category and exposure category, the following more mathematical description is offered for guidance (Irwin 2006). The ground surface roughness is best measured in terms of a roughness length parameter called z_0. Each of the surface roughness categories B through D correspond to a range of values of this parameter, as does the even rougher category A used in previous versions of the standard in heavily built-up urban areas but removed in the present edition. The range of z_0 in ft (m) for each terrain category is given in Table C26.7-1. Exposure A has been included in Table C26.7-1 as a reference that may be useful when using the Wind Tunnel Procedure. Further information on values of z_0 in different types of terrain can be found in Simiu and Scanlan (1996) and Table C26.7-2 based on Davenport et al. (2000) and Wieringa et al. (2001). The roughness classifications in Table C26.7-2 are not intended to replace the use of exposure categories as required in the standard for structural design purposes. However, the terrain roughness classifications in Table C26.7-2 may be related to ASCE 7 exposure categories by comparing z_0 values between Table C26.7-1 and C26.7-2. For example, the z_0 values for Classes 3 and 4 in Table C26.7-2 fall within the range of z_0 values for Exposure C in Table C26.7-1. Similarly, the z_0 values for Classes 5 and 6 in Table C26.7-2 fall within the range of z_0 values for Exposure B in Table C26.7-1.

Research described in Powell et al. (2003), Donelan et al. (2004), and Vickery et al. (2008b) showed that the drag coefficient over the ocean in high winds in hurricanes did not continue to increase with increasing wind speed as previously believed (e.g., Powell 1980). These studies showed that the sea surface drag coefficient, and hence the aerodynamic roughness of the ocean, reached a maximum at mean wind speeds of about 30 m/s. There is some evidence that the drag coefficient actually decreases (i.e., the sea surface becomes aerodynamically smoother) as the wind speed increases further (Powell et al. 2003) or as the hurricane radius decreases (Vickery et al. 2008b). The consequences of these studies are that the surface roughness over the ocean in a hurricane is consistent with that of exposure D rather than exposure C. Consequently, the use of exposure D along the hurricane coastline is now required.

For Exposure B the tabulated values of K_z correspond to z_0 = 0.66 ft (0.2 m), which is below the typical value of 1 ft (0.3 m), whereas for Exposures C and D they correspond to the typical value of z_0. The reason for the difference in Exposure B is that this category of terrain, which is applicable to suburban areas, often contains open patches, such as highways, parking lots, and playing fields. These cause local increases in the wind speeds at their edges. By using an exposure coefficient corresponding to a lower than typical value of z_0, some allowance is made for this. The alternative would be to introduce a number of exceptions to use of Exposure B in suburban areas, which would add an undesirable level of complexity.

The value of z_0 for a particular terrain can be estimated from the typical dimensions of surface roughness elements and their spacing on the ground area using an empirical relationship, due to Lettau (1969), which is

$$z_0 = 0.5 H_{ob} \frac{S_{ob}}{A_{ob}} \qquad \text{(C26.7-1)}$$

where

H_{ob} = the average height of the roughness in the upwind terrain

S_{ob} = the average vertical frontal area per obstruction presented to the wind

A_{ob} = the average area of ground occupied by each obstruction, including the open area surrounding it

Vertical frontal area is defined as the area of the projection of the obstruction onto a vertical plane normal to the wind direction. The area S_{ob} may be estimated by summing the approximate vertical frontal areas of all obstructions within a selected area of upwind fetch and dividing the sum by the number of obstructions in the area. The average height H_{ob} may be estimated in a similar way by averaging the individual heights rather than using the frontal areas. Likewise A_{ob} may be estimated by dividing the size of the selected area of upwind fetch by the number of obstructions in it.

As an example, if the upwind fetch consists primarily of single family homes with typical height H_{ob} = 20 ft (6 m), vertical frontal area (including some trees on each lot) of 1,000 ft^2 (100 m^2), and ground area per home of 10,000 ft^2 (1,000 m^2), then z_0 is calculated to be $z_0 = 0.5 \times 20 \times 1{,}000/10{,}000 = 1$ ft (0.3 m), which falls into exposure category B according to Table C26.7-1.

Trees and bushes are porous and are deformed by strong winds, which reduce their effective frontal areas (ESDU, 1993). For conifers and other evergreens no more than 50 percent of their gross frontal area can be taken to be effective in obstructing the wind. For deciduous trees and bushes no more than 15 percent of their gross frontal area can be taken to be effective in obstructing the wind. Gross frontal