TECHNICAL REPORT

ISO TR 9209

First edition
1989-07-01

Measurement of liquid flow in open channels — Determination of the wetline correction

Mesure de débit des liquides dans les canaux découverts — Détermination de la correction de câble immergé

Reference number
ISO/TR 9209 : 1989 (E)

Foreword

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ISO/TR 9209, which is a technical report of type 2, was prepared by Technical Committee ISO/TC 113, *Measurement of liquid flow in open channels.*

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Printed in Switzerland

Introduction

When the need arises for correction to the wetline sounding obtained during a discharge measurement, the recommended procedure is to consult airline and wetline correction tables, using the observed angle of entry of the wetline and the observed depth.

Hitherto, the recommended tables to be consulted have been those based on the work of F.C. Shenehon (see [1] and [2]). This Technical Report presents the theory and procedures for the use of an alternative set of tables based on the work of the Ministry of Water Resources and Electric Power of the People's Republic of China. This alternative procedure requires further technical studies after which it will be included in a future edition of ISO 748. This Technical Report should be treated as an acceptable basis for such further studies.

Shenehon's work, carried out prior to 1900, is reported in [1]. The full tables and a synopsis of the methodology and thinking behind the tables are contained in [2]. The tables given in ISO 748 are an abbreviated version only.

Since a future edition of ISO 748 will contain both sets of tables to enable the user to decide which set is more appropriate to the case in hand, a short description of the Shenehon method is given before presentation of the more recent alternative methodology of the People's Republic of China.

The principle of Shenehon's method is as follows.

"The method depends on an elementary principle of mechanics: if a known horizontal force is applied to a weight suspended on a cord, the cord takes a position of rest at some angle with the vertical, and the tangent of the vertical angle of the cord is equal to the horizontal force divided by the vertical force due to the weight. If several additional horizontal and vertical forces are applied to the cord, the tangent of the angle of the cord above any point is equal to a summation of the horizontal forces below that point, divided by a summation of the vertical forces below the point.

In applying the above principle to conditions of measurements of depths of flowing water it is assumed that with a properly designed sounding weight the horizontal pressure on the weight in the comparatively still water near the bottom can be neglected. The distribution of total horizontal water pressure along the sounding line is made in accordance with the variation of velocity from surface to bottom. The excess in length of the curved line over the vertical depth is the sum of the products of each tenth of depth and the exsecants of the corresponding angles derived for each tenth of depth by means of the tangent relation of the forces acting below any point."

Advice to the user of this method is also given in [2]:

"The following points concerning the method for determining the vertical depth of water from the wet-line depth and vertical angle of the line at or above the surface should be kept in mind by users of the method: —

1. The weight and line are such that the weight will go to the bottom despite the force of the water.

2. The sounding is made when the weight is at the bottom but entirely supported by the line.

3. Horizontal pressure on the weight when in the sounding position is neglected.

4. The table is general, not for any particular line or wire or sounding weight, provided they are designed so as to offer little resistance to the current, as the vertical angle is a function of the resistance offered by the line and weight."

The approach in the method of the People's Republic of China outlined below differs in a number of respects from that of the Shenehon method, notably in the following ways.

a) The contention that the horizontal pressure on the sounding weight at rest on the river bed is negligible and can be ignored is disputed. The pressure can be quite considerable, particularly in shallow swift-flowing streams. The Chinese method takes such horizontal pressure on the sounding weight into consideration.

b) The tables are specific in allowing for different weights.

c) The effects of horizontal pressure on the current meter, sounding line and any accompanying signal cable are allowed for.

d) The tables are specific in that they allow for different diameters of sounding lines in use.

References

[1] LYDECKER, G.J. Survey of northern and northwestern lakes, *Ann. Rep. Chief of Engineers,* US Army, pt. 8, Appendix III, 1900: pp. 5329-5330.

[2] CORBETT, D.M. *et al.* Stream-gauging procedure, *Geological Survey Water Supply Paper 888,* US Dept. of Interior, 1945: pp. 44-51.

Measurement of liquid flow in open channels — Determination of the wetline correction

1 Scope

This Technical Report provides an alternative to the procedure given in ISO 748 : 1979, annex C, for the determination of the wetline correction.

2 Normative reference

The following standard contains provisions which, through reference in this text, constitute provisions of this Technical Report. At the time of publication, the edition indicated was valid. All standards are subject to revision, and parties to agreements based on this Technical Report are encouraged to investigate the possibility of applying the most recent edition of the standard indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 748 : 1979, *Liquid flow measurement in open channels — Velocity-area methods.*

3 Theoretical considerations

3.1 Determination of the wetline correction, ΔW

The equation for the determination of the wetline correction, ΔW, is obtained using figure 1.

For any element $E_{(x,y)}$ of the sounding line taken as a free body, the following equations may be derived.

$$\frac{P_x + Q_x}{G_0} = \frac{dx}{dy} \qquad \ldots (1)$$

where

P_x is the impulsive force on the sounding line;

Q_x is the impulsive force on the sounding weight;

G_0 is the weight of the sounding weight in water.

$$v_y = v_0 \sqrt{1 - P\eta^2} \qquad \ldots (2)$$

where

v_y is the velocity at point E;

v_0 is the velocity at the water surface;

P is the velocity distribution parameter;

η is the relative depth:

$$\eta = \frac{y}{H}$$

where H is the water depth.

$$P_x = K_1' \frac{\varrho / g}{2} d \int_y^H v_y^2 \, dy = K_1 v_0^2 H \left[(1 - \eta) - \frac{P}{3} (1 - \eta^3) \right] \qquad \ldots (3)$$

where

K_1' is the resistance coefficient of the sounding line;

K_1 is the impulsive coefficient of the sounding line;

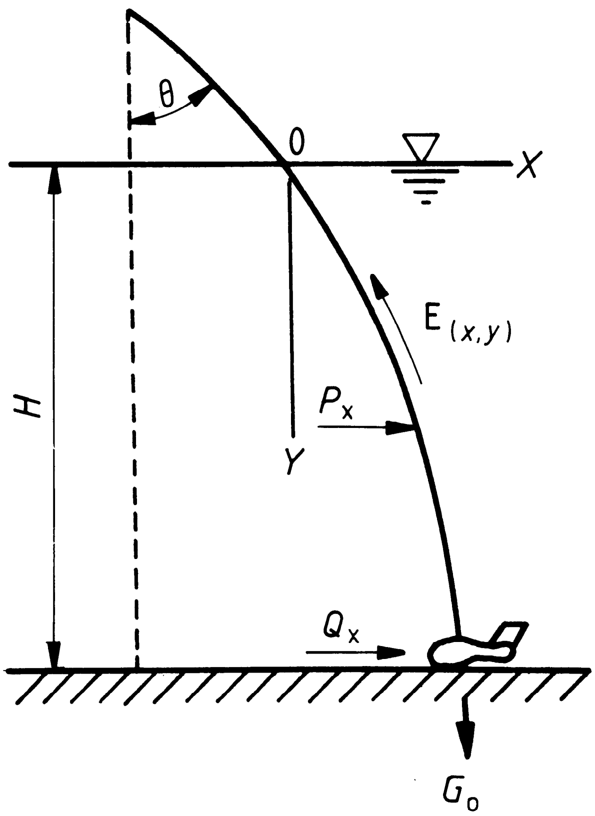

Figure 1 — The forces acting on the sounding line

$\varrho/g = 102\ \text{kg}\cdot\text{s}^2\cdot\text{m}^{-4}$

where ϱ is the density of water;

d is the diameter of the sounding line.

$$Q_x = K_2' \frac{\varrho/g}{2} \Omega v_H^2 = K_2 v_0^2 (1 - P) \qquad \dots (4)$$

where

K_2' is the resistance coefficient of the sounding weight;

K_2 is the impulsive coefficient of the sounding weight;

Ω is the frontal area of the sounding weight;

v_H is the velocity at the river bed.

$$\beta = \frac{K_2}{K_1} \qquad \dots (5)$$

where β is the impulsive parameter.

Substituting equations (3), (4) and (5) into equation (1), one obtains the following equation:

$$\frac{dx}{dy} = \frac{K_1 v_0^2 H}{G_0}(1 - \eta) - \frac{P}{3}(1 - \eta^3) + \frac{\beta}{H}(1 - P) \qquad \dots (6a)$$

When $\eta = 0$, $\frac{dx}{dy} = \tan\theta$, where θ is the oblique angle.

Then one obtains, on the basis of equation (6a), the following equation:

$$\frac{K_1 v_0^2 H}{G_0} = \frac{\tan\theta}{\left(1 - \frac{P}{3}\right) + \frac{\beta}{H}(1 - P)} \qquad \dots (6b)$$

Substituting equation (6b) into equation (6a), one obtains the following equation:

$$\frac{dx}{dy} = 1 - \frac{\eta\left(1 - \frac{P}{3}\eta^2\right)}{\left(1 - \frac{P}{3}\right) + \frac{\beta}{H}(1 - P)} \tan\theta \qquad \dots (6)$$

The other equations for the determination of the wetline correction, ΔW, are as follows:

$$L_H = H \int_0^1 \sqrt{1 + \left(\frac{dx}{dy}\right)^2}\, d\eta \qquad \dots (7)$$

where L_H is the length of the wetline,

$$\Delta W' = L_H - H \qquad \dots (8)$$

$$K_H = \frac{\Delta W}{L_H} = 1 - \frac{1}{\int_0^1 \sqrt{1 + \left(\frac{dx}{dy}\right)^2}\, d\eta} \qquad \dots (9)$$

where K_H is the correction coefficient.

Since H is an unknown quantity, the wetline correction, ΔW, can be calculated using an empirical solution of equation (9):

$$\Delta W = K_H L_H \qquad \dots (10)$$

The results of this solution are listed in tables 4, 5 and 6.

3.2 Determination of the impulsive parameter, β

From equation (5), the impulsive parameter, β, depends on the selection of impulsive coefficients for the sounding line, K_1, and for the sounding weight, K_2. From equations (3) and (4), these coefficients are:

$$K_1 = K_1' \frac{\varrho/g}{2} d \qquad \dots (11)$$

$$K_2 = K_2' \frac{\varrho/g}{2} \Omega \qquad \dots (12)$$

From equation (11), when the resistance coefficient of the sounding line, K_1', is constant, K_1 is proportional to d. Two sets of field tests, with 112 trials in each set, were carried out to determine K_1':

a) with signal cable;

b) without signal cable.

The tests were carried out with sounding lines of diameters 4 mm, 5,4 mm, 7,4 mm and 9,2 mm at velocities between 1,03 m/s and 3,04 m/s. The final results are shown in table 1, i.e.

$K'_{1\,\text{mean}} = 1,5$ (without signal cable);

$K'_{1\,\text{mean}} = 1,7$ (with signal cable).

The signal cable is attached to the sounding line with movable retaining rings at intervals of about 0,1 m.

The empirical values derived from equation (11) for the coefficient K_1 are as follows:

$$K_1 = 0{,}076\,5\, d \text{ (without signal cable)} \qquad \dots (13a)$$

$$K_1 = 0{,}084\,7\, d \text{ (with signal cable)} \qquad \dots (13b)$$

From equation (12), the impulsive coefficient of the sounding weight, K_2, is proportional to the frontal area of the sounding weight, Ω, or to the square of the maximum diameter of the sounding weight, D_{max}. For a given density and shape of sounding weight, its weight in water, G_0, is proportional to D^3_{max}. Thus equation (12) can be rewritten as follows:

$$K_2 = K_2'' G_0^{2/3} \qquad \dots (14)$$

The coefficient K'' is determined by experiment. Using sounding weights of 35 kg to 375 kg at velocities between 0,75 m/s and 4,25 m/s and an angle of entry varying between 10° and 40°, field tests consisting of 74 trials were carried out to obtain values of K''. If the quantity $\frac{Q_x}{G_0^{2/3}}$ is plotted against v

Table 1 — Test results for the determination of the resistance coefficient of the sounding line, K'_1

Diameter of the sounding line, d mm	Resistance coefficient of the sounding line, K'_1	
	without signal cable	with signal cable
4	1,58	1,87
5,4	1,54	1,7
7,4	1,5	1,68
9,2	1,38	1,55
	mean 1,5	mean 1,7

as shown in figure 2, the empirical equation for the impulsive coefficient of the sounding weight, K_2, is obtained:

$$K_2 = 0{,}031\, G_0^{2/3} \qquad \ldots (15)$$

If equations (13a) or (13b) and (15) are substituted into equation (5), and, for convenience, converting the weight of the sounding weight in water, G_0, to that in air, G, the equation for β becomes:

$$\beta = 0{,}4 \frac{G^{2/3}}{d} \text{ (with signal cable)} \qquad \ldots (16)$$

$$\beta = 0{,}3 \frac{G^{2/3}}{d} \text{ (without signal cable)} \qquad \ldots (17)$$

If the sounding weight is made of iron, the equation becomes:

$$\beta = 0{,}5 \frac{G^{2/3}}{d} \qquad \ldots (18)$$

3.3 Determination of the velocity distribution parameter, P

The velocity distribution parameter, P, varies with the Chezy coefficient, C. For values of C ranging from 40 to 60, $P = 0{,}6$. On the basis of the observed data collected from stations in the Yangtze Basin, as shown in table 2, the mean value of P is 0,6, which correlates with the value stated above.

Table 2 — Test results for the determination of the velocity distribution parameter, P

Station	Velocity distribution parameter, P
Baihe	0,6
Xiangyang	0,65
Yichang	0,59
Cuntan	0,59
Xinchang	0,58
Hankou	0,61
	mean 0,6

3.4 Examination of the wetline correction, ΔW

In order to examine the reliability of equations (7) and (8), field tests were made at the Yichang, Cuntan and Baihe stations in the Yangtze Basin in 1958. The depth H was measured using an echo sounder, observing at the same time the length of the sounding line, L_H. The measured wetline correction, $\Delta W'$, from equation (8) is compared with the computed correction, ΔW, from equation (10). The relation between $\Delta W'$ and ΔW is shown in figure 3. The mean error in the depth is $\pm$ 0,8 %. Table 3 shows the range of data used for the field tests of wetline corrections.

The wetline correction equation suggested is based on the actual force on the sounding line, and the parameters selected are based on measured and experimental data. The result is that the random relative error is less than $\pm$ 1 % and the systematic error is zero. The method accounts for various dimensions of suspension equipment. The measuring accuracy will be ensured for angles of entry from the vertical up to 30°.

4 Development and use of the working tables

4.1 The correction coefficient, K_H, is computed by empirical solution of equation (9). The wetline correction, ΔW, is then computed using equation (10). The results are presented in tables 4, 5 and 6. The range of parameters is as follows:

$P = 0{,}6$

$\beta = 1$ to 5

$H = 1$ m to 30 m

$\theta = 4°$ to 30°

4.2 To use the tables at a station, the value of β is computed from equations (16), (17) or (18), according to the weight of the sounding weight in air, G, in kilograms, and the sounding line diameter, d, in millimetres, which are in use at the station. The value of β may be rounded up to the nearest whole number which is then used to select the appropriate table, i.e. 4, 5 or 6. From the selected table the wetline correction, ΔW, can be obtained from the length of measured wetline and the angle of entry. If the same sounding line and weight are always used at a station, β will be constant, and only one table is necessary for that station. If various lines and weights are used at different times, then different tables will be applicable for the appropriate dimensions of sounding lines and weights.

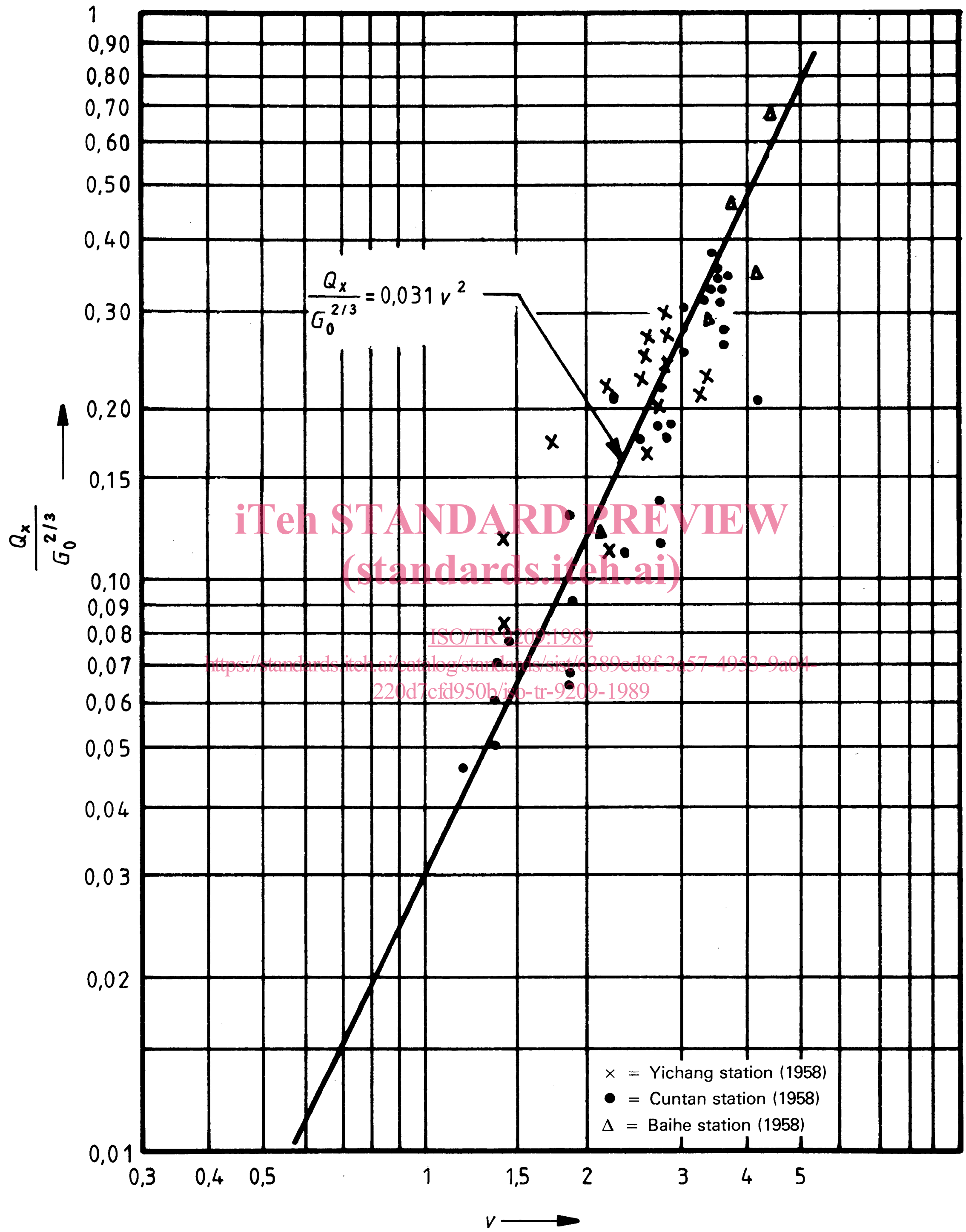

Figure 2 — $\frac{Q_x}{G_0^{2/3}}$ versus v relation

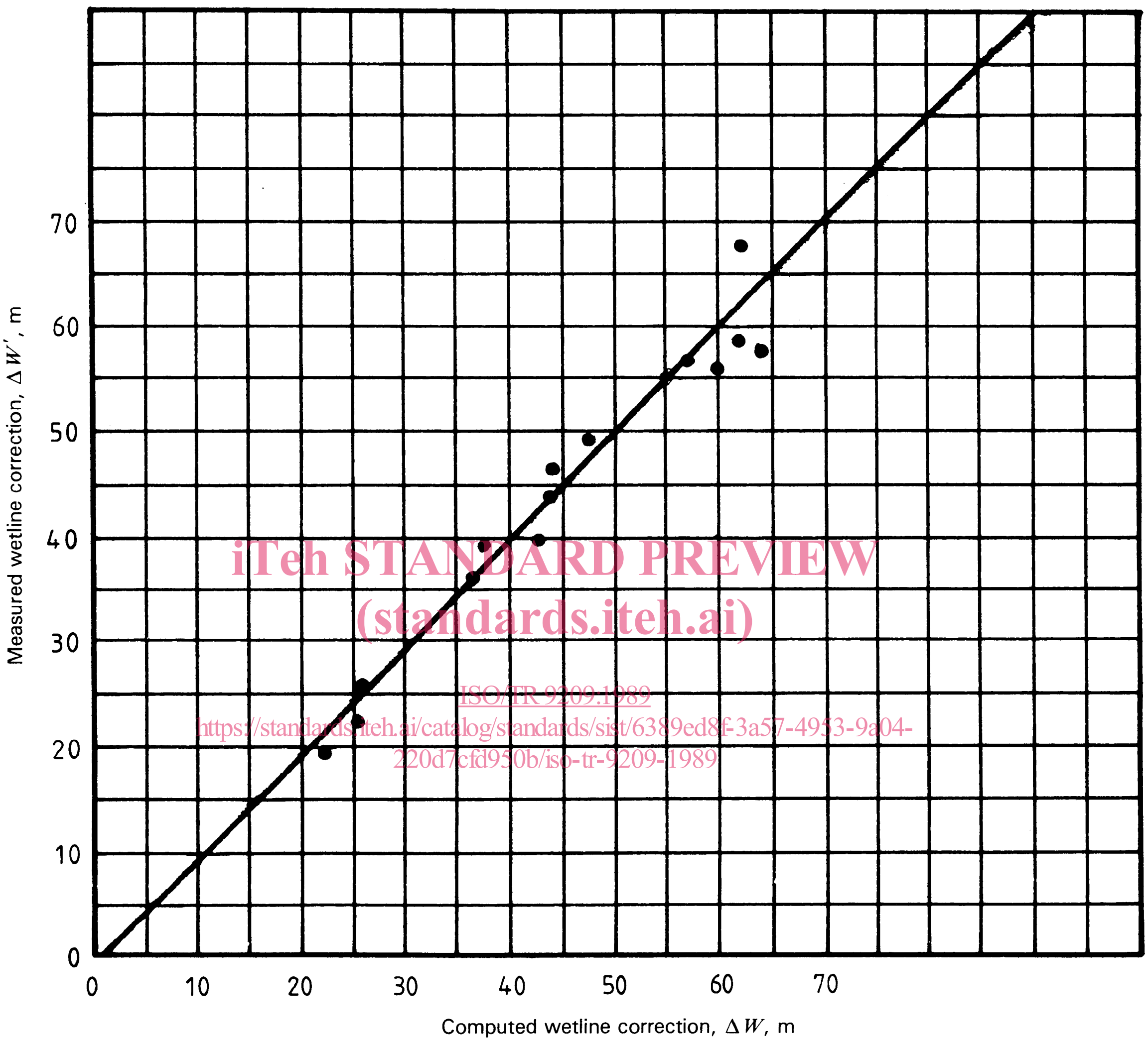

Figure 3 — The relationship between $\Delta W'$ and ΔW

Table 3 — Examination of the wetline correction, ΔW

Depth, H m	**Weight of sounding weight in air, G** kg	**Velocity, v** m/s	**Oblique angle, θ** degrees
22,3 to 30	40 to 200	3 to 4,5	35 to 60