that any blockage narrower than 30 ft would trap some or all of the transported debris. Likewise, typical root mass diameters are on the order of 3 to 5 ft, and it is therefore assumed that blockages of this width would fully trap any trees or long logs. Recommended values for the blockage coefficient are given in Table C5-3 and Fig. C5-2 based on interpolation between these limits. No test data are available to fully validate the recommended values of this coefficient.

The *maximum response ratio,* $R_{\max}$, is used to increase or decrease the computed load, depending on the degree of compliance of the building or building component being struck by debris. Impact loads are impulsive in nature, with the force rapidly increasing from zero to the maximum value in time Δt, then decreasing to zero as debris rebounds from the structure. The actual load experienced by the structure or component will depend on the ratio of the impact duration Δt relative to the natural period of the structure or component, T_n. Stiff or rigid buildings and structures with natural periods similar to the impact duration will see an amplification of the impact load. More flexible buildings and structures with natural periods greater than approximately four times the impact duration will see a reduction of the impact load. Likewise, stiff or rigid components will see an amplification of the impact load; more flexible components will see a reduction of the impact load. Successful use of Eq. C5-3, then, depends on estimation of the natural period of the building or component being struck by flood-borne debris. Calculating the natural period can be carried out using established methods that take building mass, stiffness, and configuration into account. One useful reference is Appendix C of ACI 349 (1985). Design professionals are also referred to Chapter 9 of ASCE 7 for additional information.

Natural periods of buildings generally vary from approximately 0.05 s to several seconds (for high-rise, moment frame structures). For flood-borne debris impact loads with a duration of 0.03 s, the critical period (above which loads are reduced) is approximately 0.11 s (see Table C5-4). Buildings and structures with natural periods above approximately 0.11 s will see a reduction in the debris impact load, while those with natural periods below approximately 0.11 s will see an increase.

Recent shake table tests of conventional, one- to two-story wood-frame buildings have shown natural periods ranging from approximately 0.14 s (7 Hz) to 0.33 s (3 Hz), averaging approximately 0.20 s (5 Hz). Elevating these types of structures for flood-resistant design purposes will act to increase these natural periods. For the purposes of flood-borne debris impact load calculations, a natural period of 0.5 to 1.0 s is recommended for one- to three-story buildings elevated on timber piles. For one- to three-story buildings elevated on masonry columns, a similar range of natural periods is recommended. For one- to three-story buildings elevated on concrete piles or columns, a natural period of 0.2 to 0.5 s is recommended. Finally, design professionals are referred to Section 12.8.2 of this standard, where an approximate natural period for one- to 12-story buildings (story height equal to or greater than 10 ft [3 m]), with concrete and steel moment-resisting frames, can be approximated as 0.1 times the number of stories.

Special Impact Loads. U.S. Army Corps of Engineers (1995) states that, absent a detailed analysis, special impact loads can be estimated as a uniform load of 100 lb per ft (1.48 kN/m), acting over a 1 ft (0.31 m) high horizontal strip at the design flood elevation or lower. However, Kriebel et al. (2000) suggests that this load may be too small for some large accumulations of debris and suggests an alternative approach involving application of the standard drag force expression

$$F = (1/2)C_D\rho AV^2 \qquad \text{(C5-4)}$$

where

F = drag force due to debris accumulation, in lb (N)
V = flow velocity upstream of debris accumulation, in ft/s (m/s)
A = projected area of the debris accumulation into the flow, approximated by depth of accumulation times width of accumulation perpendicular to flow, in ft^2 (m^2)
ρ = density of water in slugs/ft^3 (kg/m^3)
C_D = drag coefficient = 1

This expression produces loads similar to the 100 lb/ft guidance from U.S. Army Corps of Engineers (1995) when the debris depth is assumed to be 1 ft and when the velocity of the floodwater is 10 ft/s. Other guidance from Kriebel et al. (2000) and Haehnel and Daly (2001) suggests that the depth of debris accumulation is often much greater than 1 ft, and is only limited by the water depth at the structure. Observations of debris accumulations at bridge piers listed in these references show typical depths of 5 to 10 ft, with horizontal widths spanning between adjacent bridge piers whenever the spacing of the piers is less than the typical log length. If debris accumulation is of concern, the design professional should specify the projected area of the debris