velocity distributions in open channels showed that, in uniform equilibrium open channel flows, the velocity distribution exponent is related to the flow resistance :

$$N = K \times \sqrt{\frac{8}{f}}$$

where f is the Darcy-Weisbach friction factor and K is the von Karman constant (K = 0.4) (CHEN 1990, CHANSON 1999).

3.2 Roughness effects

The boundary roughness has an important effect on the flow in the wall-dominated region (i.e. "viscous" sub-layer region and turbulent zone). Numerous experiments showed that, for a turbulent boundary layer along a rough plate, the "law of the wall" follows :

$$\frac{V_x}{V_*} = \frac{1}{K} \times \mathrm{Ln}\left(\frac{V_* \times y}{\nu}\right) + D_1 + D_2 \qquad \text{Turbulent zone : } \frac{y}{\delta} < 0.1 \text{ to } 0.15 \quad (4\text{-}24)$$

where D_1 = 5 and D_2 is a function of the type of roughness and of roughness shape, height and spacing (e.g. SCHLICHTING 1979, SCHETZ 1993). For smooth turbulent boundary layer flows, D_2 equals zero.

In the turbulent zone, the roughness effect (i.e. $D_2 < 0$) implies a downward shift of the logarithmic velocity distribution (Fig. 4-10). Figure 4-10 illustrates some effect of the boundary roughness on the law of wall. For example, let us compare Figure 4-9A (smooth boundary) and Figure 4-11B (rough plate). For large roughness, the "viscous" sub-layer region disappears and the flow is said to be "fully-rough".

For fully-rough turbulent flows in circular pipes with uniformly distributed sand roughness, D_2 equals :

$$D_2 = 3 - \frac{1}{K} \times \mathrm{Ln}\left(\frac{k_s \times V_*}{\nu}\right) \qquad \text{fully-rough turbulent flows in circular pipes} \quad (4\text{-}25)$$

where k_s is the equivalent sand roughness height. After transformation, the velocity distribution in the turbulent zone for fully-rough turbulent flow becomes :

$$\frac{V_x}{V_*} = \frac{1}{K} \times \mathrm{Ln}\left(\frac{y}{k_s}\right) + 3 + D_1 \qquad \frac{y}{\delta} < 0.1 \text{ for fully-rough turbulent flow} \quad (4\text{-}26)$$

Figure 4-11 illustrates some turbulent velocity measurements above a flat, rough plate. Figure 4-11A presents the time-averaged velocities and turbulent intensity distributions. Figure 4-11B compares the velocity distributions with Equation (4-26). The results show that the data followed closely Equation (4-26) for y/k_s < 5 to 30 depending upon the longitudinal distance x from the leading edge.

<u>Note</u>

The velocity distribution in the turbulent zone for fully-rough turbulent flow becomes:

$$\frac{V_x}{V_*} = \frac{1}{K} \times \mathrm{Ln}\left(\frac{y}{k_s}\right) + 8$$

with D_1 = 5.0.