Mean Drag Coefficients for Very Porous Golf Driving Range Netting

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Introduction

In dense urban environments the tops of tall buildings may be used for multi-level golf driving ranges. The perimeters of these roof areas have tall, porous nets, which curve inwards at the top, to keep the balls from flying into the street or neighbouring buildings. This type of driving range is particularly popular in Japan. A similar vertical style of netting is also used on land-based golf courses to protect adjacent roads, as shown in Figure 1. In order to assess the wind loads on the vertical or inclined support structures more accurately a client wished to know the mean drag coefficient that could be associated with this very open, flexible netting.

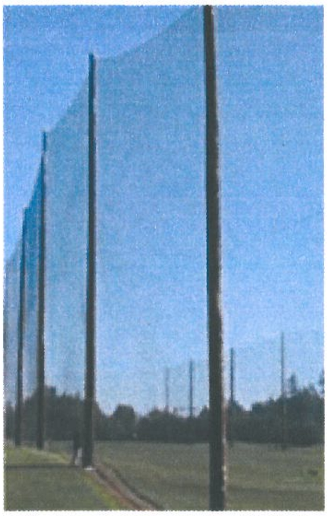

Figure 1: Very porous barrier netting is used around many sports facilities, such a golf course near a busy road (shown) or even on the roofs of tall buildings.

Materials

The netting is shown in Figure 2 at approximately full scale. It is a knotted weave of twine with many nominally square holes. The diagonal opening dimension is about 30 mm and the twine diameter is about 1.2 mm. The relatively large distance between successive twine elements suggests that one might be able to estimate the total drag by summing the drag on the individual woven elements - since interference should be quite small in such an open weave. The impact of the knot at each intersection on the total drag coefficient could not be easily estimated. Thus, the manufacturer decided to proceed with direct netting measurements of mean drag coefficients in the wind tunnel using a force balance.

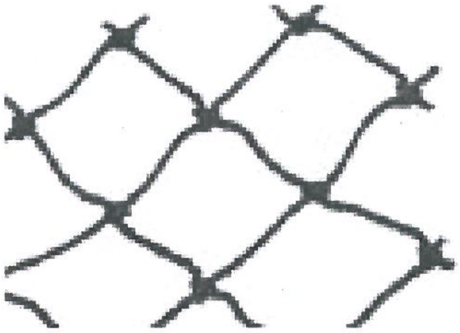

Figure 2: The open-weave sports barrier netting has an approximately square opening with a 30 mm diagonal dimension. The twine used was about 1.2 mm in diameter.

Methodology and Results

A sample of this open netting was installed on a frame attached to the sting of a strain-gauged force balance, as shown in Figure 3. By repeating all the measurements with and without the netting on the frame one could subtract out the mean load of the steel frame and force-balance sting, yielding the drag on the netting material.

Since the prime use for this product was on rooftop golf driving ranges it was decided that the mean velocity profile approaching the sample should be uniform with height (i.e. representing a small vertical section of the mid atmospheric boundary layer well above the ground). This flow condition should also produce conservative data for the ground installation case. Using the clean wind-tunnel floor shown in Figure 3 easily created this uniform flow at the frame height. By using the elevated sting to support the frame, with the netting attached, the small boundary layer on the smooth wind-tunnel floor could be avoided (see Figure 4). The rooftop location also results in a design that leans away from the vertical towards the golfer – an inwardly curved wall of porous netting. Since the designer needs to know the total wind load transferred to the supporting curved braces or columns the impact of various approach angles of the wind was explored.

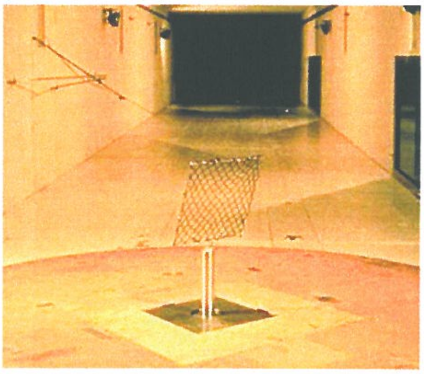

Figure 3: The porous netting material in a uniform-flow region (with low turbulence) of the approaching boundary layer. A full range of azimuth and tilt angles were explored to obtain the mean drag data.

The issue of the appropriate longitudinal turbulence intensity to use was the topic of some discussion. At high elevation in a rough city (rooftop designs), or near the ground in open country (golf course perimeters) the ambient turbulence intensity may vary greatly (say, about 15% in open country at ground level to a larger value in a complex cityscape). The small netting sample in Figure 3 is significantly smaller than the full-scale turbulence length scales – obviously not modeled in the wind tunnel. Thus, the code approach of using measured mean drag coefficients, local gust wind speeds and area reduction factors is a preferred technique. Also, noting the rough surface of the twine, the low typical Reynolds Number of the twine elements (about 3000) and the tradition in wind engineering of presenting the mean drag coefficients of member sections measured in low turbulence flows (Simiu and Scanlan, 1996) it was decided to run the experiment with the low longitudinal turbulence intensity of about 3% shown in Figure 4. One could argue that higher turbulence intensities could have been used, but it was believed that a smoother flow was consistent with the mean drag coefficients presented in code calculations, and that the resulting data were probably conservative.

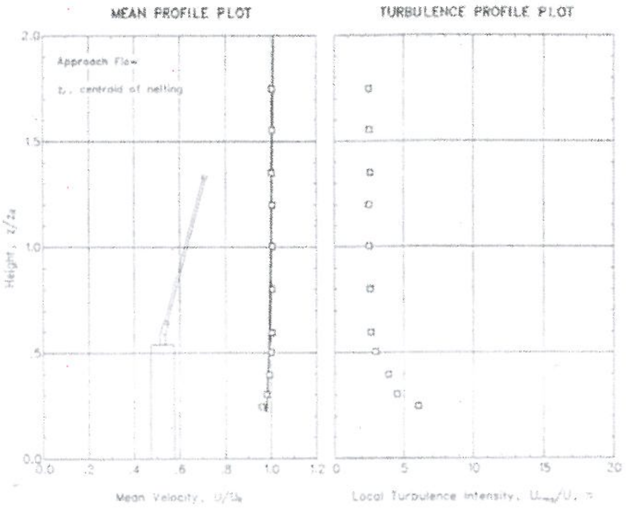

Figure 4: The vertical profiles of the mean windspeed and longitudinal turbulence intensity in the wind-tunnel set-up shown in Figure 3. The reference velocity was measured upwind of the centre of the vertical frame. The uniform approach profile meant that this reference velocity was maintained as the frame lent over as various tilt angles. The approaching longitudinal turbulence intensity was about 3% at the elevation of the frame and netting.

The mean base moments M_x and M_y were combined with the varying lever arm (with tilt angle) from the centre of the netting to the base of the force balance. This produced a drag force in the direction of the wind at the center of the netting, which was then converted to a mean dimensionless drag coefficient made up of the mean drag force ($\overline{F}_d$), air density (ρ), mean reference velocity ($\overline{U}_R$) at the height of the frame centre, and the total area of the netting in the frame (A_n). The resulting mean drag coefficients were measured for a range of tilt angles (α) and azimuth angles (θ) as defined in Figure 5.

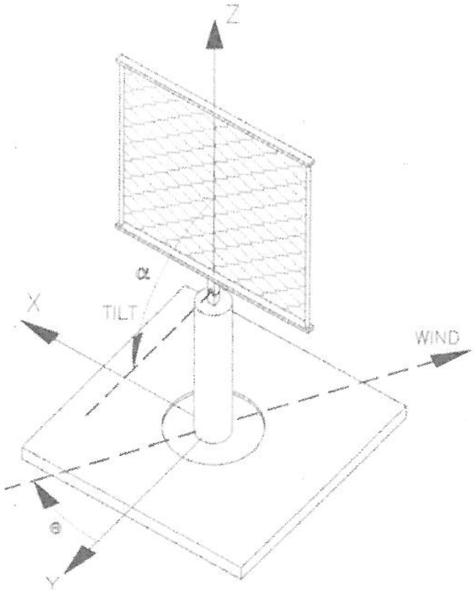

Figure 5: Coordinate system used to reduce the force balance data to a mean drag force on the netting in the direction of the wind.

$$\overline{C}_d = \frac{\overline{F}_d}{0.5\rho \overline{U}_R^{\,2} A_n}$$

The data presented in Figure 6 show the mean drag coefficients as a function of wind azimuth (0 degrees being perpendicular to the sample and 80 degrees being almost parallel to the netting sample) for a variety of tilt angles (90 degrees when the netting sample is vertical and 15 degrees when it is close to horizontal). It is interesting to note that for any tilt angle the largest mean drag coefficient in the direction of the wind is not at the zero wind azimuth, but is typically somewhere between 20 and 40 degrees from the direct flow onto the netting surface. This trend can be seen in Figure 6, although the three-dimensional presentation of the data in Figure 7 is a somewhat more visual representation of this trend. If the designer wishes to use a single value for the mean drag coefficient for this open porous netting, then 0.12 might be a reasonable choice. It is interesting to note that this is about one tenth of the individual circular cylinder (twine) drag coefficient based on the actual twine area, and that the ratio of the twine area to total area is about 1 to 9 – suggesting a comparable measured drag coefficient to that generated by summing elements alone. On the other hand, an enveloping design function for vertical netting (quite conservative for inclined netting geometries too) as a function of wind azimuth may be given by,

$$\overline{C}_d(\theta) = 0.114\cos(\theta - 24^o)$$

Since the porous netting has some planar symmetry (except, perhaps, for the directionality of the twine twist orientation) one can use vector geometry to reasonably reduce the two-angle drag dependence (θ and α) to a single angle dependence relative to the normal of the local plane netting surface. If η is defined as the angle between the approach flow vector and the normal to the netting surface then a more general angular drag dependency becomes,

$$\overline{C}_d(\eta) = 0.114\cos(\eta - 30^o)$$

Conclusions

In summary, the mean drag characteristics for very porous netting, used at sports facilities, were explored in the wind tunnel so that the structural engineer could estimate the wind loads on the support structures with more confidence. When based on the total area of netting surface a reasonable design drag coefficient of 0.12 is suggested. Additionally, some functions giving the directional dependency of the mean drag coefficient (in the direction of the flow) are presented.

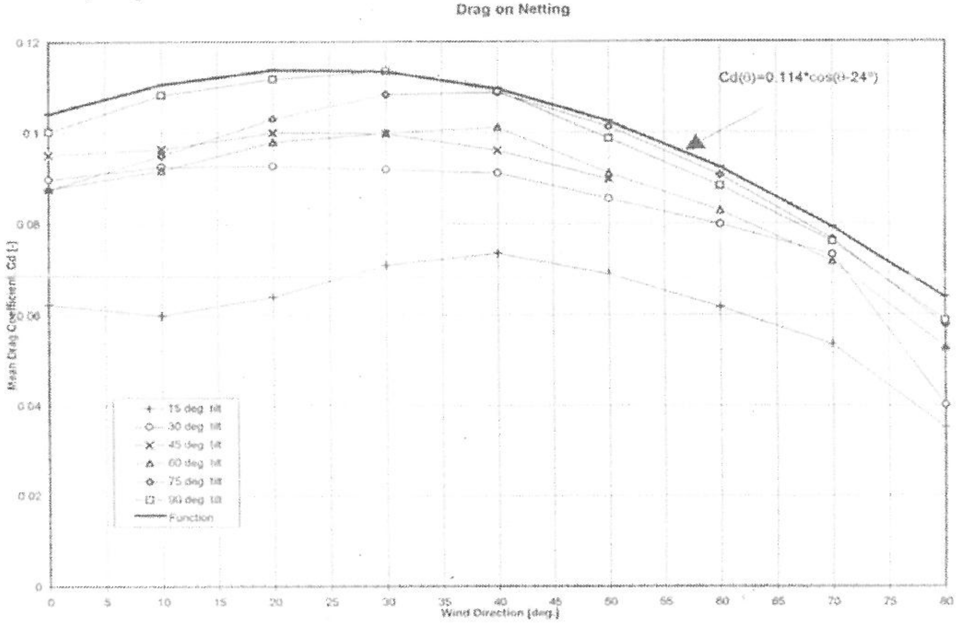

Figure 6: Mean drag coefficients of the porous netting as a function of wind azimuth for various tilt angles. A designer may wish to use a value of 0.12 to estimate the wind loads on the support structure. An enveloping drag function is suggested for a more detailed design where directional wind statistics are known.

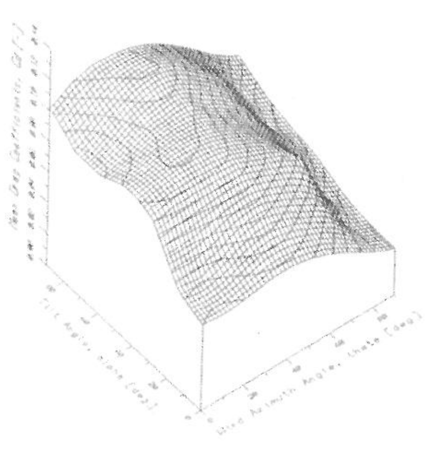

Figure 7: A three-dimensional representation of the data in Figure 6, highlighting the larger mean drag coefficients for non-oncoming flow directions (i.e. θ about 20 to 40 degrees).

References

Cochran, L.S., Peterka, J.A. and Cermak, J.E. (1996). "Wind-Tunnel Tests for Golf Ball Barrier Net", CPP Final Report (#96-1417) for Tex-Net Incorporated, Roebling, New Jersey.

Simiu, E. and Scanlan, R.H., "Wind Effects on Structures: an Introduction to Wind Engineering", Third Edition, John Wiley & Sons, New York, 1996.