# 8. DIFFRACTION OVER SMOOTH EARTH AND OVER IRREGULAR TERRAIN

Diffraction attenuation over an isolated ridge or hill has been discussed in section 7. The following methods are used to compute attenuation over the bulge of the earth and over irregular terrain. The methods are applicable to the far diffraction region, where the diffracted field intensity may be determined by the first term of the Van der Pol-Bremmer residue series [Bremmer, 1949]. This region extends from near the radio horizon to well beyond the horizon. A criterion is given to determine the minimum distance for which the method may be used. In some situations the first term of the series provides a valid approximation to the diffracted field even at points slightly within line-of-sight [Vogler, 1964].

A simplified graphical method for determining ground wave attenuation over a spherical homogeneous earth in this far diffraction region was recently developed by Vogler [1964], based on a paper by Norton [1941]. The method described in section 8.1 is applicable to either horizontal or vertical polarization, and takes account of the effective earth's radius, ground constants, and radio frequency. In section 8.2, a modification of the method for computing diffraction attenuation over irregular terrain is described, and section 8.3 considers the special case of a common horizon which is not an isolated obstacle.

For frequencies above 1000 MHz, the attenuation due to gaseous absorption should be added to the diffraction loss. See (3.1) and figure 3.6.

## 8.1 Diffraction Attenuation Over a Smooth Earth

The attenuation relative to free space may be expressed in terms of a distance dependence, the dependence on antenna heights, and the dependence on electromagnetic ground constants, the earth's radius, and the radio frequency:

$$A = G(x_0) - F(x_1) - F(x_2) - C_1(K, b^\circ) + A_a \tag{8.1}$$

where $A_a$ is the atmospheric absorption, given by (3.5), and

$$x_0 = d\,B_o, \quad x_1 = d_{Lt}\,B_o, \quad x_2 = d_{Lr}\,B_o \tag{8.1a}$$

$$B_o = f^{\frac{1}{3}}\,C_o^2\,B(K, b^\circ), \qquad C_o = (8497/a)^{\frac{1}{3}}. \tag{8.1b}$$

The basic diffraction transmission loss $L_{bd}$ is

$$L_{bd} = L_{bf} + A \quad \text{db}, \tag{8.2}$$

where the basic transmission loss in free space, $L_{bf}$, is given by (2.16).

The distances $d$, $d_{Lt}$, $d_{Lr}$, and the effective earth's radius, $a$, have been defined in sections 4 and 6, and $f$ is the radio frequency in megahertz.

The parameters $K$ and $b°$ depend on polarization of the radio wave and the relative dielectric constant, $\epsilon$ , and conductivity, $\sigma$ , of the ground. Figures 8.1 and 8.2 show curves of $K$ and $b°$ versus frequency for combinations of $\epsilon$ and $\sigma$ corresponding to poor, average, and good ground, and to sea water. Figure 8.1 shows $K$ for $a = 8497$ km. For other values of effective earth's radius,

$$K(a) = C_o K(8497). \tag{8.3}$$

General formulas for $K$ and $b°$ for both horizontal and vertical polarization are given in section III.4 of annex III.

The parameter $B(K, b°)$ in (8.2b) is shown as a function of $K$ and $b°$ in figure 8.3. The limiting value $B = 1.607$ for $K \to 0$ may be used for most cases of horizontal polarization. The parameter $C_1(K, b°)$ in (8.1) is shown in figure 8.4.

The function $G(x_0)$ in (8.1) is shown on figures 8.5 and 8.6, and is defined as

$$G(x_0) = 0.05751\, x_0 - 10 \log x_0 \tag{8.4}$$

and the height functions $F(x_{1,2})$ are plotted in figures 8.5 and 8.6 versus $K$ and $b°$. For large values of $x_1$ or $x_2$, $F(x)$ is approximately equal to $G(x)$.

Because this method is based on only the first term of the residue series, it is limited to the following distances to insure that $A$ is accurate within approximately 1.5 db:

$$x_0 - x_1(\Delta x_1) - x_2(\Delta x_2) > 335\,, \quad \text{for } B = 1.607,\ (K \le 0.1) \tag{8.5a}$$

$$x_0 - x_1(\Delta x_1) - x_2(\Delta x_2) > 115\,, \quad \text{for } B = 0.700,\ (K \ge 10), \tag{8.5b}$$

For values of $B$ lying between these two limits, linear interpolation between the $\Delta(x)$ curves of figure 8.6, and the two minimum values in (8.5) gives a fair approximation of the range of validity of (8.1). Using linear interpolation:

$$x_0 - x_1\, \Delta(x_1, B) - x_2\, \Delta(x_2, B) > x_{min} \tag{8.6}$$

where

$$x_{min} = 335 - 242.6\,(1.607 - B) \tag{8.7a}$$

$$\Delta(x, B) = \Delta(x, 1.607) + 1.103(1.607 - B)\,[\Delta(x, 0.700) - \Delta(x, 1.607)]\,, \tag{8.7b}$$

$\Delta(x, 0.700)$ and $\Delta(x, 1.607)$ are the values read from the upper and lower curves of $\Delta x$ in figure 8.6.

## 8.2 Diffraction Over Irregular Terrain

To compute diffraction attenuation over irregular terrain, the single effective earth's radius, $a$, used in (8.2) is replaced by four different radii as shown in figure 8.7. The radii $a_1$ and $a_2$ of the terrain between the antennas and their horizons, and the radii $a_t$ and $a_r$ of the terrain between radio horizons and the crossover point of horizon rays are defined by

$$a_1 = d_{Lt}^2/(2\,h_{te}), \qquad a_2 = d_{Lr}^2/(2\,h_{re}) \tag{8.8}$$

$$a_t = D_s\, d_{st}/(\theta\, d_{sr}), \qquad a_r = D\, d_{sr}/(\theta\, d_{st}). \tag{8.9}$$

The distances $D_s$, $d_{st}$, $d_{sr}$, $d_{Lt}$, $d_{Lr}$, the effective antenna heights $h_{te}$ and $h_{re}$, and the angular distance $\theta$ are defined in section 6.

These four radii are used in (8.2) and (8.3) to obtain values of $K(a) = K_{1,2,t,r}$ for each of the four radii. Corresponding values $B_{1,2,t,r}$ are then read from figure 8.3 for each value of $K$.

The diffraction attenuation relative to free space is then:

$$A = G(x_0) - F(x_1) - F(x_2) - \overline{C}_1\,(K_{1,2}) + A_a \tag{8.10}$$

where $A_a$ is the atmospheric absorption defined by (3.1), and is negligible for frequencies less than 1 GHz, and $\overline{C}_1\,(K_{1,2})$ is the weighted average of $C_1\,(K_1, b)$ and $C_1\,(K_2, b)$ read from figure 8.4:

$$\overline{C}_1\,(K_{1,2}) = [x_1\, C_1\,(K_1) + x_2\, C_1\,(K_2)]/(x_1 + x_2) \tag{8.11}$$

$$x_1 = B_{01}\, d_{Lt}, \qquad x_2 = B_{02}\, d_{Lr} \tag{8.12a}$$

$$x_0 = B_{ot}\, d_{st} + B_{or}\, d_{sr} + x_1 + x_2 \tag{8.12b}$$

$$B_{01} = f^{\frac{1}{3}}\, C_{01}^2\, B_1, \qquad B_{02} = f^{\frac{1}{3}}\, C_{02}^2\, B_2 \tag{8.13a}$$

$$B_{ot} = f^{\frac{1}{3}}\, C_{ot}^{\;2}\, B_t, \qquad B_{or} = f^{\frac{1}{3}}\, C_{or}^{\;2}\, B_r \tag{8.13b}$$

This method is applicable to computation of diffraction attenuation over irregular terrain for both vertical and horizontal polarization for transhorizon paths. The method may be somewhat simplified for two special cases: diffraction over paths where $d_{st} \cong d_{sr}$, and for most paths when horizontal polarization is used.

### 8.2.1 Diffraction over paths where $d_{st} \approx d_{sr}$

For paths where the distances $d_{st}$ and $d_{sr}$ are equal, the parameter $x_0$ may be defined in terms of $D_s$ and the corresponding earth's radius $a_s$:

$$x_0 = B_{os} D_s + x_1 + x_2 \qquad (8.14)$$

$$D_s = 2\, d_{st} = 2\, d_{sr}, \qquad a_s = D_s/\theta, \qquad C_{os} = (8497/a_s)^{\frac{1}{3}}, \qquad B_s = B\,(K_s, b°) \qquad (8.15a)$$

$$B_{os} = f^{\frac{1}{3}}\, C_{os}^{\;2}\, B_s \qquad (8.15b)$$

where $x_1$ and $x_2$ are defined by (8.12). The diffraction attenuation is then computed using (8.10).

### 8.2.2 For horizontal polarization

For horizontally polarized radio waves, at frequencies above 100 MHz, and with $K(a) \leq 0.001$, the parameter $B(K, b)$ approaches a constant value, $B \approx 1.607$, and $C_1(K, b) = 20.03$ dB Assuming $B = 1.607$ and $C_1 = 20.03$, the diffraction attenuation may be computed as follows:

$$A = G(x_0) - F(x_1) - F(x_2) - 20.03 \quad \text{db} \qquad (8.16a)$$

$$x_1 = 669\, f^{\frac{1}{3}}\, d_{Lt}/a_1^{\frac{2}{3}}, \qquad x_2 = 669\, f^{\frac{1}{3}}\, d_{Lr}/a_2^{\frac{2}{3}} \qquad (8.16b)$$

$$x_0 = 669\, f^{\frac{1}{3}}\, \theta^{\frac{2}{3}}\, D_{str} + x_1 + x_2 \qquad (8.16c)$$

where

$$D_{str} = (d_{st}\, d_{sr})^{\frac{1}{3}} \left(d_{st}^{\frac{1}{3}} + d_{sr}^{\frac{1}{3}}\right) \Big/ (d_{st} + d_{sr})^{\frac{2}{3}}.$$

The parameter $D_{str}$ is shown in figure 8.8 as a function of $d_{st}$ and $d_{sr}$.

For paths where $d_{st} = d_{sr}$, using horizontal polarization, the parameter $x_0$ simplifies to

$$x_0 = 669\, f^{\frac{1}{3}}\, (\theta^2 D_s)^{\frac{1}{3}} + x_1 + x_2 \,. \qquad (8.16d)$$

## 8.3 Single-Horizon Paths, Obstacle not Isolated

In some cases, over rather regular terrain or over the sea, a common horizon may be the bulge of the earth rather than an isolated ridge or mountain. For such paths, the path distance, d, is just the sum of $d_{Lt}$ and $d_{Lr}$, and in this case, the method described in section 8.2 is simplified to one with only two earth's radii instead of four. The parameters $x_1$ and $x_2$ are defined by (8.12), and $x_0 = x_1 + x_2$. The diffraction attenuation is then computed using (8.10).

The diffraction loss predicted by this method agrees very well with observed values over a number of paths in the United Kingdom and the United States where the common horizon is not isolated.

For transhorizon paths of short to medium length, when it is not known whether diffraction or scatter is the dominant propagation mechanism, both diffraction and scatter loss should be computed. The next section shows how to compute scatter loss, and how to combine the two computed values when they are nearly equal.

THE PARAMETER K FOR AN EFFECTIVE EARTH RADUIS, a = 8497 km

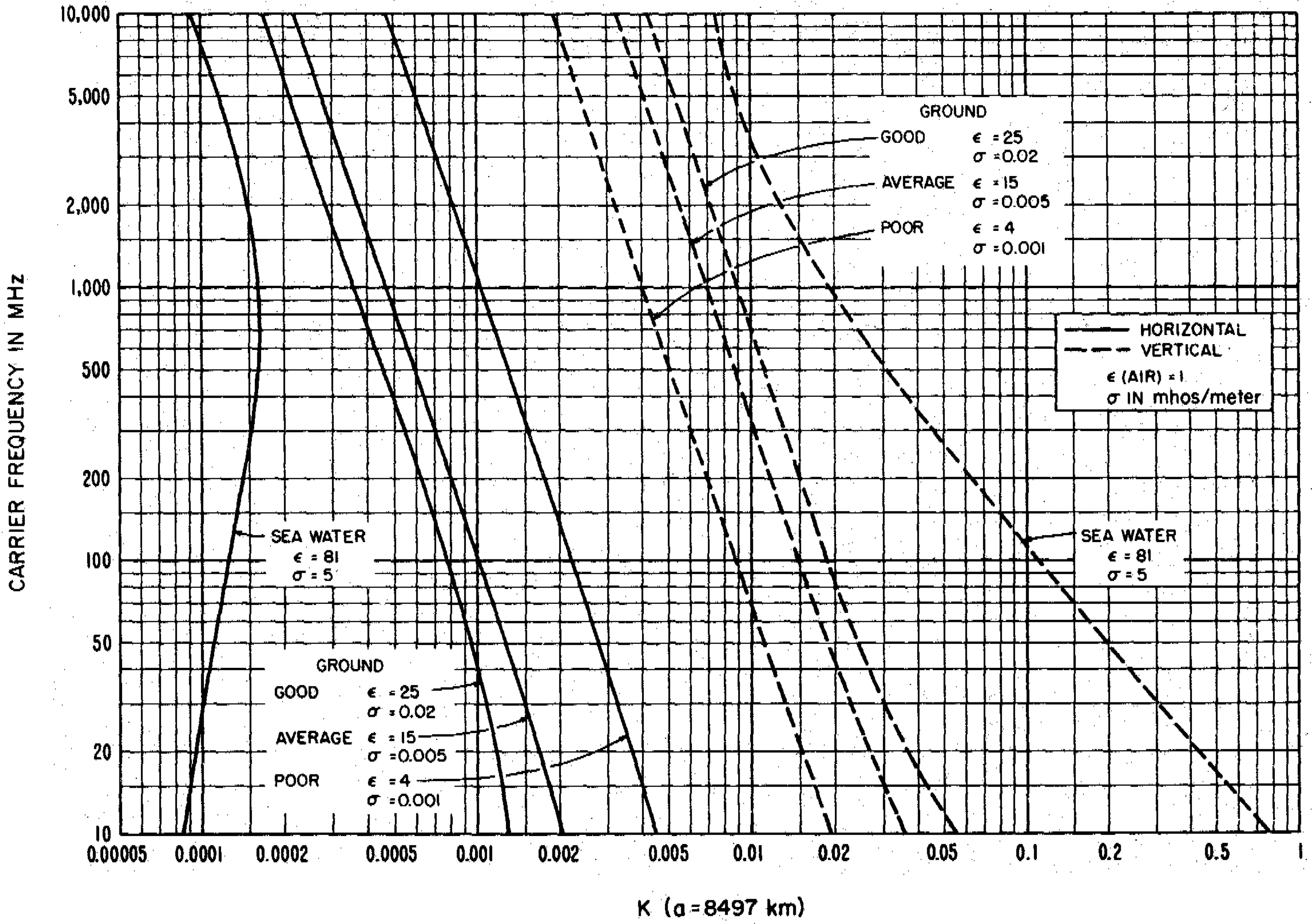


Figure 8.1

THE PARAMETER b° IN GROUND WAVE PROPAGATION
OVER A SPHERICAL EARTH

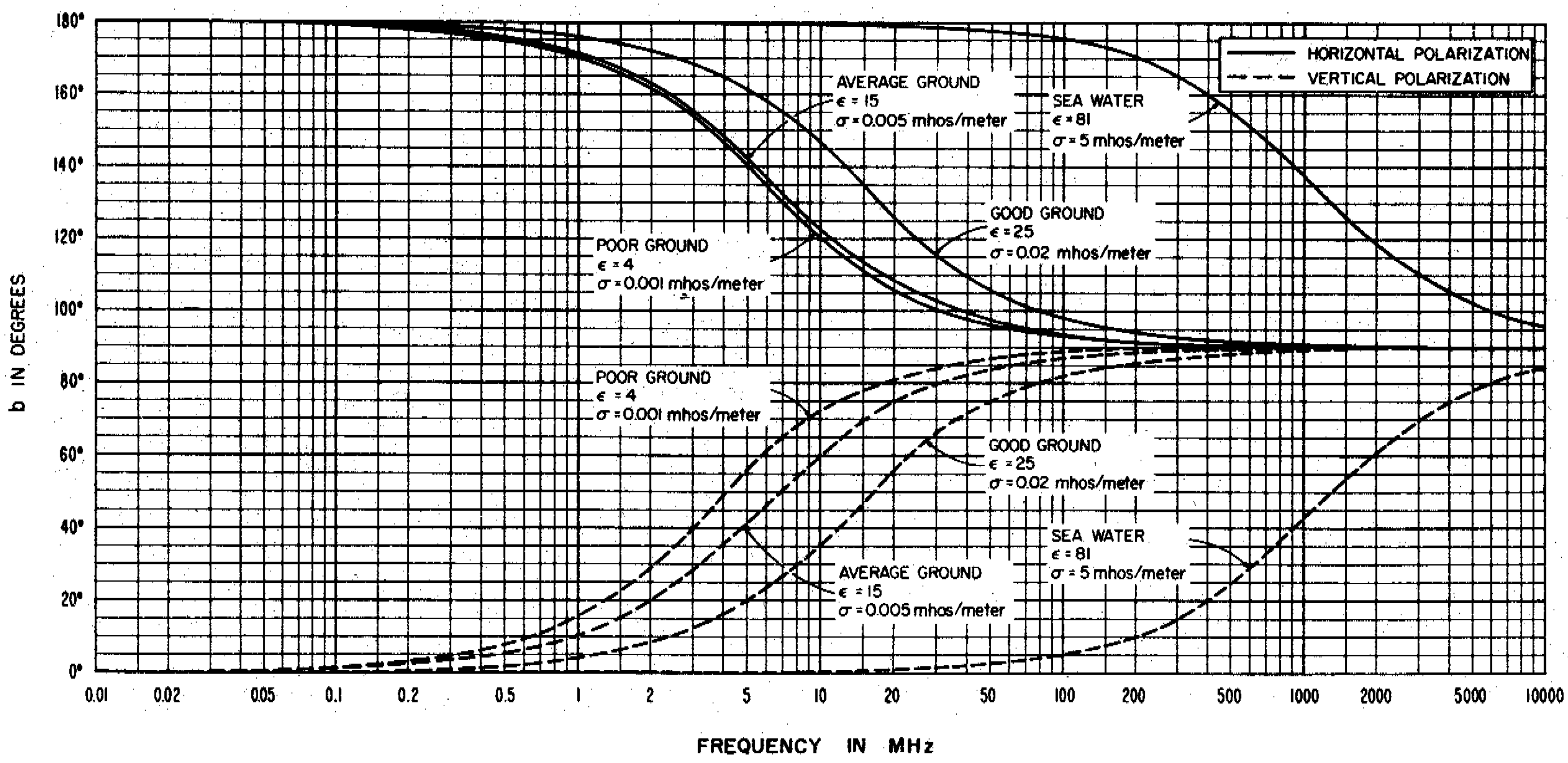


Figure 8.2

THE PARAMETER B(K,b)

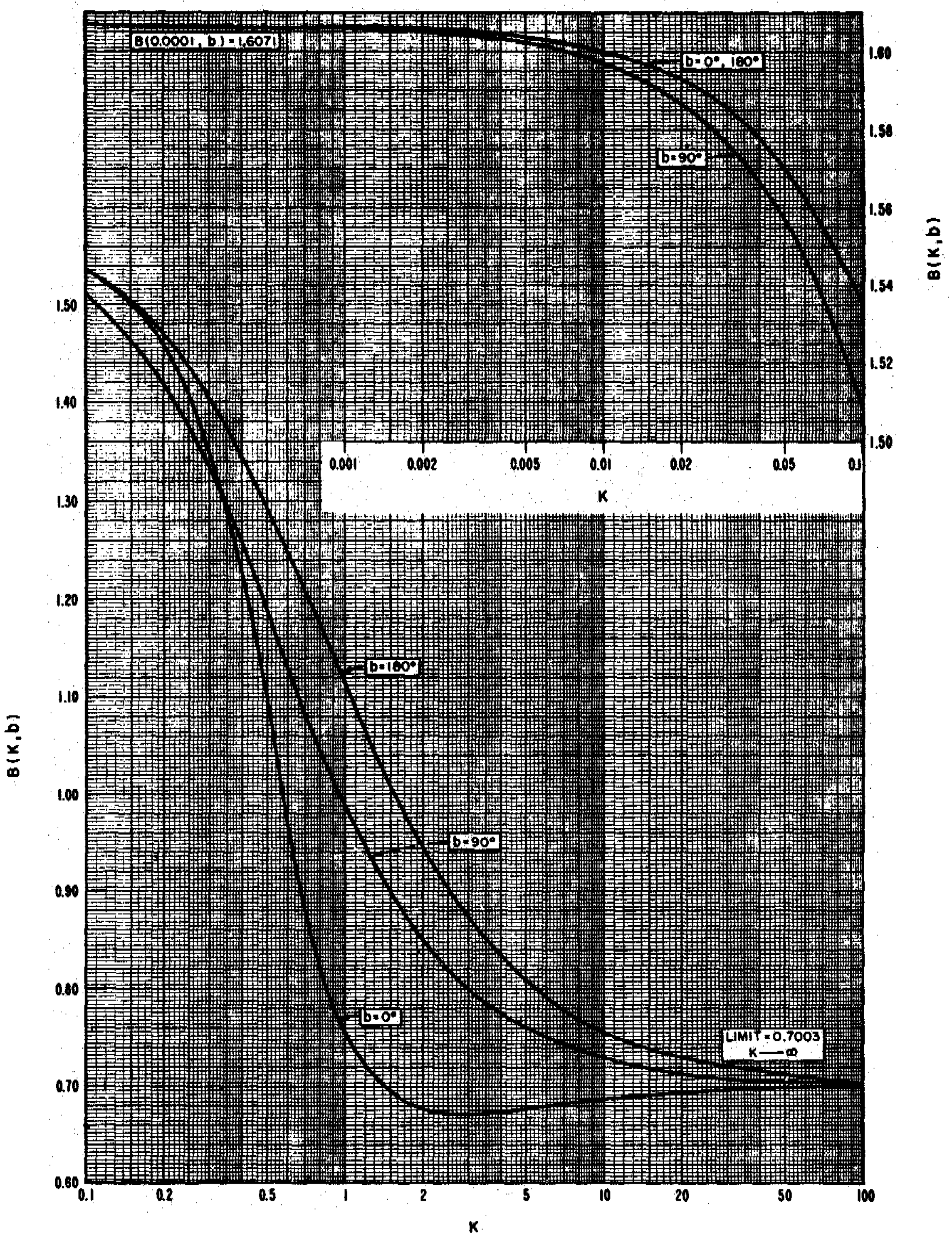


Figure 8.3

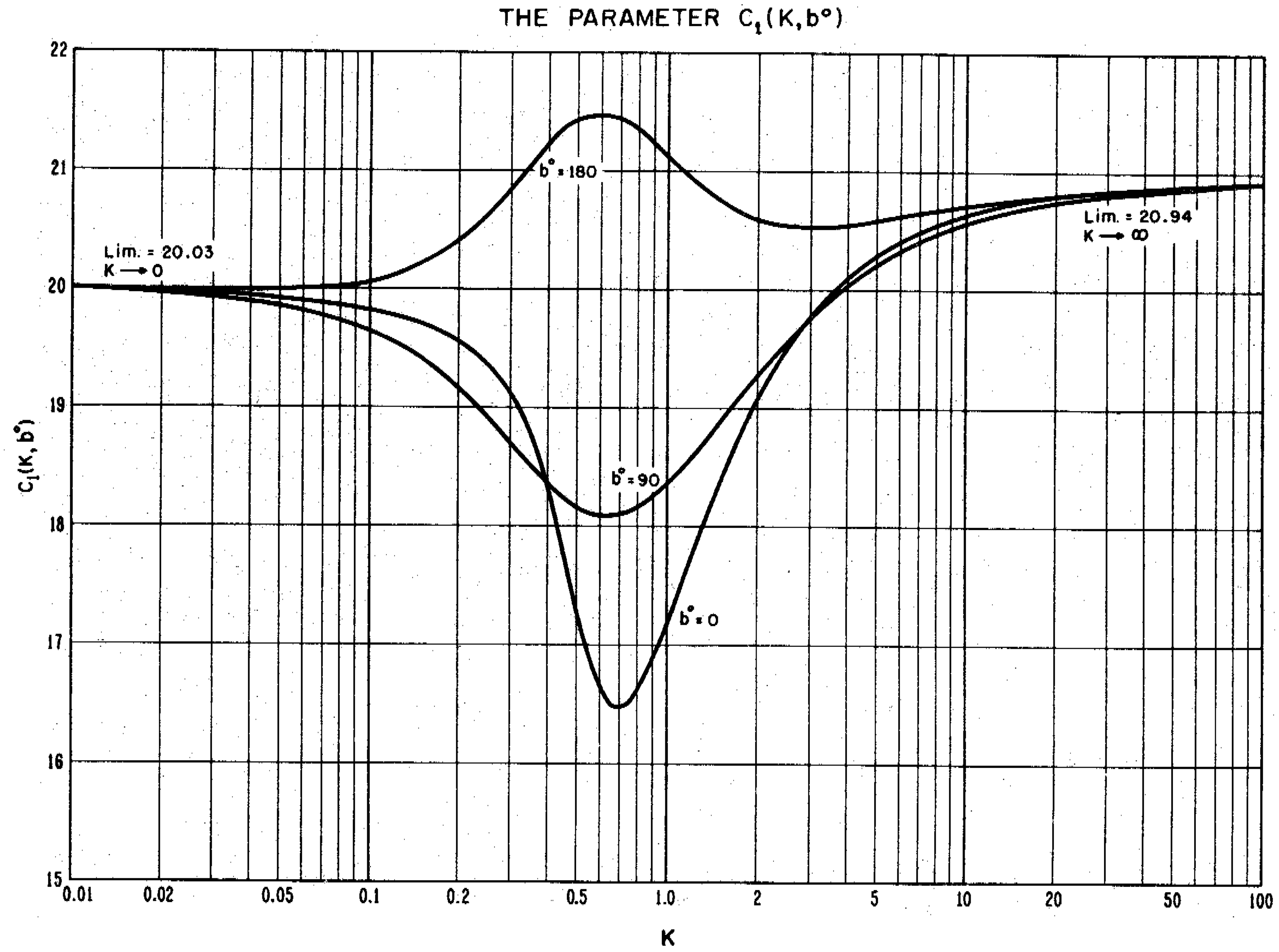
THE PARAMETER $C_1(K,b°)$
22
21
20
19
18
17
16
15
$C_1(K,b°)$
Lim. = 20.03
K ⟶ 0
$b° = 180$
$b° = 90$
$b° = 0$
Lim. = 20.94
K ⟶ ∞
0.01
0.02
0.05
0.1
0.2
0.5
1.0
2
5
10
20
50
100
K

Figure 6.4

THE FUNCTIONS $F(x_1, x_2)$ FOR $K \leq 0.1$ AND $G(x_0)$.
FOR LARGE $x: F(x) \sim G(x)$

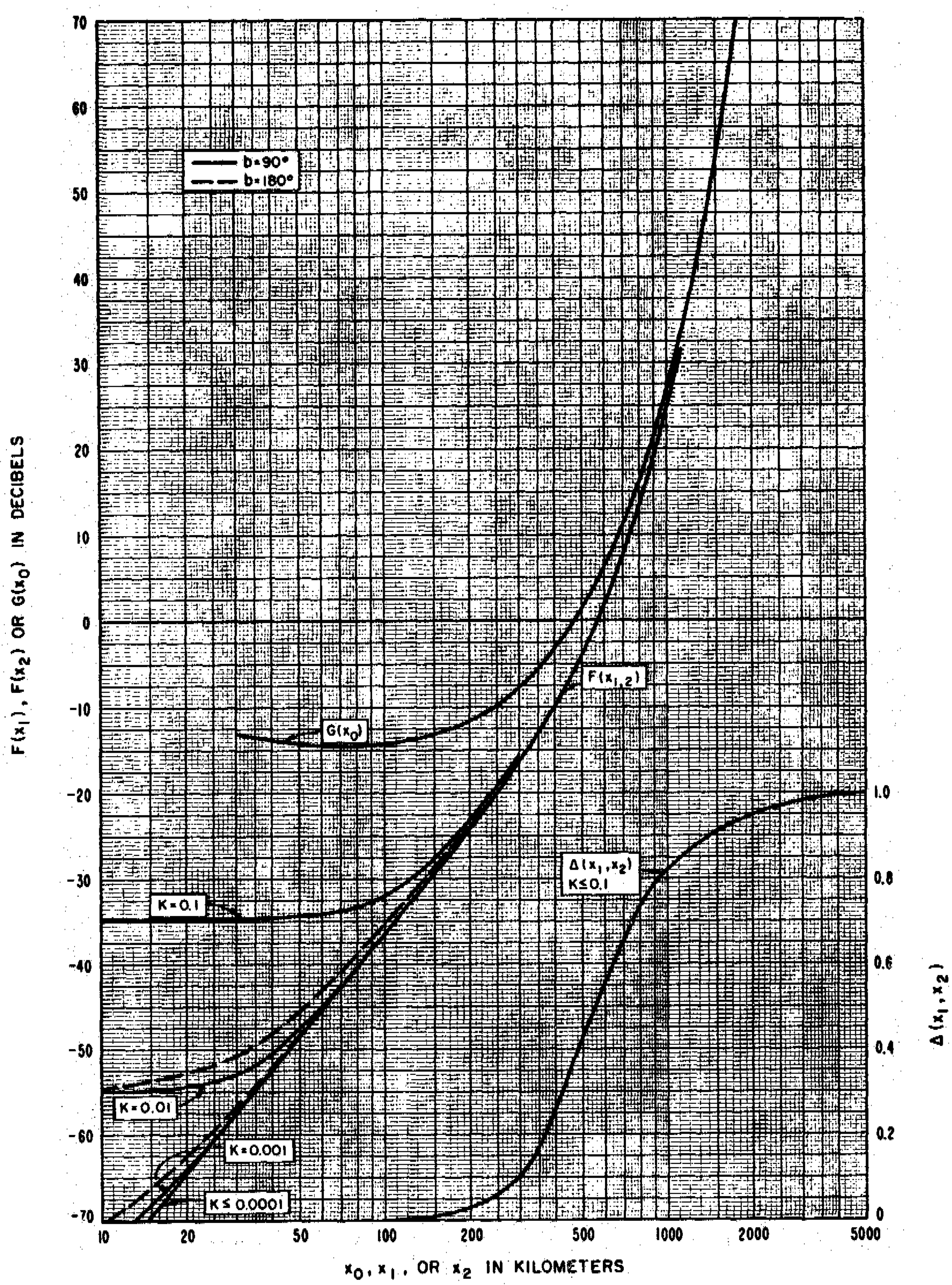


Figure 8.5

## THE FUNCTIONS $F(x_1)$, $F(x_2)$ AND $G(x_0)$ FOR THE RANGE $0 \leq K \leq 1$

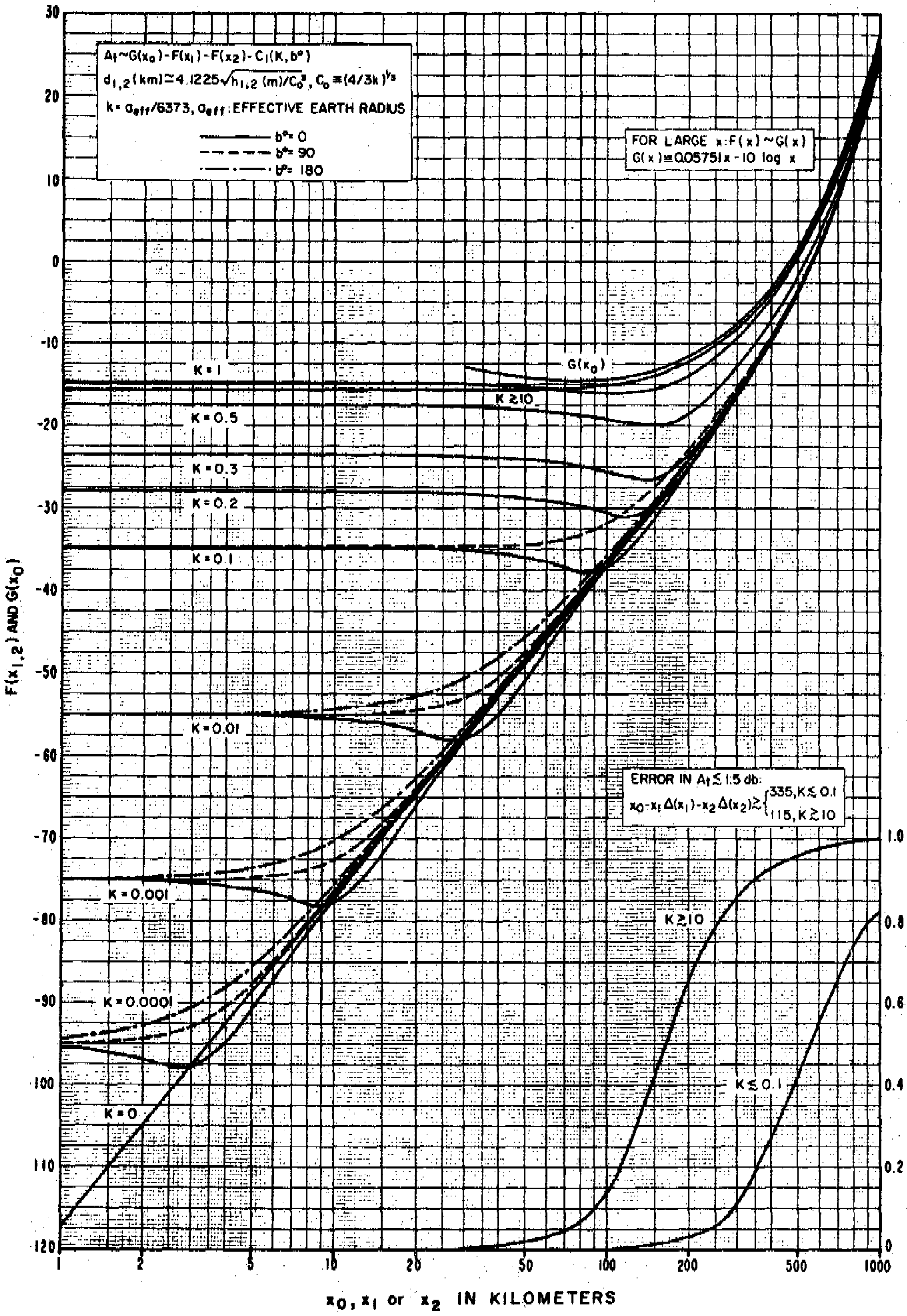


Figure 8.6

GEOMETRY FOR DIFFRACTION
OVER IRREGULAR TERRAIN

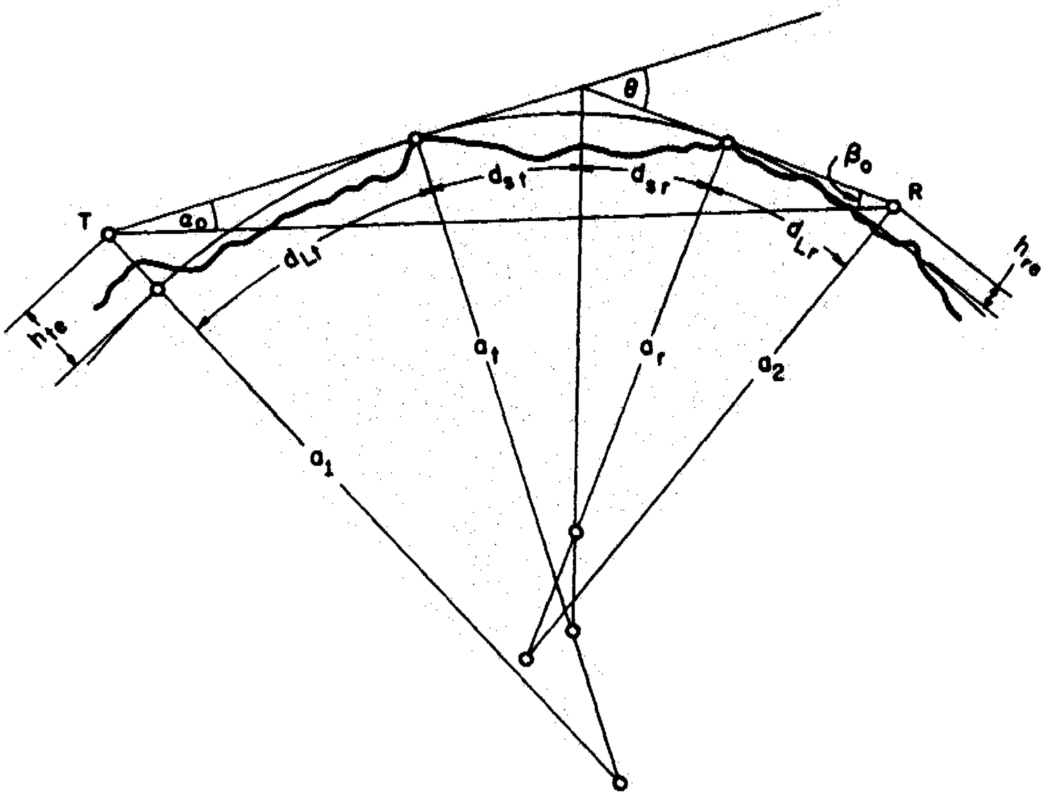


Figure 8.7

THE PARAMETER $D_{str}$

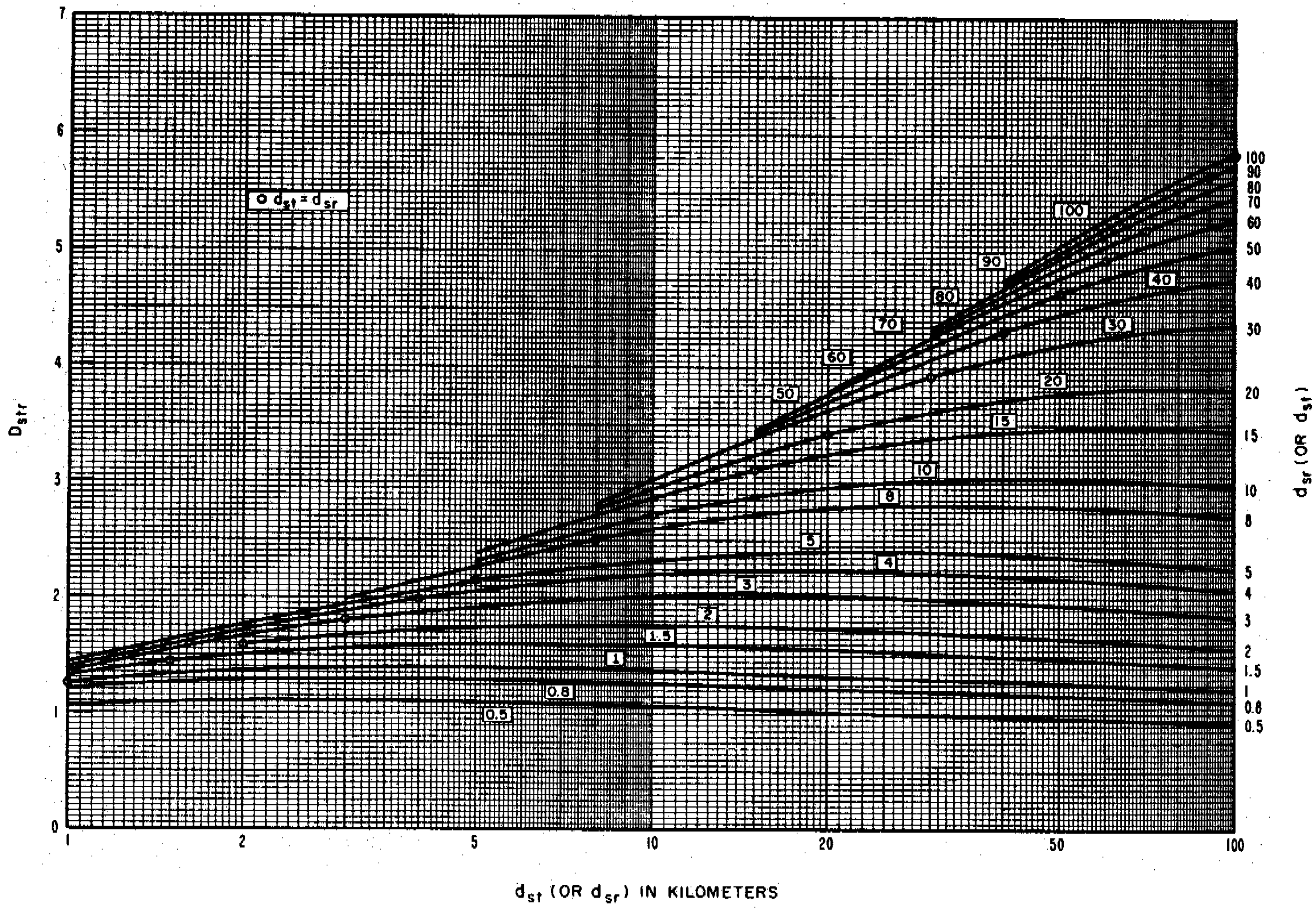


Figure 8.8