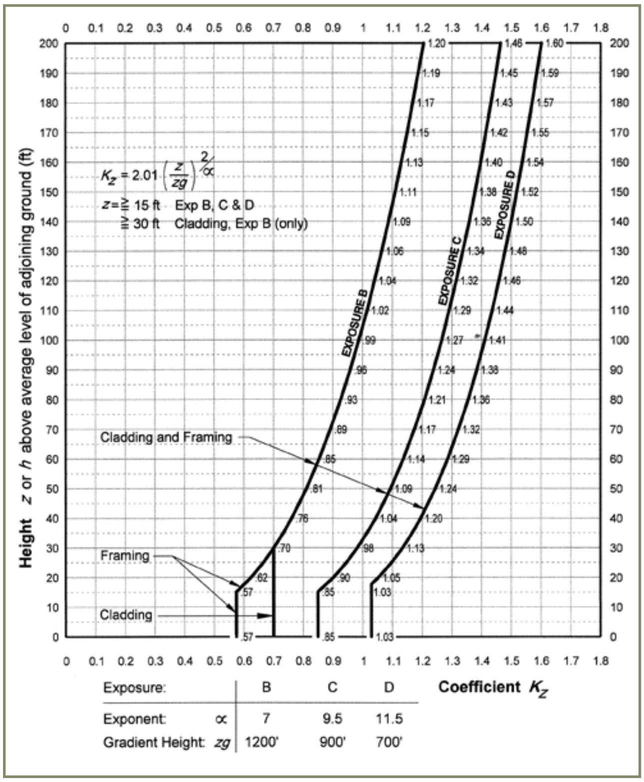


Figure 3: The Simplified Height and Exposure Factor

wind design, the opposite case exists. That is, these higher estimates of the structure's natural frequency can incorrectly categorize very slender buildings as rigid, when they are, in fact, flexible. Alternate equations for natural frequency of various building types, and comparison of results of these equations to values used in other countries, are given in the ASCE 7-05 commentary. When using ASCE 7, or the RSM, an engineer needs to determine whether the structure can be categorized as rigid.

Topographic Factor

ASCE 7 and the RSM both utilize a topographic factor. This factor was first introduced into the ASCE 7 methodology in ASCE 7-98. The equations in ASCE 7 used to calculate the topographic factor are approximations derived from curve fitting these equations to the accumulated data from wind tunnel tests. The equations and curves are complex, and the use of footnotes is confusing. Experienced engineers often miscalculate the topographic factor. SEAW's Wind Engineering Committee found a way to simplify this calculation. Much of the confusion in the calculation of K_{zt} is based on how the equations or charts are manipulated when the height of the topographic feature exceeds half of L_h, the half-length of the topographic feature. This occurs at a slope of 14 degrees. SEAW's RSM includes two charts for the topographic factor. One chart covers features with a slope greater than 14 degrees; the other covers those with a slope of 5.7 through 14 degrees. By using two figures in the RSM, **all** footnotes in ASCE 7 used for determining the topographic factor were eliminated!

Height and Exposure Factor

The RSM uses a velocity pressure exposure coefficient, K_z, as does ASCE 7. To highlight the basis of the K_z value, and to make it easier and faster to determine the K_z value, the RSM plots out values versus height and shows values for different exposures. It also puts equations and constants on the graph to aid those who want to create spreadsheets. The graphs also show where Case 2 controls for Exposure B and, thus, should eliminate the often-asked questions about Case 1 and Case 2 for Exposure B.

Torsion

Wind torsional load cases were changed in ASCE 7-02. ASCE 7-05 did not change those load cases again, but did make it explicit that Method 1 can not be used if a building is torsionally sensitive, unless it is a one story building with h less than or equal to 30 feet; a building two stories or less in height framed with light frame construction; or a building two stories or less in height designed with flexible diaphragms. The RSM does not have a simplification for torsion. Whether using ASCE 7 or the RSM, torsion must be checked.

C_{rsm} for the Main Wind Force Resisting System

The use of ASCE 7 Figure 6-6 to determine the "External Pressure Coefficient, C_p" is not easy or intuitively obvious. Graders of structural exams have observed that experienced engineers frequently make mistakes when using this figure. The RSM provides four pages of charts to determine C_{rsm} values for windward and leeward walls and roofs, and for sidewalls of enclosed or partially enclosed buildings subjected to ballooning (positive internal pressure) or deflation (negative internal pressure). The RSM charts utilize graphic icons, in addition to chart titles, to aid the user in determining the correct values, thus saving considerable time and greatly minimizing chances of error.

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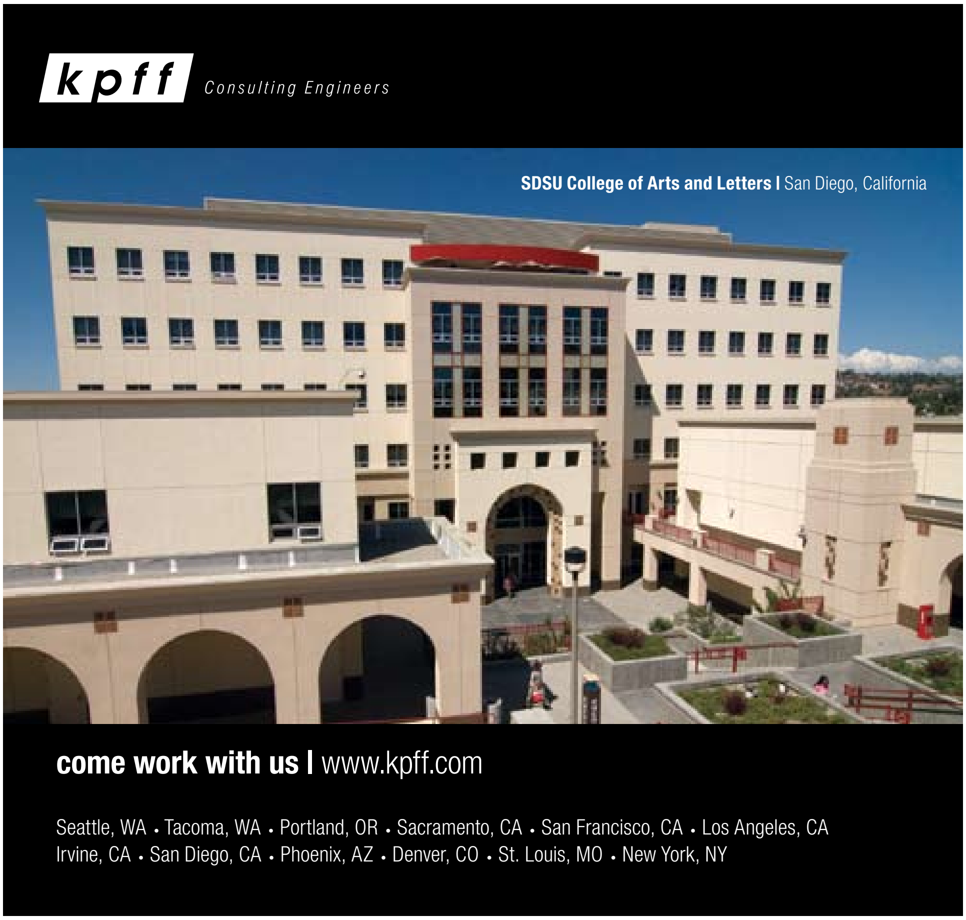

C_{rsm} for Components and Cladding

The RSM provides 64 pages of charts to determine C_{rsm} values for the most common configurations of walls and roofs. Wall charts are repeated multiple times to place them adjacent to each roof chart, so that users do not have to continually flip back and forth. Users can simply open the book to the appropriate roof chart, based on the roof slope and configuration, and have all the information needed for both walls and roofs on two facing pages. These charts are arranged for either enclosed or partially enclosed buildings subjected to either ballooning or deflation. The use of graphic icons is continued on these charts, again aiding users in determining correct values, thus saving considerable time and greatly minimizing chances of error.

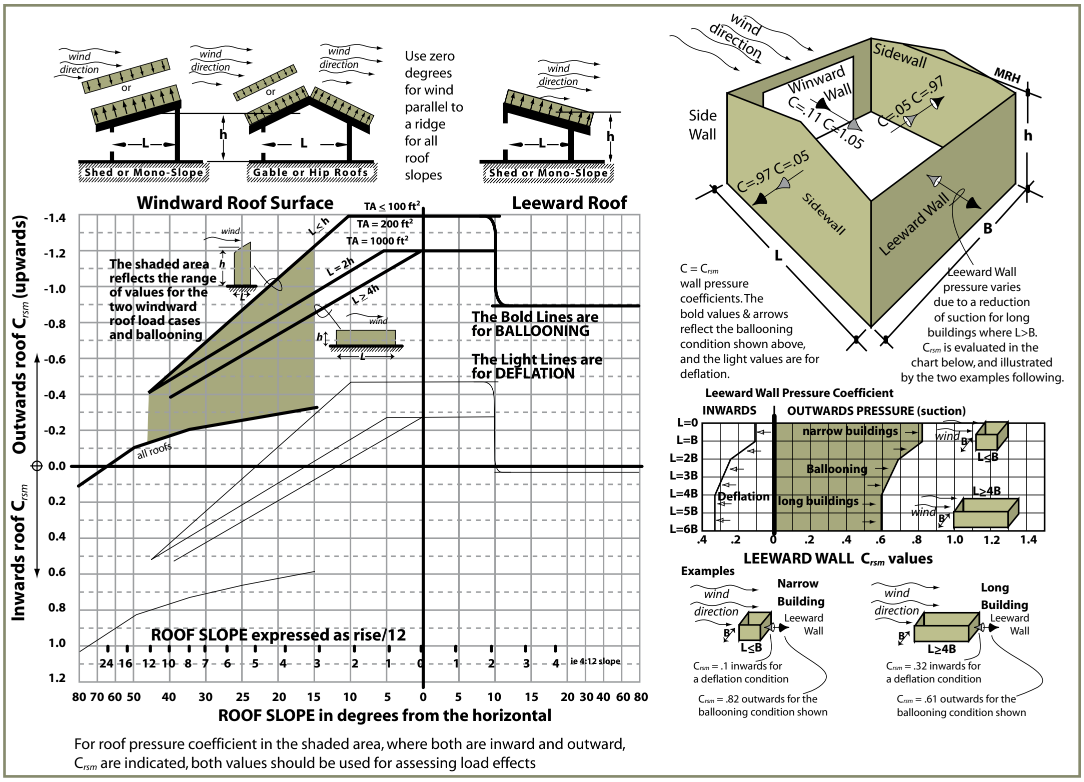

Figure 4: C_{rsm} for the Main Wind Force Resisting System

SEAW *Rapid-Solution Methodology*™ and the *2006 IBC*:

The SEAW Wind Engineering Committee is working on an update for its Commentary and RSM to address changes in ASCE 7-05 and in the *2006 IBC*, and to make minor improvements in format and content. ASCE 7-05 made many changes to wind provisions, but did not change the basic equations of Method 2. The small changes made in this section consist of minor tweaks to the definition of exposure categories, a better definition of how to estimate wind speeds from regional climatic data, specification of ANSI Standards for resistance to glazing damage in wind-borne debris regions, and a slight reduction in parapet C_p values for main wind force resisting systems. These minor changes do not affect, or invalidate, the use of the RSM. They do make its use slightly more conservative than ASCE 7-05 if the building has a parapet due to the decrease in parapet pressures in ASCE 7-05.

Major changes were made to the design of open buildings and solid freestanding signs and solid freestanding walls. However, the vast majority of engineers design very few, if any open buildings, or fences. Therefore, the SEAW RSM can continue to be used with the 2006 IBC and ASCE 7-05 for the design of almost all structures, until new versions of the documents are published, later this year or early in 2008.▪

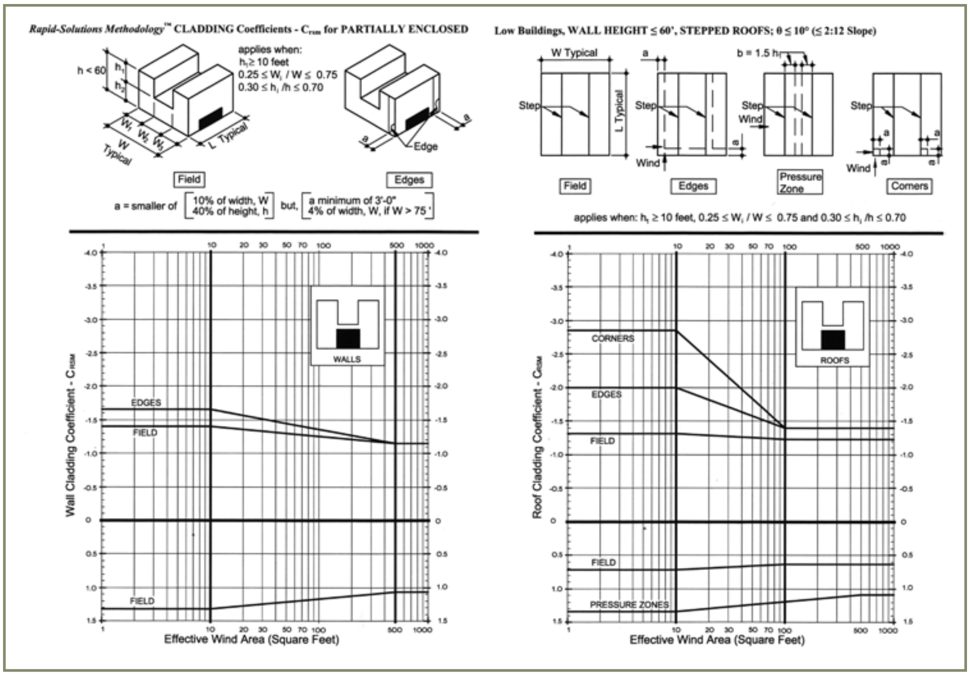

Figure 5: C_{rsm} for Components and Cladding.

Ed Huston, P.E., S.E., has over 35 years of experience in structural design, evaluation, investigation, and code and standards development. Ed is a co-author of the Wind Commentary to the Uniform Building Code (1991 Edition & 1994 Editions), ATC-60, SEAW Commentary on Wind Code Provisions, as well as the SEAW RSM-03, SEAW's Handbook of a Rapid Solution Methodology™ for Wind Design. He also served on the Project Engineering Panel for the ATC Design Guide 2: Basic Wind Engineering of Low-Rise Buildings and currently serves as President of the Board of Directors of NCSEA.

Graphics have been published in the 2004 SEAW's *Handbook of a Rapid-Solutions Methodology™ for Wind Design SEAW RSM-03*.