Hydraulics Research
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FLOOD DISCHARGE ASSESSMENT

Peak Velocity Meter - evaluation of a device for measuring flood plain flow velocity

Progress to March 1990

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SUMMARY

Hydraulics Research Ltd are studying methods of improving the assessment of flood discharge on behalf of the Ministry of Agriculture, Fisheries and Food. The research is being carried out with the co-operation of the National River Authorities in England and Wales, and includes the analysis of existing flood flow data, and the development of new methods for assessing flood discharge.

This report describes the development of a technique for measuring flow velocity, which uses the principle of a deflecting vane and can be interrogated after the passage of a flood event.The instrument is principally designed for use on the flood plain.

The report also reviews velocity and flow measurement techniques which provide an alternative to the more commonly accepted methods.

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1 INTRODUCTION

1.1 Background

The Water Resources Act 1963 placed on the Water Resources Board the duty of collecting data relating to the demand for water and the actual and prospective water resources for England and Wales. Consequently, many gauging stations were primarily designed to establish the quantity of water available for the community. The provision of flood data was originally considered to be of secondary importance.

When a flow measurement structure or rated channel section is out flanked by a flood flow the uncertainties associated with flow measurement rise from 3-10% for in-bank flow conditions to 30% or more for out of bank flood conditions. Uncertainties of this magnitude can have a profound impact on the return period associated through standard statistical techniques with a particular discharge. They may also lead to the design of a flood protection scheme being too conservative with associated economic losses, or alternatively inadequate with the benefits of the proposed scheme not being achieved. Reporting upon the errors in flood discharge measurement the Wolf Report (1985) stated :

" A research programme should be set up to develop new methods for measuring or estimating flow particularly over a flood plain. The objective of the project should be to produce a method which is inexpensive and effective and can possibly be applied after the event".

These recommendations formed the basis for the present research, which is being carried out by Hydraulics Research Ltd (HRL) for the Ministry of Agriculture, Fisheries and Food (MAFF). This report describes the laboratory experiments undertaken up to March 1990.

1.2 Objectives

The objectives for any new method of estimating or assessing the discharge, particularly peak discharge, of a flood that can be used at typical lowland gauging sites in the UK were that :

a) the method can be applied after the event.

b) the error in discharge measurement is not greater than +/- 10%.

c) no appreciable afflux is caused by the method.

d) the method is cheap.

1.3 The problem

The main hydraulic problem associated with the assessment of flood discharge is the estimation of discharge for sites where overbank flow occurs. A number of different methods of estimating discharge can be applied and are described by Ramsbottom (1989). These can be summarised as :

a) single channel method.

b) division line methods.

c) apparent shear method.

d) correction factor method.

e) lateral velocity distribution method.

When considering the estimation of overbank discharge at a site where gauged data is limited or unavailable, a number of problems arise.

Estimation of the bankfull value of Manning's n is difficult. The guidelines presented by Chow (Chow, 1959) refer to normal depth flows.Research work in N.Ireland has provided a relationship between the bankfull value of Manning's n and the bankfull discharge for rivers in Northern Ireland (Higginson and Johnston, 1988). Where no data exists, guidelines of this sort must be used.

The estimation of the roughness of the flood plain including natural channels formed by depressions in a flood plain is difficult because of the mixture of roughness coefficients which may occur.

Cowan (Cowan, 1956) estimated composite hydraulic roughness coefficients in a systematic and rational manner.However, these estimates require the exercising of a critical judgement in the evaluation of the factors that influence the roughness coefficient. Another method for estimating Manning's n for different components of a complex flood plain requires the total discharge, channel geometry and slope to be known (Bruk and Volf, 1967). The flow resistance of grass cover has been studied and a method is available for calculating Manning's n for grasses of different length (USDA, 1954). The most suitable available approach is that based on the method of Petryk and Bosmajian (1975) but application of the method is difficult. Individual components of flood plain roughness have been studied by various researchers (eg. hedges and orchards, Klaasen and Van Der Zwaard, 1974; grass in flood channel, Klaassen and Van Urk, 1985).

It is concluded, however, that at present no satisfactory method of estimating the roughness of flood plains exist except for sites with uniform grass cover.

Several methods of measuring flow velocity and stage on a flood plain have been suggested by Ramsbottom (1989). These range from the use of float tracking, permanently installed current meters through to the use of flood plain structures such as roads and hedgerows.

With the exception of the latter they require staff input during the flood event or the use of relatively expensive equipment, neither of which may be readily available. Flood plain structures are not necessarily conveniently positioned to serve the purpose of being used as a control structure.

Any field installation is also subject to damage or clogging by trash, and is also liable to damage by vandalism. The whole question of staff safety must be carefully considered in the selection and development of a field measurement method.

1.4 Review of flood plain data

Ramsbottom (1989) reviewed site data relating to 15 gauging stations throughout the UK. From this data it was possible to determine the maximum flow depth recorded on the flood plain at 14 of the sites and for 5 of the sites flood plain velocity information was available.

Flood plain depths for the recorded events ranged from 0.19m to 1.86m, see Table 1, with maximum recorded velocities of between 0.108 m/s and 1.178 m/s. The greater depths and higher velocities tended to be associated with the sites where the flood flow was constrained at the gauging sites between man-made embankments with the maximum velocities being measured adjacent to the main river channel. Velocities over the majority of the flood plain at the sites for which data are available are notably lower.

1.5 The proposed solution

If the flow velocity on a flood plain could be registered along with the maximum stage by instruments that were cheap, simple and efficient then assessment of flood discharge assessment would be improved.

This proposition contains a number of practical complications.

1. The instrument must be sensitive to a wide range of velocities over a small depth range.

2. The instrument must be able to be read after the passage of the flood event.

3. The instrument must be able to operate and replicate velocity readings under flow conditions containing silt and trash.

A complete solution to to these problems would require a relatively sophisticated powered system. The present tests, however, were carried out with a very simple mechanical system avoiding the use of power. The instrument operates on the principle of a deflecting vane and comprises a vane suspended centrally from a horizontal shaft, one end of which is located in a needle roller bearing, the other in a roller clutch bearing. The clutch bearing will only allow rotation in the direction of flow, consequently after the passage of a flood the vane will retain the deflection due to the peak velocity, see Plate 1.

2 TEST PROGRAMME

2.1 Introduction

Deflection vanes, current meters and pitot tubes are examples of flow measuring devices which use impact force or momentum to indicate flow velocity. Deflection vanes or vane flowmeters have been developed with a consideration to application for measuring flows in irrigation systems (Robinson 1963), (Edwards et al 1967), (Svendsen et al 1982), (Weller 1986). These meters have been designed to measure discharge by registering either the deflection of, or restoring moment on a flat plate and are usually designed uniquely for the channel or pipe in which they are measuring flow. Replogle (1968) identified two objectives in the development and design of target or vane flowmeters for the measurement of velocity and discharge in open channels. These were :

a) " to give an integrated, or average velocity in a sheet flow ".

b) " to indicate discharge rate in a wide range of channel geometries independent of the depth of flow ".

Replogle goes on to further state that :

" The first of these objectives is not too difficult to achieve. A sensing element that will reach from the surface of the flow to the channel floor can be used to indicate an average velocity in the vertical section sampled. The element must have a stable drag coefficient over a wide range of Reynold's numbers to avoid problems of nonrepresentative sampling in different portions of the velocity profile into which the element is inserted.

The second objective is more complex. In order to indicate discharge rate independent of flow depth, a shaped element that is some function of the channel dimensions is required ".

Due to the variable geometry of a flood plain it would be impractical to develop an instrument which would give a discharge rate independent of flow depth. Instruments designed for this purpose are unique to the channel being monitored. Consequently it was decided to develop an adaptation of the sensing element mentioned in the first objective. A simple deflecting vane was designed which could be used to sample the average velocity in the vertical section covered by the vane in either free surface or drowned flow conditions.

2.2 The experimental facility

The experimental work was carried out in a flume with a working length of 24.4m, breadth of 0.91m and depth of 0.3m. Stilling and smoothing were provided at the upstream end and an adjustable tailgate was used to set tailwater levels.

Water was delivered to the flume by a centrifugal pump via a constant head system which minimised fluctuations in discharge. The maximum capacity of the installation was 0.17 cumecs and the discharge was measured using a British Standard fully contracted 90 degree 'V' notch weir.

Mean flow velocities, time averaged over a 60 second period, were measured at 0.6 of the depth, 300mm upstream of and in line with the centre of the peak velocity meter, using a miniature current meter.

2.3 Instrument design

Two instruments for measuring the flow velocity were designed working on the principle of a deflecting vane, see Figs 1 and 2.

Five vane shapes were tested with Design 1 and nine with Design 2, see Figs 3 and 4. The instrument consisted of a base plate supporting two side walls. The vanes were suspended centrally from a horizontal shaft mounted in the side walls, one end of the shaft being located in a caged needle roller bearing, the other in a roller clutch bearing.

The roller clutch bearing will only allow rotation in the direction of flow. Consequently after the passage of a flood the vane will retain the deflection due to the peak velocity.
Deflections of the vane were measured by a pointer referable to a protractor. The support frame was constructed of stainless steel with the vanes being constructed of dural and stainless steel for Design 1 and dural only for Design 2.

2.4 Test procedure

The proposed test programme can be summarised as follows :

a) flow alignment - testing the velocity meter with the vane normal to the flow and at 10 degrees and 20 degrees to the flow alignment.

b) flow depth - assessing the effect of the meter operating under varying flow depths.

c) effect of silt - assessing the effect of silt on the instrument bearings.

d) effect of trash - assessing the effect of trash on vane deflection.

e) effect of wind - assessing the effect of wind on vane deflection.

To date the velocity meters have been tested for items (a) and (b) above only along with a theoretical assessment of (e), see Sections 5.3 and 5.4.

3 TEST RESULTS - DESIGN 1

3.1 General

The instrument was tested with vane lengths of 135mm with the shaft axis 150mm above the channel bed, see Fig 1 and Plate 1. Dural and Stainless Steel plate, 6mm thick, were used to make two sets of vanes in order to assess the influence of different density materials upon the calibration of the vane. The five vanes tested, see Fig 3, consisted of three rectangular elements 12.5, 25 and 50mm wide and two trapezoidal elements. The first trapezoidal element had a top width of 10mm with a base width of 60mm, the second being the invert of the first. The data from the tests were fitted by third order polynomials.

3.2 Flow alignment

In positioning the meters along a floodplain transect the intention would be to align the vane normal to the flow line. The direction of flow may not be readily known and indeed may vary with depth. Consequently in calibrating the meter the response of the vane to normal flow and flow approaching at 10 degrees and 20 degrees to the centreline was investigated. Tests on the effect of meter alignment were undertaken by gradually increasing the flow in the flume, with no tailwater control, in order to simulate the build up and passage of a flood.

In line

The stainless steel vane calibrations are shown in Figure 5. The curves illustrate the insensitivity of the vane material at low to medium velocities with an angular deflection of 0 to 10 degrees covering a velocity range of 0.1 m/s to 0.35 m/s. The wider vanes ie Types 2,3 and 4 provide a more sensitive calibration due to the increased drag associated with the greater surface area presented to the flow. Vane type 1 is the least sensitive due to the lower drag associated with the narrower vane width. The calibration for the type 5 vane is similar to the type 1 vane at low velocity but as the vane area exposed to the flow increases the sensitivity of the calibration improves. The range of the vanes is from 0.1 m/s to 0.75 m/s with an angular deflection of 0 to 55 degrees at which point drowning of the vane occurs with the loss of an effective calibration characteristic.

The dural vane calibrations are shown in Figure 6. The threshold velocity of the vanes is 0.05 m/s with an angular deflection of 0 to 80 degrees covering a velocity range of 0.05 m/s to 0.75 m/s. Types 2,3 and 4 show the more sensitive calibration characteristics with Types 1 and Type 5 showing similar calibrations to the stainless steel vanes of the same design but with greater sensitivity. This is due to the increased buoyancy on the vane associated with the lower specific gravity of dural compared with stainless steel.

In summary it was found that the dural vanes provide the more sensitive calibrations, compare Plates 2 and 3. Consequently it was decided to only undertake further tests with vanes manufactured from dural and types 2 and 4 were chosen for further investigation. Types 2 and 4 were considered to represent the more sensitive vanes associated with the rectangular and trapezoidal shapes.

Out of line

The envelopes about the best fit line for the type 2 and 4 vanes have a band width of +/- 10% , see Figs 7 and 8, showing that for an angle of flow to the centreline of the meter of up to 20 degrees there is negligible effect on the calibrations.

3.3 Effect of flow depth

Besides giving consideration to flow alignment thought need to be given to the effect of varying depth upon the calibration of the meter. This could be caused by flood plain storage prior to the onset of flow, backwater influences due to structures or flood plain features such as hedges or fences. These effects were simulated by raising the tailgate so increasing the depth at which flow impacted the vane. Two levels of tailgate, 50mm and 100mm were tested.

The envelopes about the best fit line for the type 2 and 4 vanes have band widths of +/- 10%, see Figs 9 and 10. The spread of the data about the best fit line for the flow depth is more pronounced than for the alignment tests.

3.4 Design 1 - meter calibration

Best fit lines were derived for the type 2 and type 4 vanes for the data from both the flow alignment and flow depth tests, see Figs 11 and 12. The best fit line for the type 2 vane is represented by the third order polynomial

$$v = 0.05057 + 0.01477y - 0.0002196y^2 + 0.000001828y^3$$

and for the type 4 vane by

$$v = 0.03922 + 0.01329y - 0.0001785y^2 + 0.000001435y^3$$

where v is the mean flow velocity in metres per second and y is the angular deflection of the vane in degrees. Both vane types 2 and 4 provide good calibrations with the majority of the data points contained within the +/- 10% envelope, see Figures 11 and 12.

The initial concept of constructing the meter 150mm deep was in order that the average flow velocity registered by the meter was applied over a narrow flow band through the depth. Several meters could then, if required, be positioned through the depth at any vertical to provide a flow profile, which when associated with a maximum level gauge measuring the flow depth would enable the calculation of a segment discharge, see Figure 20.

However, in order to attempt to measure velocities over the range identified from prototype data, see Section 1.4, it was decided to increase the length of the vanes. The shaft axis to channel bed length was increased from 150mm to 300mm, see Section 4.1.

4 TEST RESULTS - DESIGN 2

4.1 General

The instrument was tested with vane lengths of 270mm with the shaft axis 300mm above the channel bed, see Fig 2 and Plate 5. Dural plate, 6mm thick, was used for the vanes. The nine vanes tested, see Fig 4, consisted of three rectangular elements 12.5, 25 and 50mm wide and two sets of three trapezoidal elements. The first set of trapezoidal elements having top widths of 10,20 and 30 mm and a common base width of 60mm and the second set being the invert of the first.

4.2 Flow alignment

In line

The vane calibrations are shown in Figs 13 and 14 with both the rectangular and trapezoidal vanes measuring a velocity range of 0.1m/s to 0.8 m/s with an angular deflection of 0 to 60 degrees before the calibration became insensitive. The rectangular vanes all have a similar calibration, see Fig 13, and of the trapezoidal vanes type 4 is the most sensitive, see Fig 14. Consequently as for Design 1 vane types 2 and 4 were chosen for the out of line flow and flow depth tests.

Out of line

The envelope about the best fit line for the type 2 and 4 vanes has a band width of +/- 10% , see Figs 15 and 16. The graphs show that, as for Design 1, with the meter at angles of 10 degrees and 20 degrees to the flow there is negligible change in the meter calibration.

4.3 Flow depth

In the case of either vane type 2 or 4 the effect of varying the flow depth is to produce a unique calibration for each vane at each of the tailwater conditions tested, see Figs 17 and 18. This is as a result of the increased buoyancy effects, associated with a larger vane, reacting on the longer moment arm. Consequently it is not possible to develop a single calibration for either vane type 2 or 4 as was the case for Design 1.

4.4 Design 2 -meter calibration

Whilst it was possible to derive calibrations for the type 2 and 4 vanes under conditions of gradually increasing depth and velocity, see Figs 15 and 16, it was not possible to develop calibrations which also took into consideration the effect of flood plain storage prior to the onset of flow, backwater influences due to structures or flood plain features such as hedges or fences.

5 SUMMARY OF RESULTS AND DISCUSSION

5.1 Summary of results

The results can be summarised as follows :

- vane types 2 and 4 made from dural provide the more sensitive calibrations for both designs of meter tested.

- for angles of flow of up to 20 degrees to the centreline of the meters the effect on the calibrations of the vanes with progressive increase of flow depth and velocity was negligible.

- data from the alignment and flow depth tests for design 1 is contained within the +/- 10% envelope about the best fit line for both vane types 2 and 4.

- design 2 vanes are affected by buoyancy in the tailwater tests.

5.2 Application to main channel

The development of an instrument for measuring flow velocities on a flood plain presupposes the capability to measure the main channel flow and its contribution to the total flood discharge.

The peak velocity meter was not designed with the intention of measuring main channel velocities. The determination of channel flow should be undertaken using one of the more commonly accepted methods of velocity and flow measurement. This could be by reference to an adjacent flow measuring structure or by current metering for in-bank flows with supplementary theoretical or computational analysis for above bank flows in the main channel, if necessary.

5.3 Wind effects

In the field the vane will be subject to both drag forces from water and wind. Consequently it is necessary to understand the effect that wind speed could have upon the deflecting vane in order to assess whether a field reading is attributable to the influence of water or wind. Weller, 1986 showed that with increasing immersion of the vane that the influence of the drag force due to the wind decreased and suggested that while vane deflection readings were being taken the vane should be sheltered. Further work may be required to assess the practicality of reducing wind effects on the meter without affecting the calibration.

A theoretical analysis of the pressure increment due to a fluid, water or wind, upon the face of a vane can be represented by :

$$q = 0.5 * \rho * v^2 \qquad \text{(Hoerner, 1958)}$$

where q = dynamic pressure (N/m^2)

ρ = density of fluid (kg/m^3)

v = flow velocity (m/s)

The dynamic pressures associated with flow velocities of 0.1m/s to 1.0m/s range between $5N/m^2$ and $500N/m^2$, see Table 2. The equivalent wind speeds necessary to produce these dynamic pressures would be 6mph to 64mph or Force 2 to 10 on the Beaufort scale.

This table can therefore be used as a reference in association with meteorological information to assess whether the vane deflection is attributable to flow velocity or wind speed.

5.4 Further testing

Assessment of the influence of silt on the bearings of the meter and the effect of trash on the vane calibration and a means of preventing trash choking the meter need to be further investigated. It is considered that these points would be best tested in the field.

6 FIELD INSTALLATION

Field testing of the instrument is to be undertaken during the winter of 1990/1991. Sites to be monitored will be chosen from data provided by the NRA units and sites visited during 1987, Tagg et al, 1987 and Ramsbottom, 1989. These will be sites where channel and flood plain flow data already exist or sites where overbank flow exists upstream of a flow measurement site where all the flood flow is contained by the flow measurement structure or cableway.

The cross section of the main channel and flood plains at the metering site will be surveyed to the flooded limit. Dependent upon the size of study site a number of peak velocity meters will be deployed in conjunction with maximum water surface level gauges.

It is proposed to undertake check current metering exercises of the flood plain flows and to assess the accuracy of the flow measurement based upon the velocity-area principle as determined from both the current meters and peak velocity meters. A schematic representation of a flow measurement site is shown in Figure 19.

7 ALTERNATIVE VELOCITY AND FLOW MEASUREMENT TECHNIQUES

More commonly accepted methods of velocity and flow measurement techniques are well documented (Ackers et al 1978), (Charlton 1978), (Herschy 1978) and BSI (1980). It is proposed here to review alternate forms of measurement that have been developed and to assess their practical application in assessing flood plain flows. The integrating float method of flow measurement was suggested by D'Auria in 1882 (Allen 1930). The mean flow velocity was calculated by measuring the displacement of a float in the direction of flow. Floats released from the bed of a channel were used by Liu (Liu et al 1968, 1970), Dyer (Dyer 1970) and John (John et al 1976, 1978) to produce the same effect.

These ideas were further developed by Sargent (Sargent 1981) who used air bubbles as rising floats, a development of a method put forward by (Miyagi 1929) and Viol (Viol and Semenov 1964). The theory of the depth integrated float technique is described in Appendix 1.

Hydrobombs dropped from aircraft and which release oil on impacting the bed allowing the integrated velocity profile to be photographed are detailed by Kuprianov (Herschy 1978). Tethered spheres have similarly been used to provide an integration through the depth of the velocity profile (Stefan and Schiebe 1968) as have suspension wires (Sharp 1964).

Applying the integrated-float technique in the field, John et al (1978) and Sargent (1981) measured main channel flows with an error band of +/- 5% relative to the flows measured at adjacent cableway and weir sites. Dyer (1970) measured flows with errors of - 8.5% to + 7% relative to flows measured by current meter. Kuprianov (Herschy 1978) estimated errors of +/- 5% for the channel rising to +/- 10% to 15% for the flood plain using the hydrobomb technique. Each of the above tests were undertaken on natural rivers with discharges ranging from 0.55 cumecs to 100,000 cumecs. Using the same method Viol and Semenov (1964) gained results which agreed within 2% of the current metered flows, these experiments were undertaken in a canal.

The advantages of the above techniques can be summarised as follows :

- the integrated-float technique gives an instant value of the discharge.

This comment is more applicable to the air bubble approach with the injection pipe laid along the wetted perimeter giving a depth integrated velocity profile at the surface across the width. The hydrobomb technique will also give an instantaneous value of discharge. Floats released from the bed still provide a depth integrated value for the velocity but are applied to segments of the flow in a similar manner to a current metering exercise.

- the integrated-float method is more efficient than a current metering exercise. Viol and Semenov (1964) indicated that a field exercise took 4% of the time to undertake a similar current metering exercise and required one person to take the readings compared with three for a current metering.

The disadvantages of attempting to apply the above techniques to an assessment of flood plain flows can be summarised as follows :

- none of the above methods can be read after the event.

- none of the above methods can be operated at night.

- with the exception of the integrated-float technique the suggested methods are applicable to small scale irrigation channels or pipes and are specifically designed for a particular site.

- each of the methods requires the presence of an observer during the flow under investigation either to operate the float release mechanism or to make observations of the float displacement on a visual or photographic record.

- during flood flows the air bubble integrated-float technique is difficult to observe due to the turbulence of the flow surface.

- flow depths on flood plains are relatively shallow compared to the channel. Consequently the air bubbles or more particularly the floats (Dyer 1970) may not reach the terminal velocity of rise or accelerate to reach the local flow velocity before reaching the surface.

- the methods, with the exception of the hydrobomb technique, can only effectively be operated over a narrow flow width. Sargent (1981) referring to the integrated float technique states that " The method becomes less accurate with increasing river width and is probably limited to widths of about 50 metres...". Flood plains on major lowland rivers in the UK can extend over large distances, eg the River Trent at Newark has a flood plain width of 3 kilometres.

8 CONCLUSIONS

An inexpensive, effective instrument capable of measuring flow velocity to an accuracy of +/- 10%, which can be read after the passage of the flood, has been developed and tested successfully.

The instrument is capable of measuring a velocity range of 0.05 m/s to 0.75 m/s for both free surface and drowned flow conditions.

A literature review of alternative methods to the commonly accepted practices has been undertaken, along with an assessment of the advantages and disadvantages of these alternatives as a means of measuring flood flows on a flood plain.

9 ACKNOWLEDGEMENTS

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TABLES

TABLE 1 Floodplain data - maximum velocity and flow depths

Station	Velocity range	Maximum flow depth
	m/s	m
R Blackwater at Ower	0.226/0.362	0.19
R Culm at Wood Mill	-	0.64
R Mole at Kinnersley Manor	-	0.82
R Ouse at Skelton	0.108/0.663	1.09
R Penk at Penkridge	0.216	0.34
R Severn at Haw Bridge	-	0.75
R Severn at Montford	0.481/0.933	1.49
R South Tyne at Hayden Bridge	-	1.86
R Stour at Hammoon	-	0.56
R Tees at Low Moor	-	1.43
R Teign at Preston	-	0.21
R Torridge at Torrington	-	0.87
R Trent at North Muskham	0.846/1.178	1.26
R Wansbeck at Mitford	-	1.19

Table 2 Dynamic pressure - comparison of water and air pressure

Water		Air				
Velocity	Pressure	Velocity	Pressure	Velocity	Beaufort Scale	
m/s	N/m^2	m/s	N/m^2	mph	Force	
0.10	5	2.85	5	6.4	2	Light wind
0.25	31	7.10	31	15.9	4	Moderate wind
0.50	125	14.30	125	32.0	7	Strong wind
0.75	281	21.40	281	47.9	9	Gale
1.00	500	28.50	500	63.8	10/11	Strong gale

FIGURES

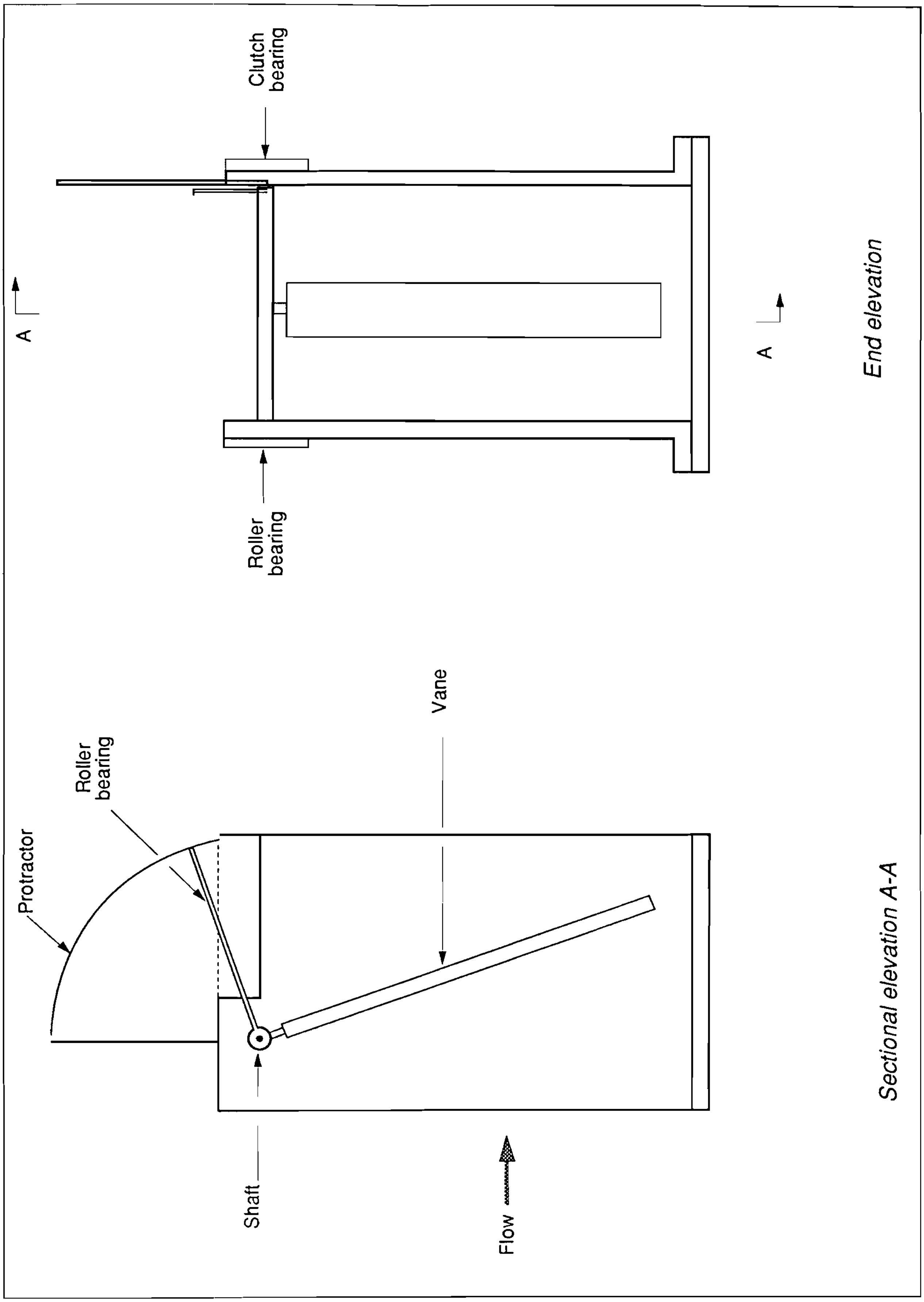


Fig 1 Peak velocity meter - Design 1

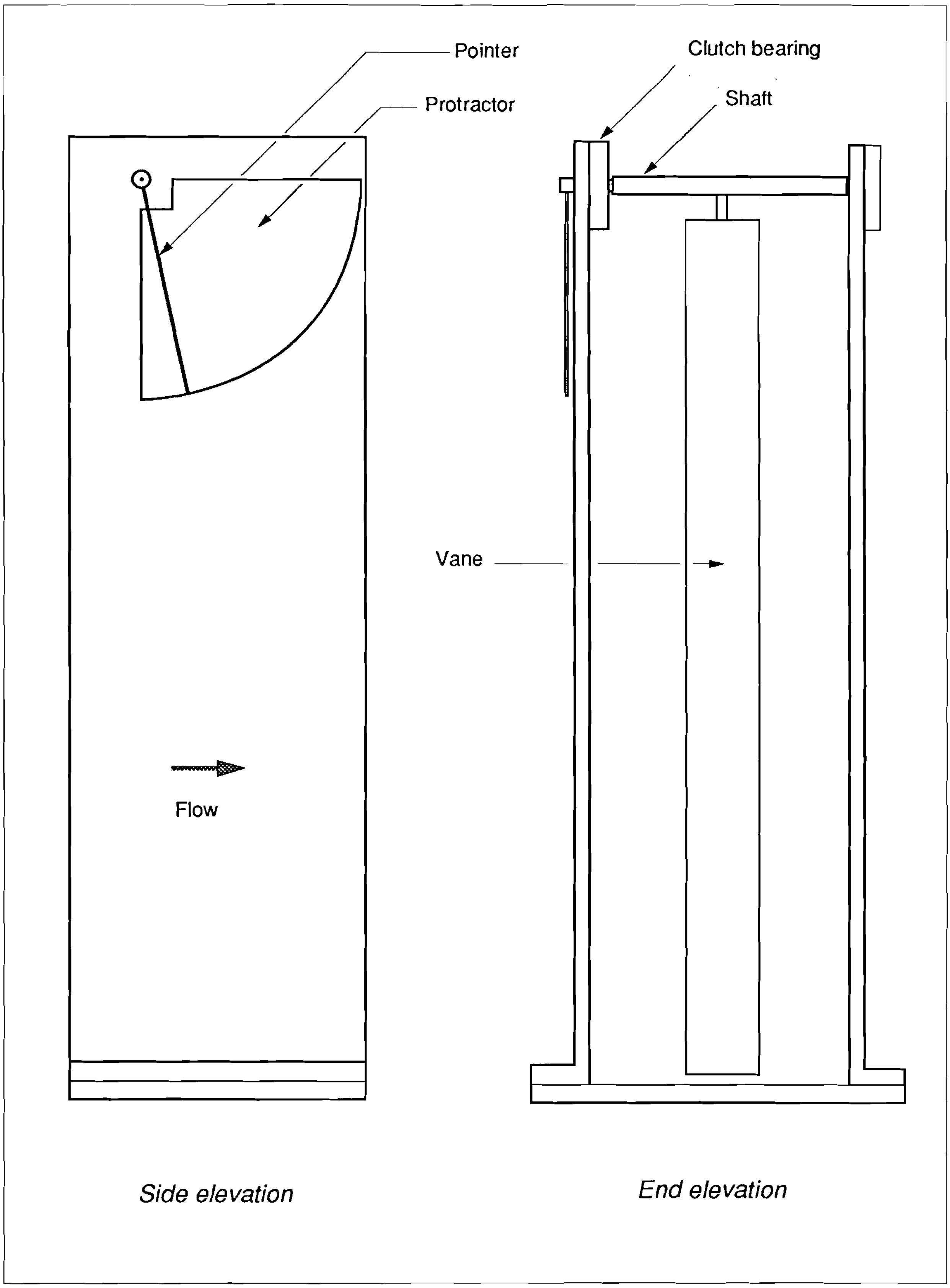


Fig 2 Peak velocity meter - Design 2

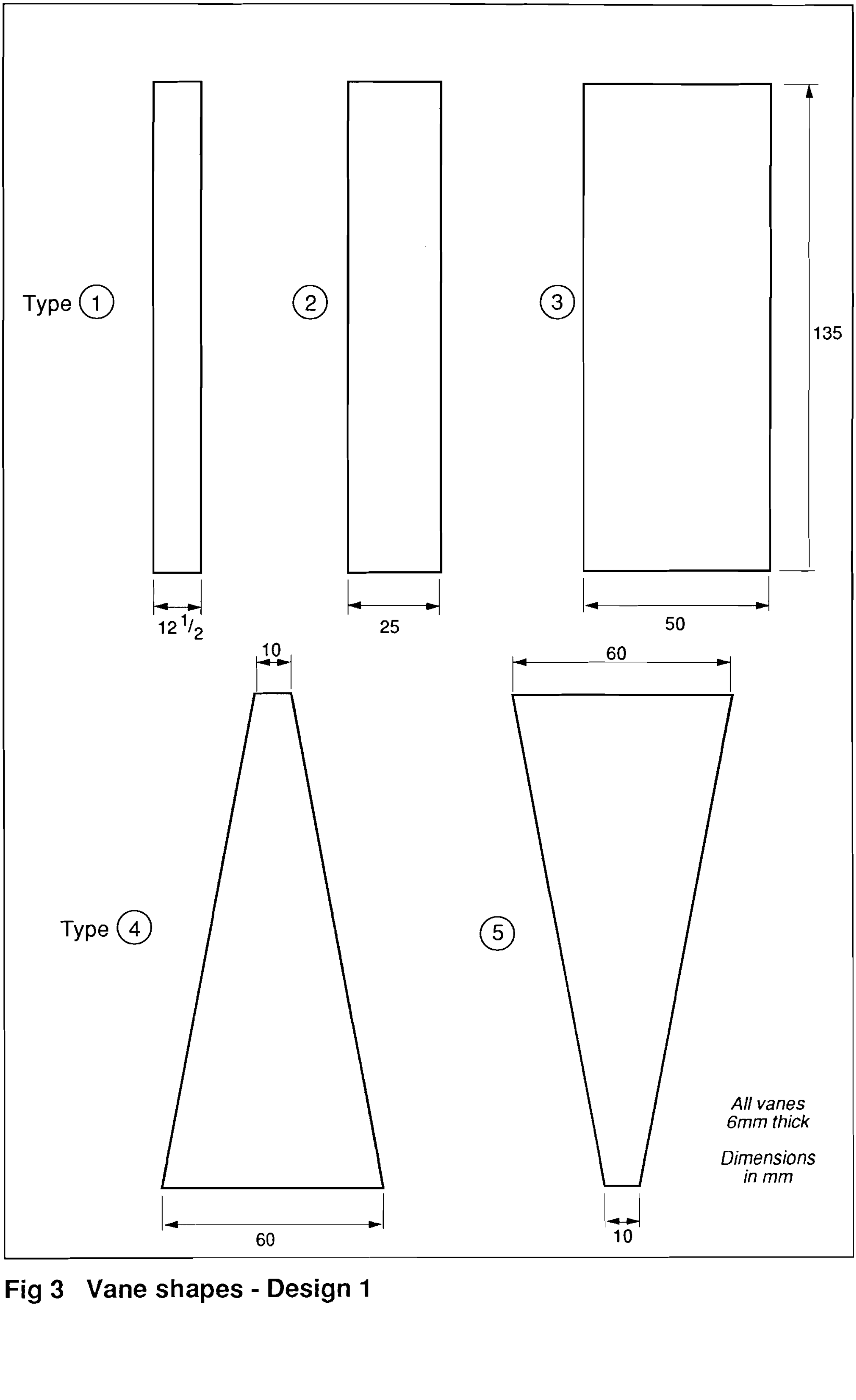


Fig 3 Vane shapes - Design 1

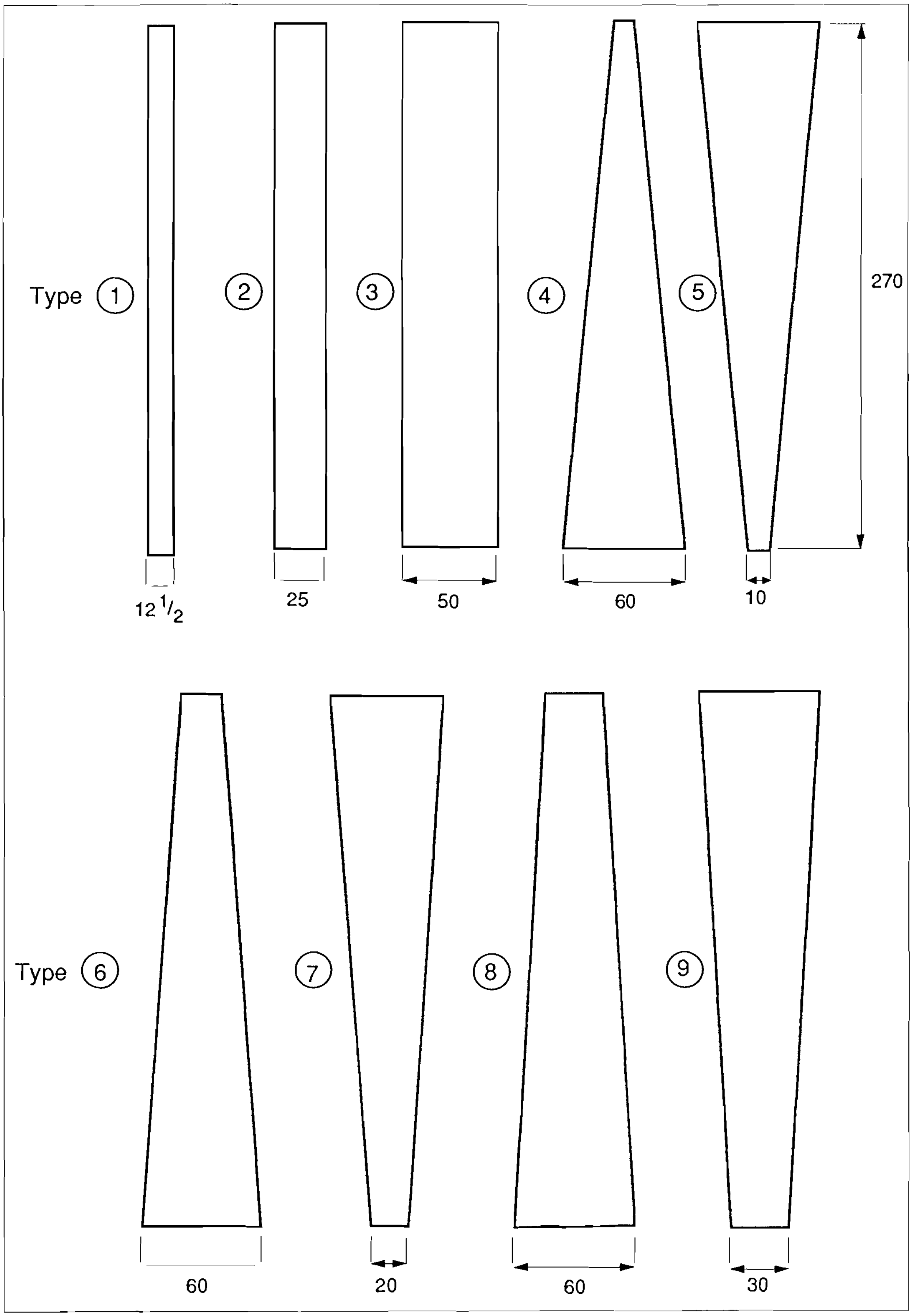


Fig 4   Vane shapes - Design 2

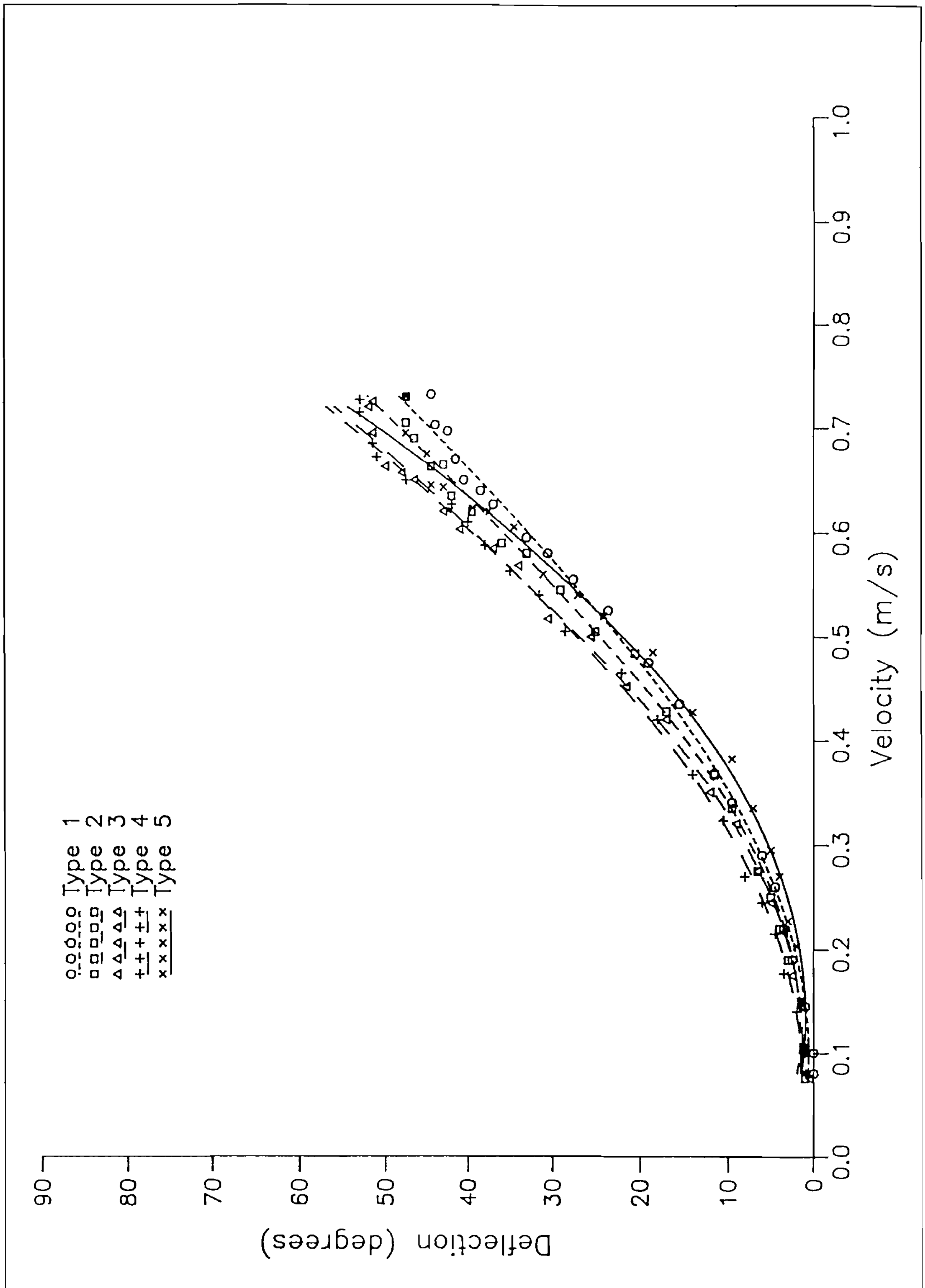


Fig 5 Design 1 - Stainless steel vane calibrations

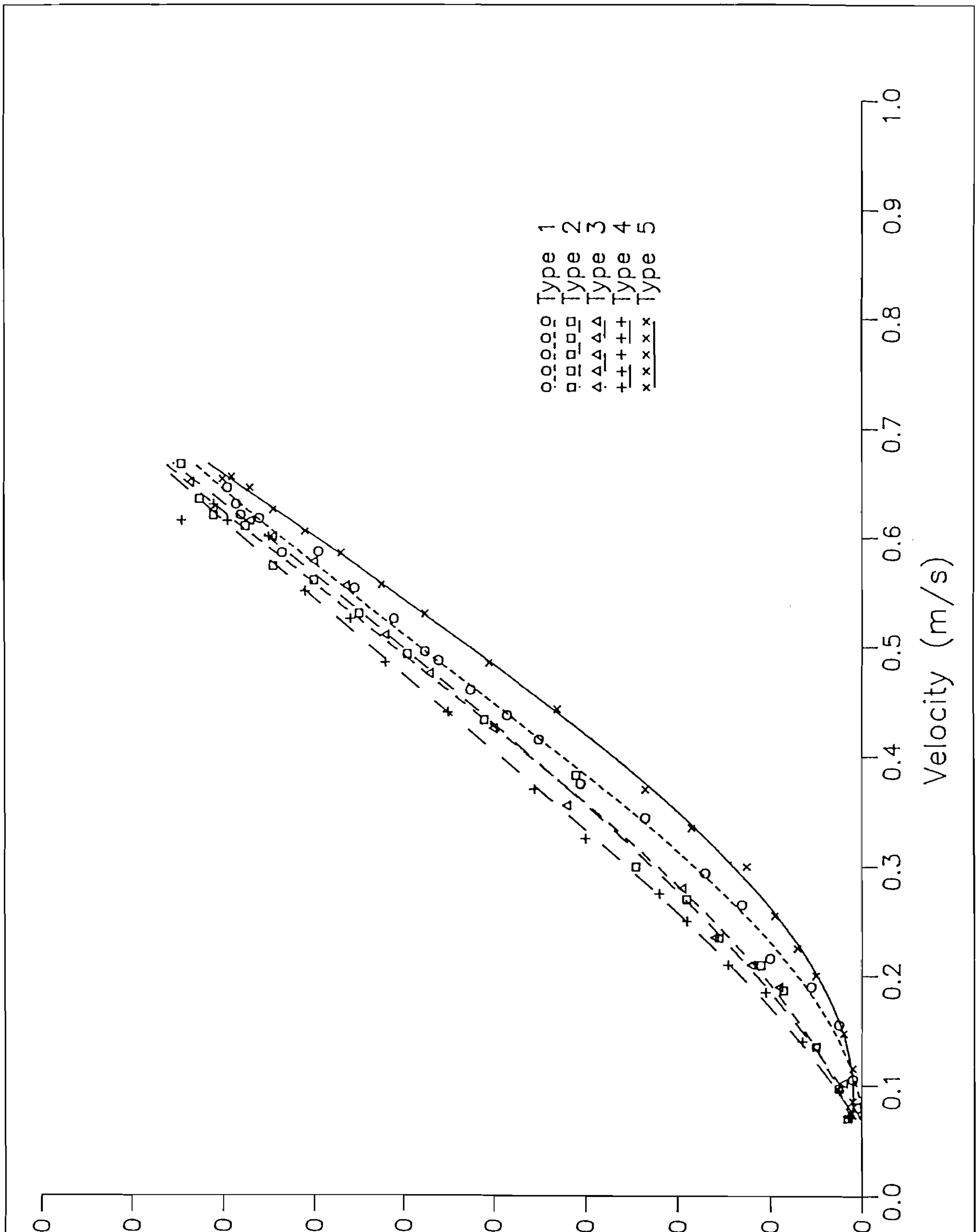


Fig 6 Design 1 - Dural vane calibrations

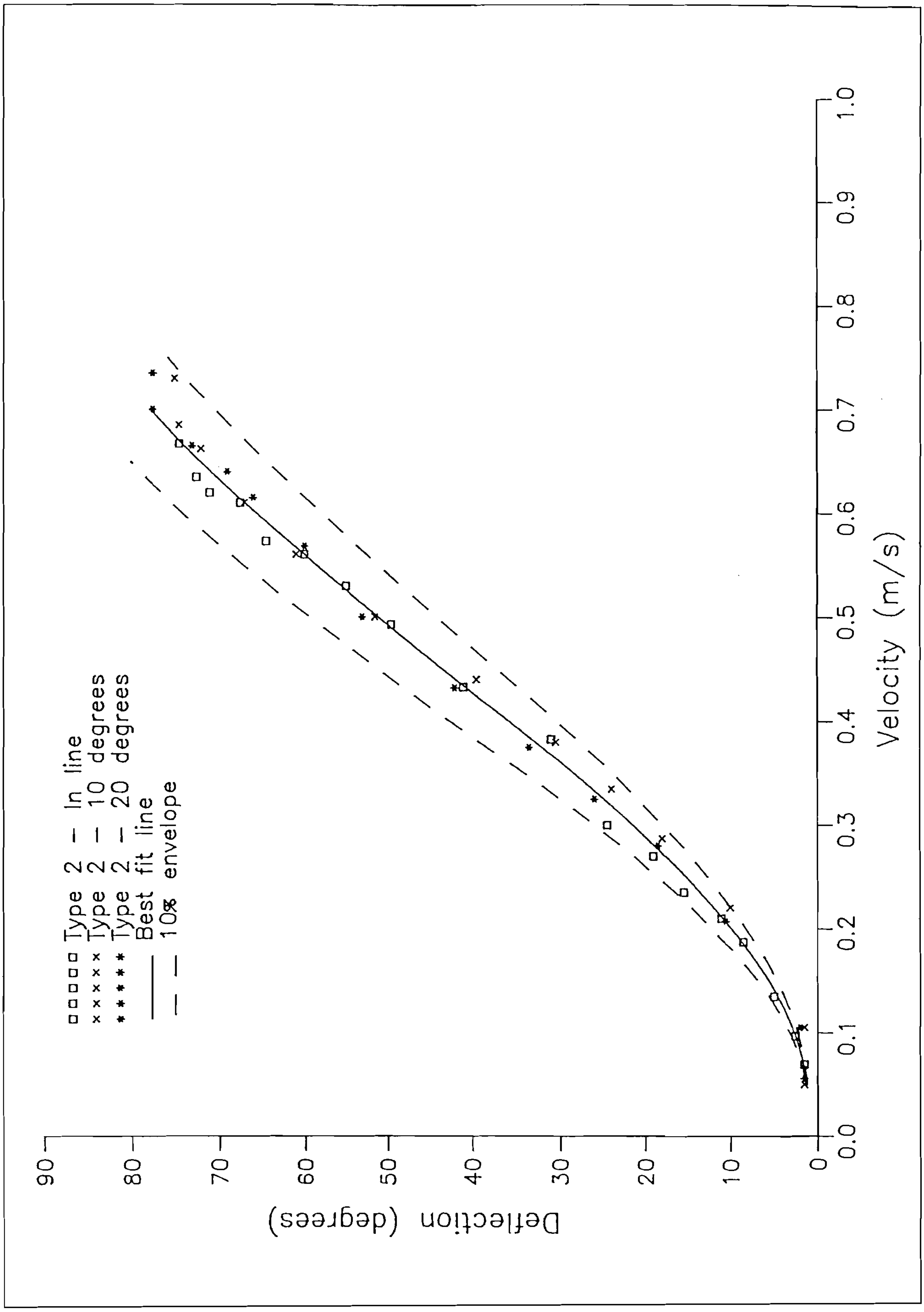


Fig 7 Design 1 - Type 2, effect of flow alignment

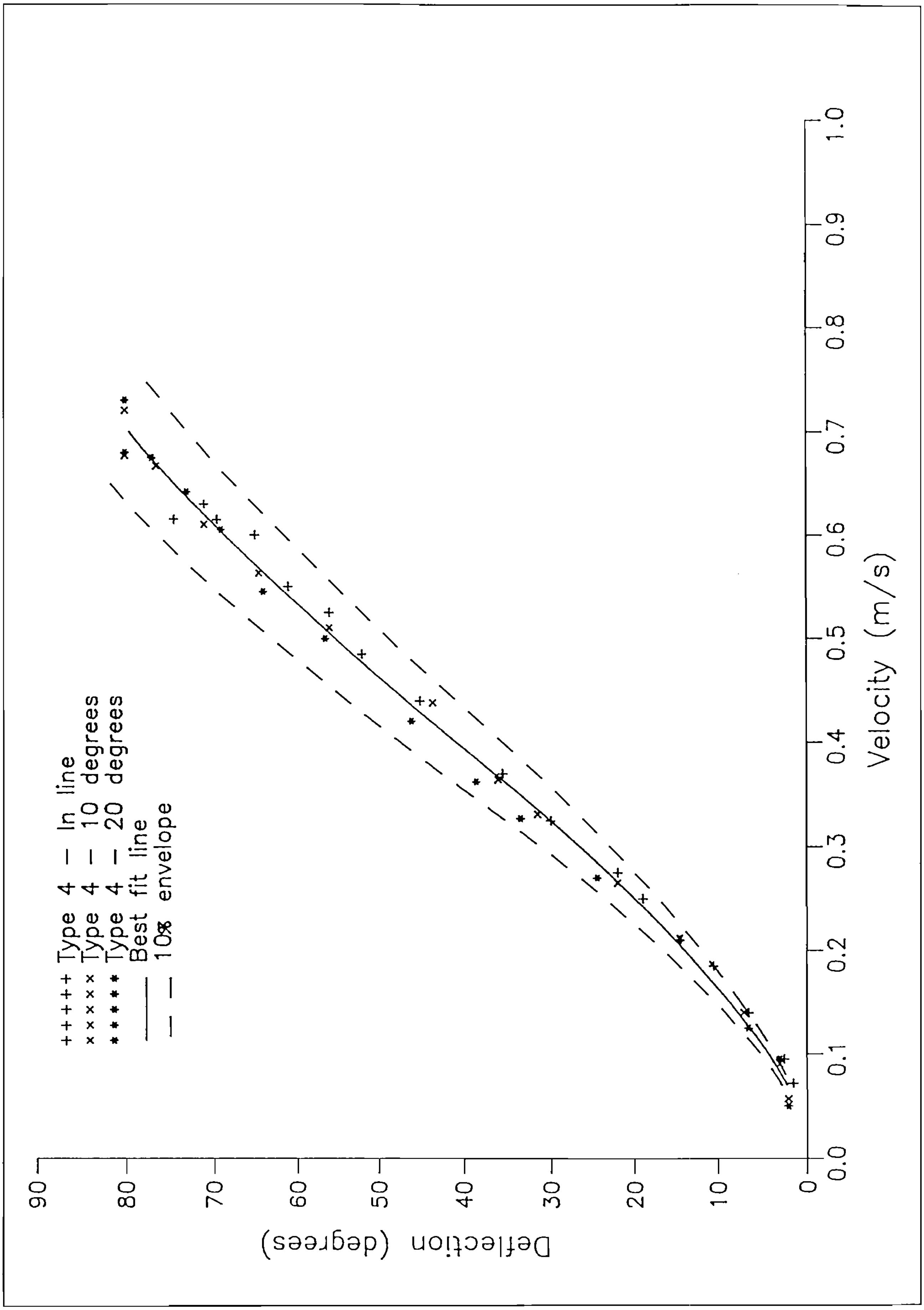


Fig 8 Design 1 - Type 4, effect of flow alignment

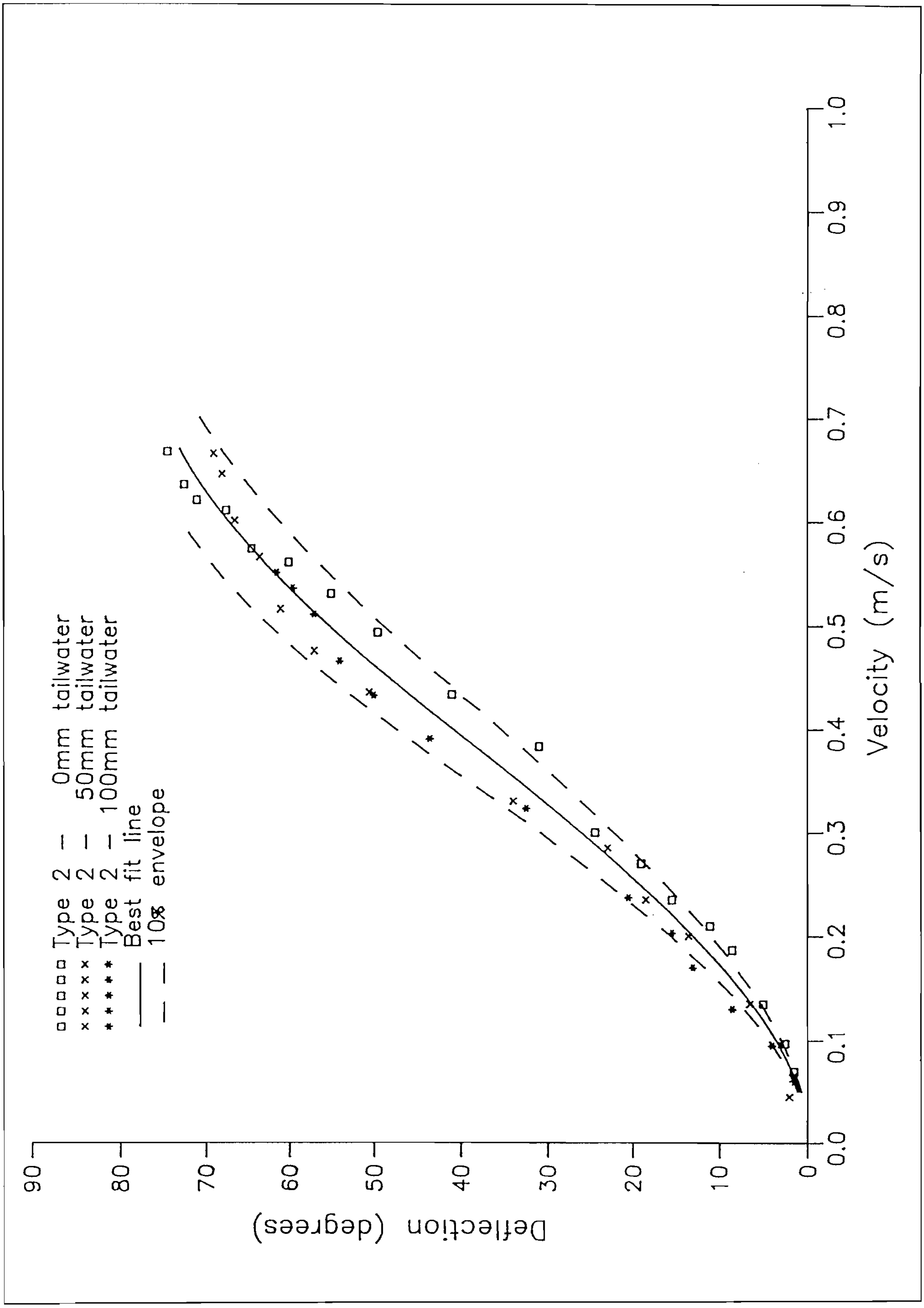


Fig 9 Design 1 - Type 2, effect of flow depth

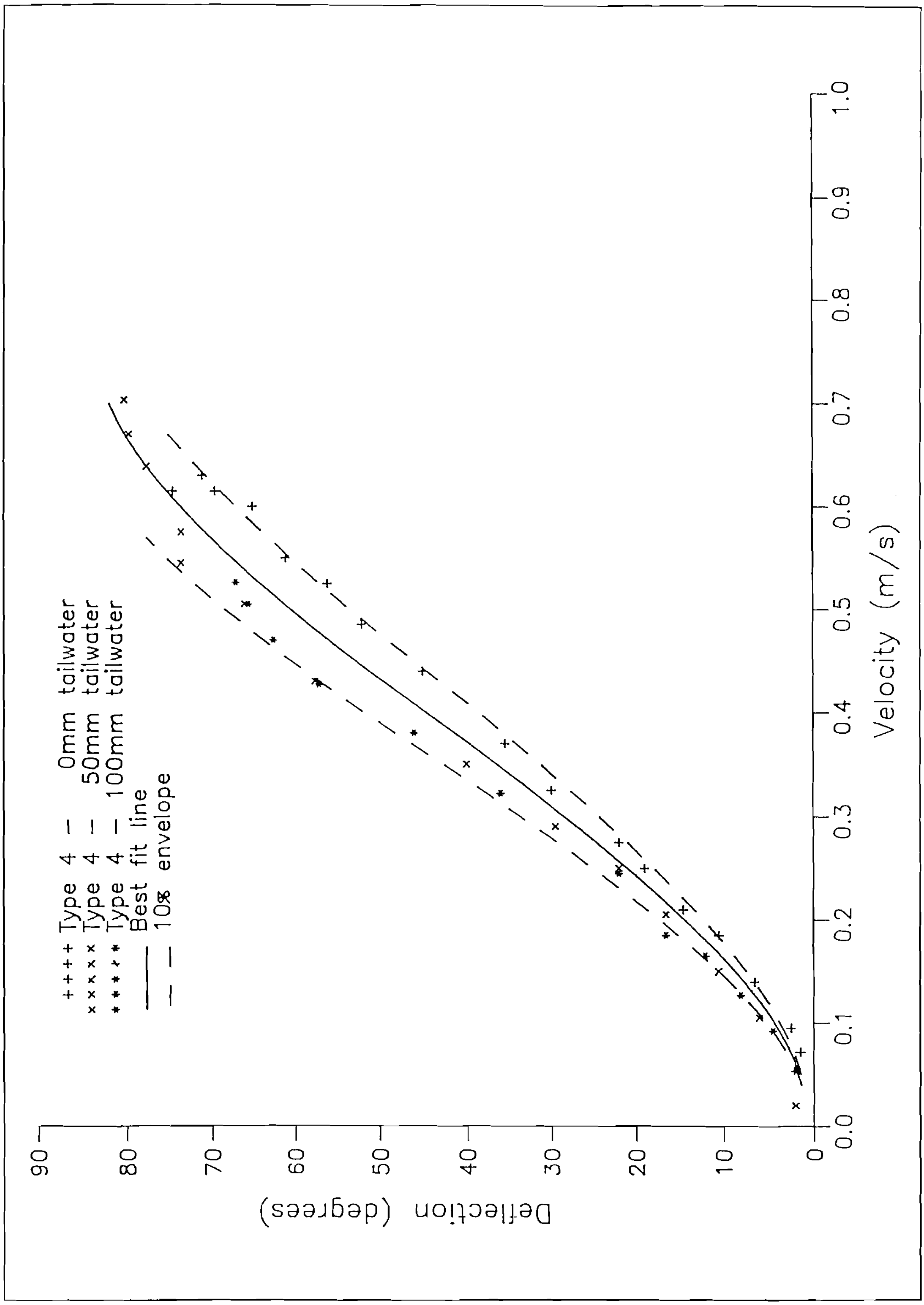


Fig 10   Design 1 - Type 4, effect of flow depth

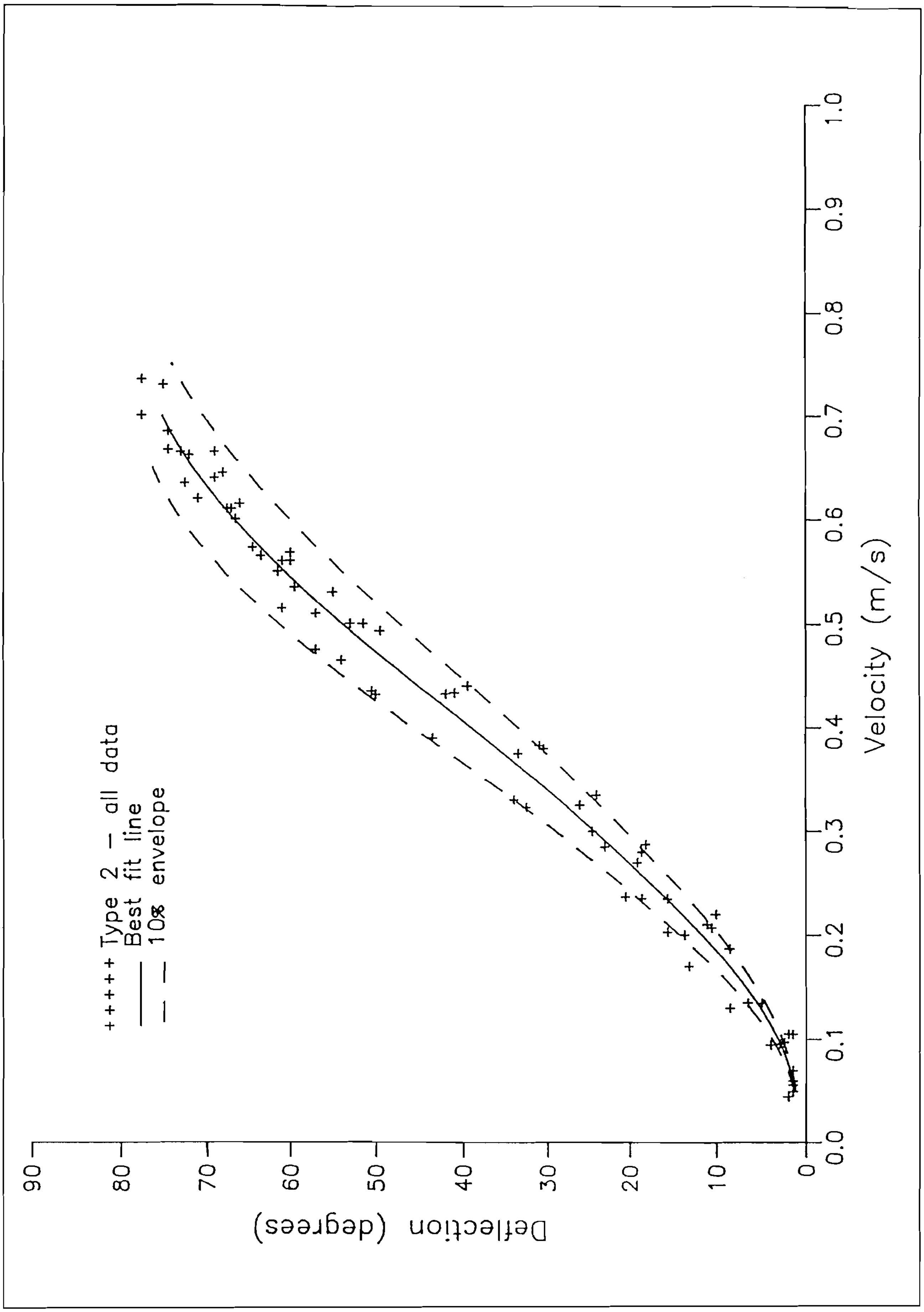


Fig 11 Design 1 - Type 2, meter calibration

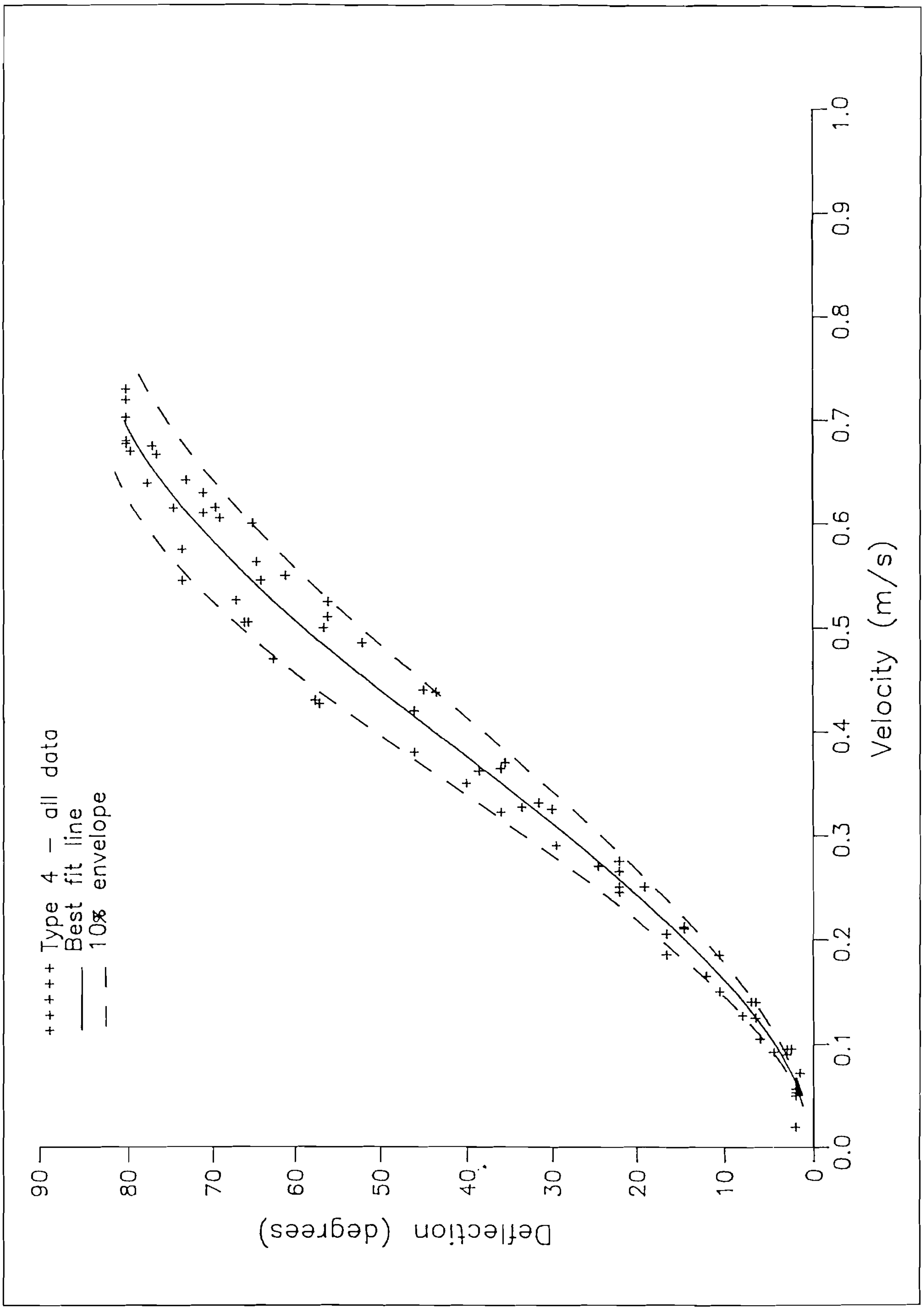


Fig 12 Design 1 - Type 4, meter calibration

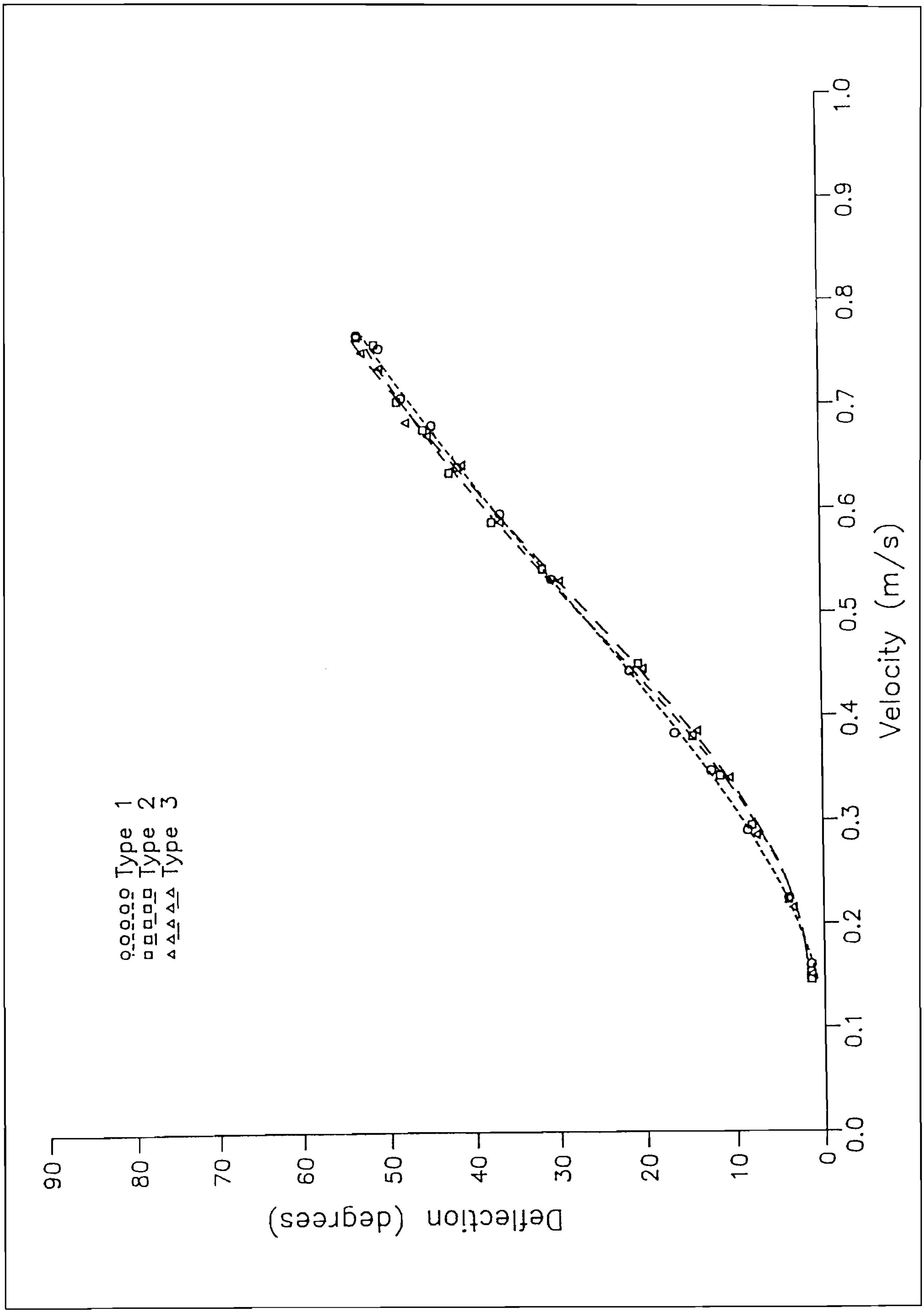


Fig 13 Design 2 - Rectangular vane calibrations

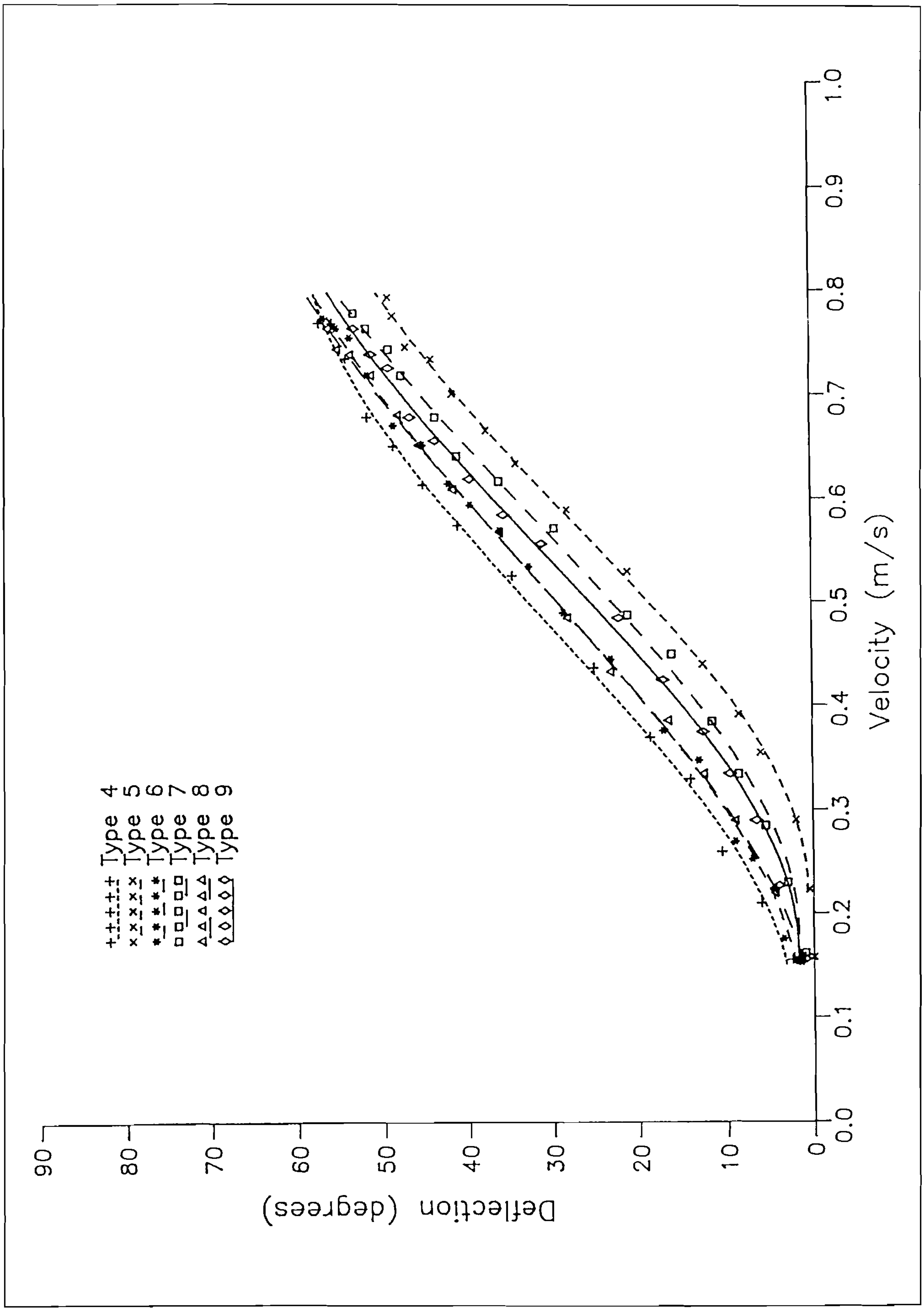


Fig 14 Design 2 - Trapezoidal vane calibrations

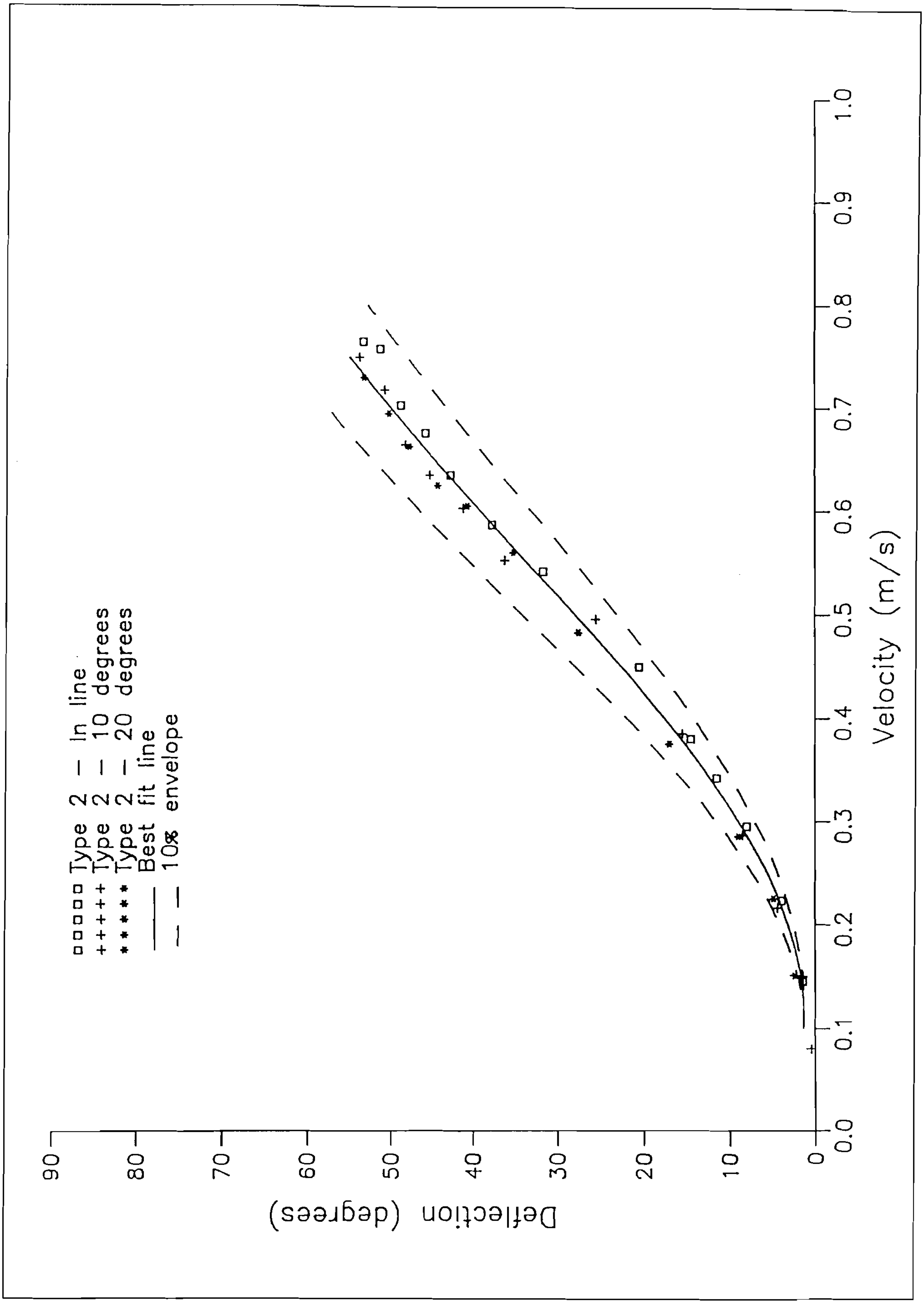


Fig 15 Design 2 - Type 2, effect of flow alignment

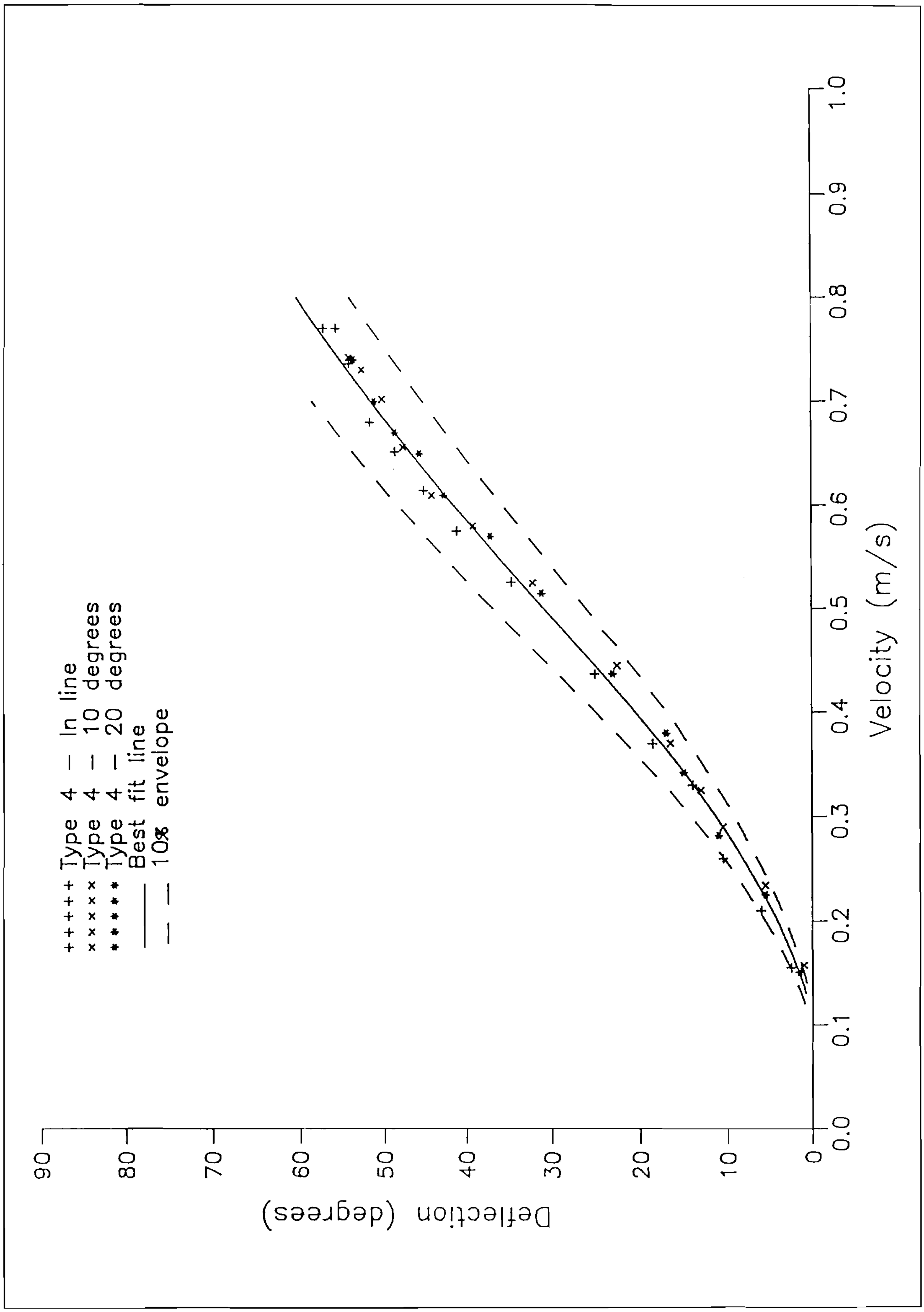


Fig 16 Design 2 - Type 4, effect of flow alignment

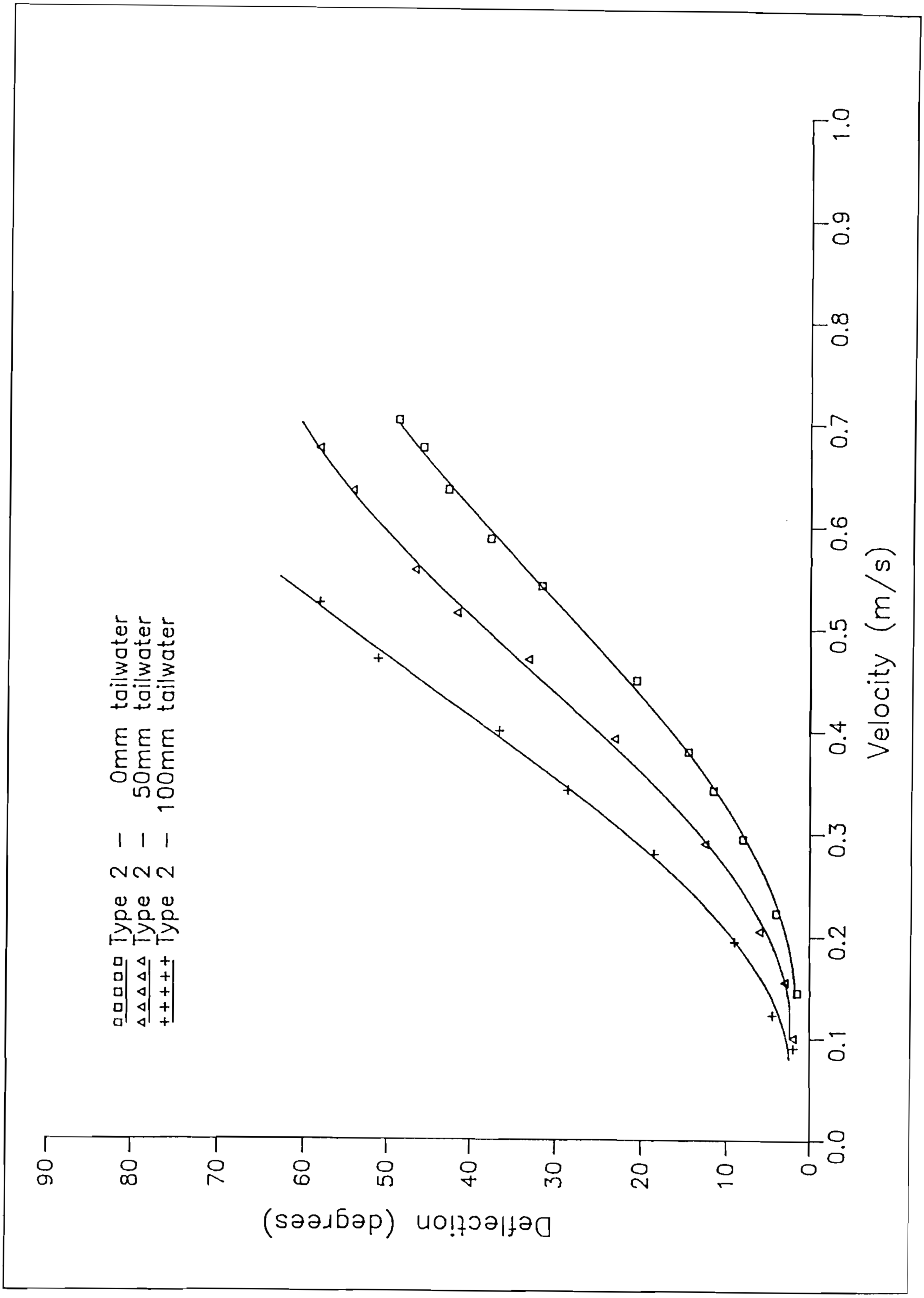


Fig 17 Design 2 - Type 2, effect of flow depth

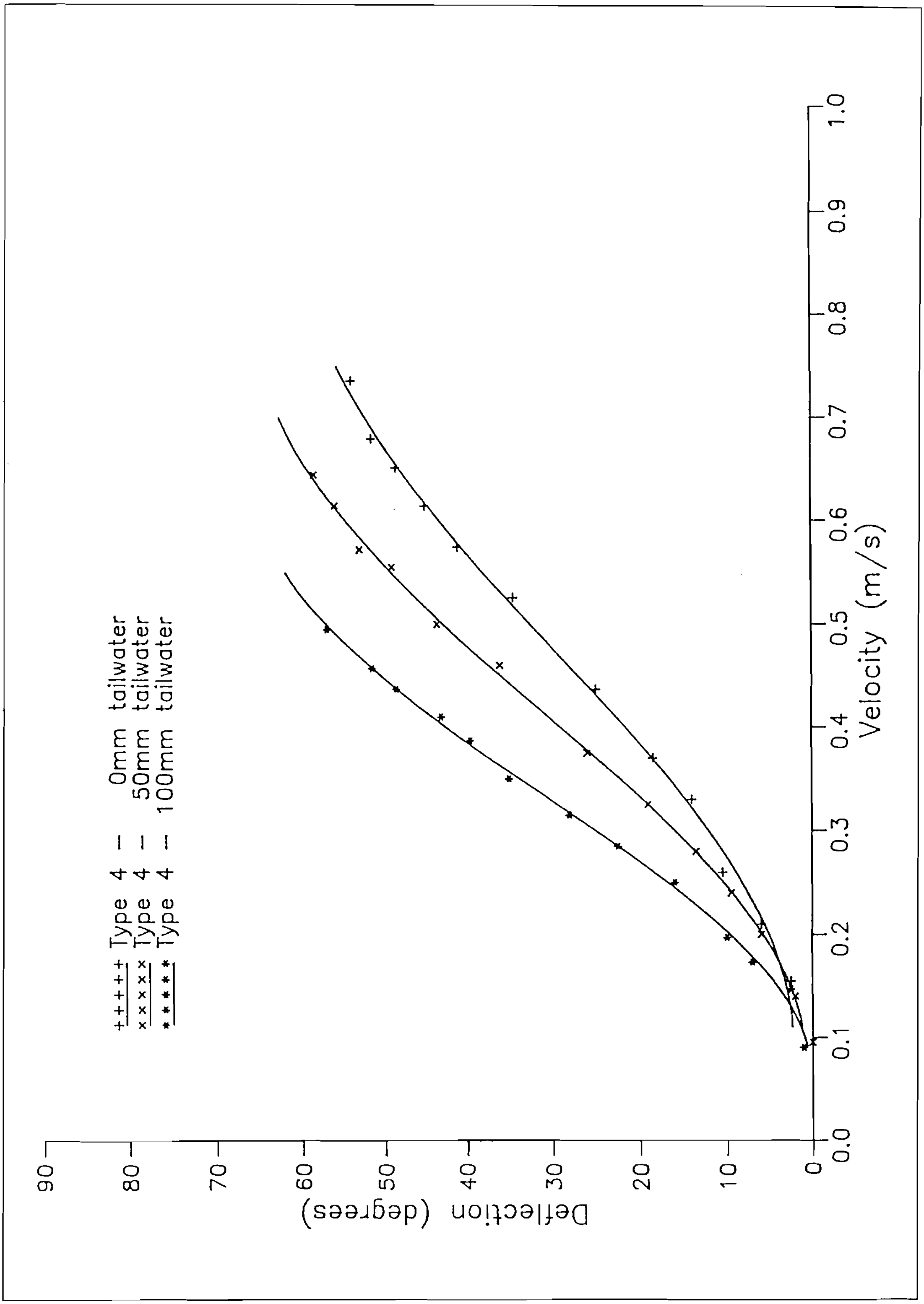


Fig 18 Design 2 - Type 4, effect of flow depth

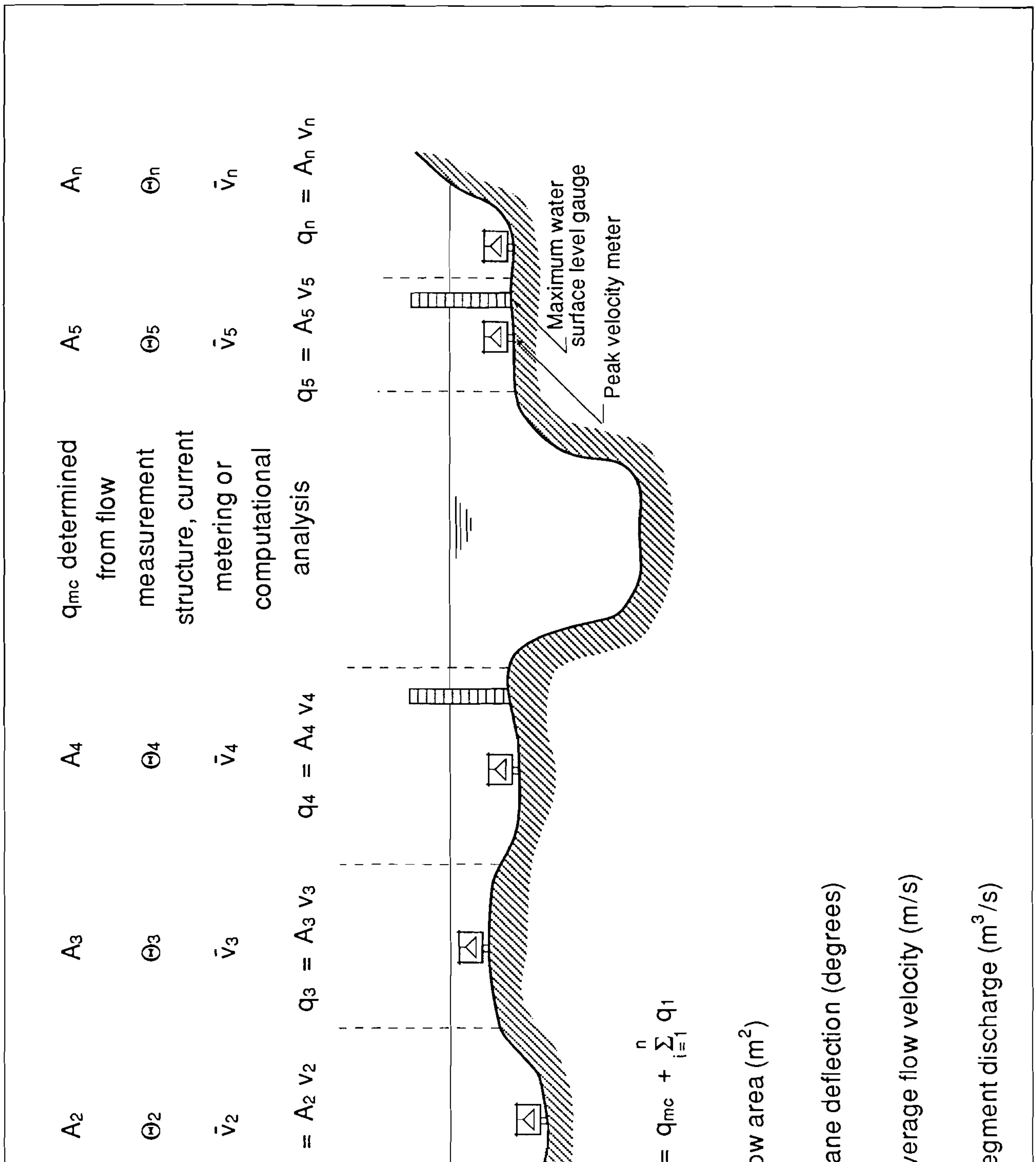
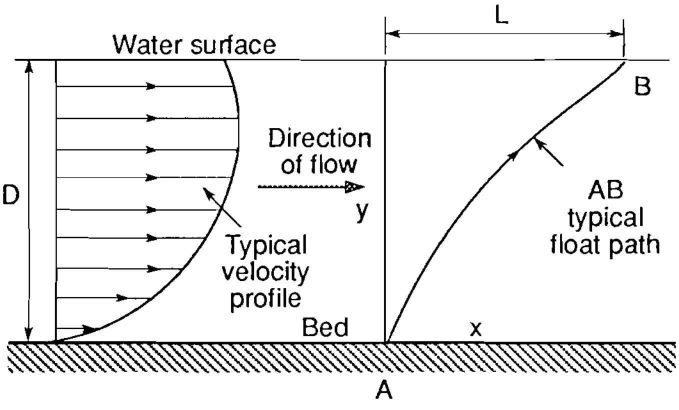


Fig 19 Flow measurement site



(a) Displacement of rising float

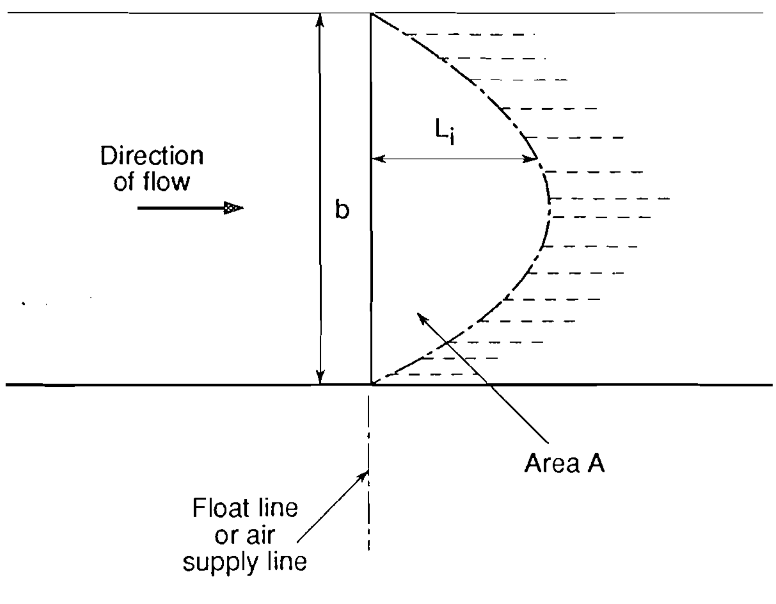


Fig 20 Depth integrated float velocity profiles

PLATES

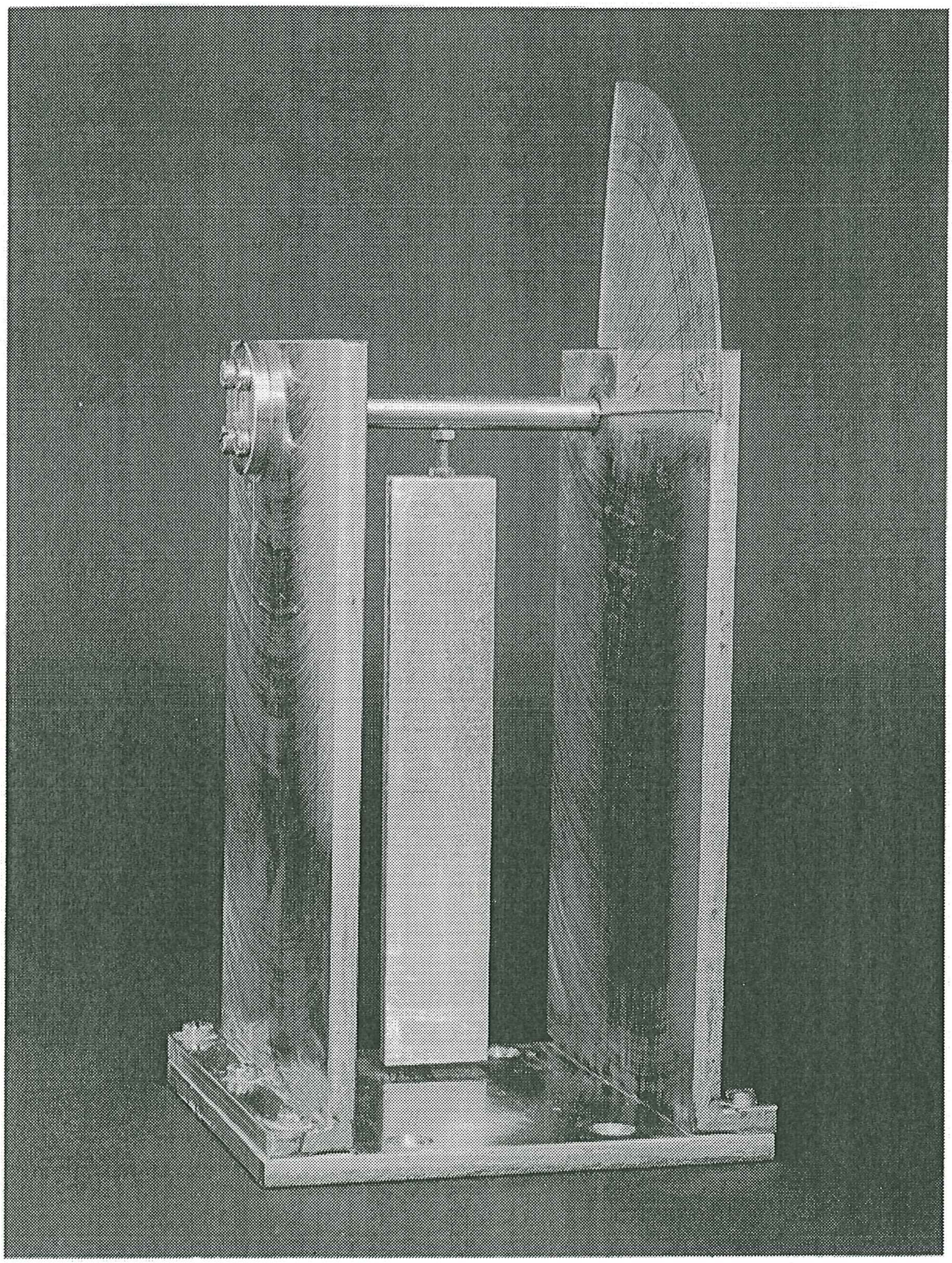


Plate 1 Design 1

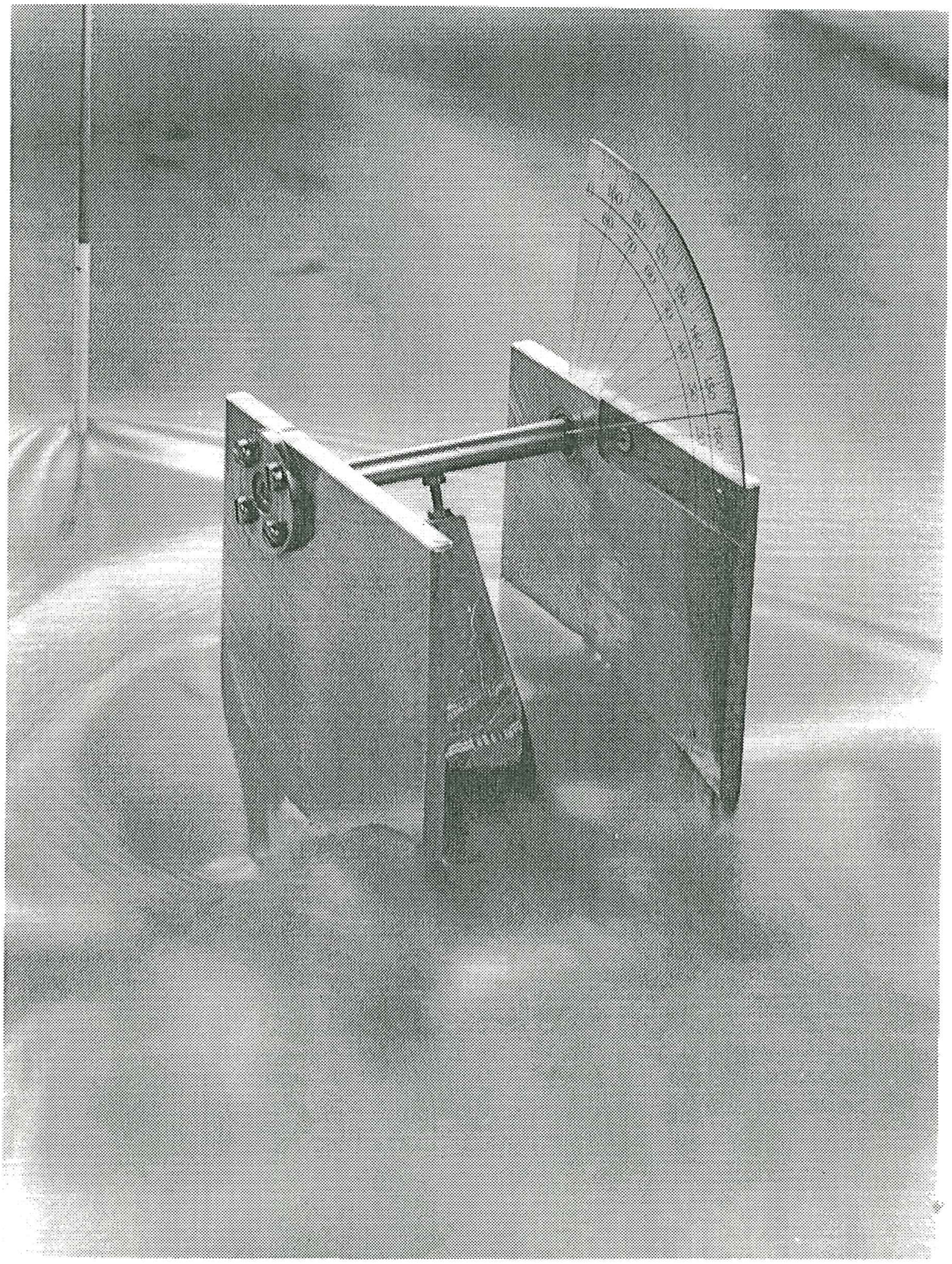


Plate 2 Design 1 - Type 4, stainless steel vane
Velocity = 0.46m/s

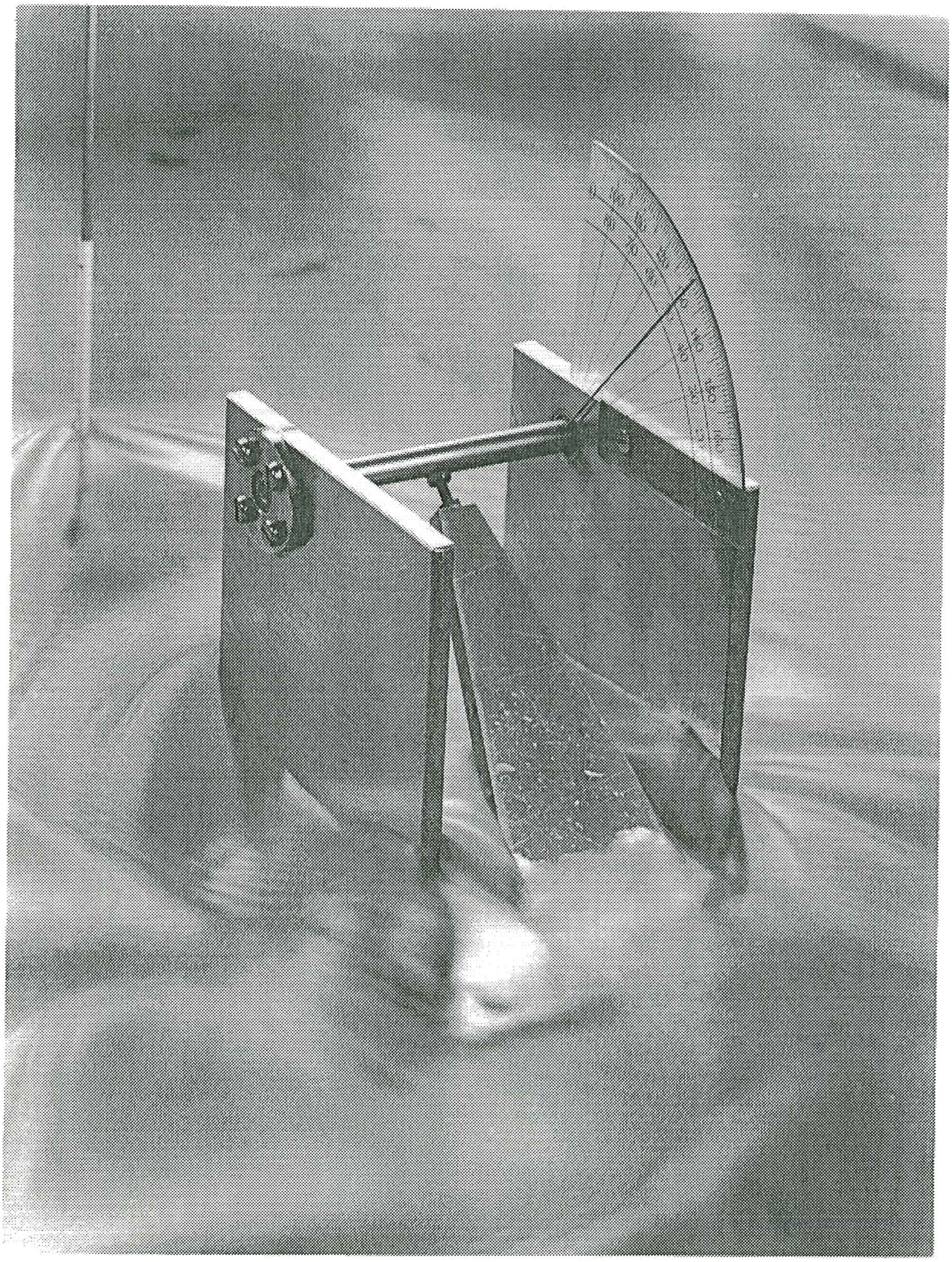


Plate 3 Design 1 - Type 4, dural vane
Velocity = 0.46m/s

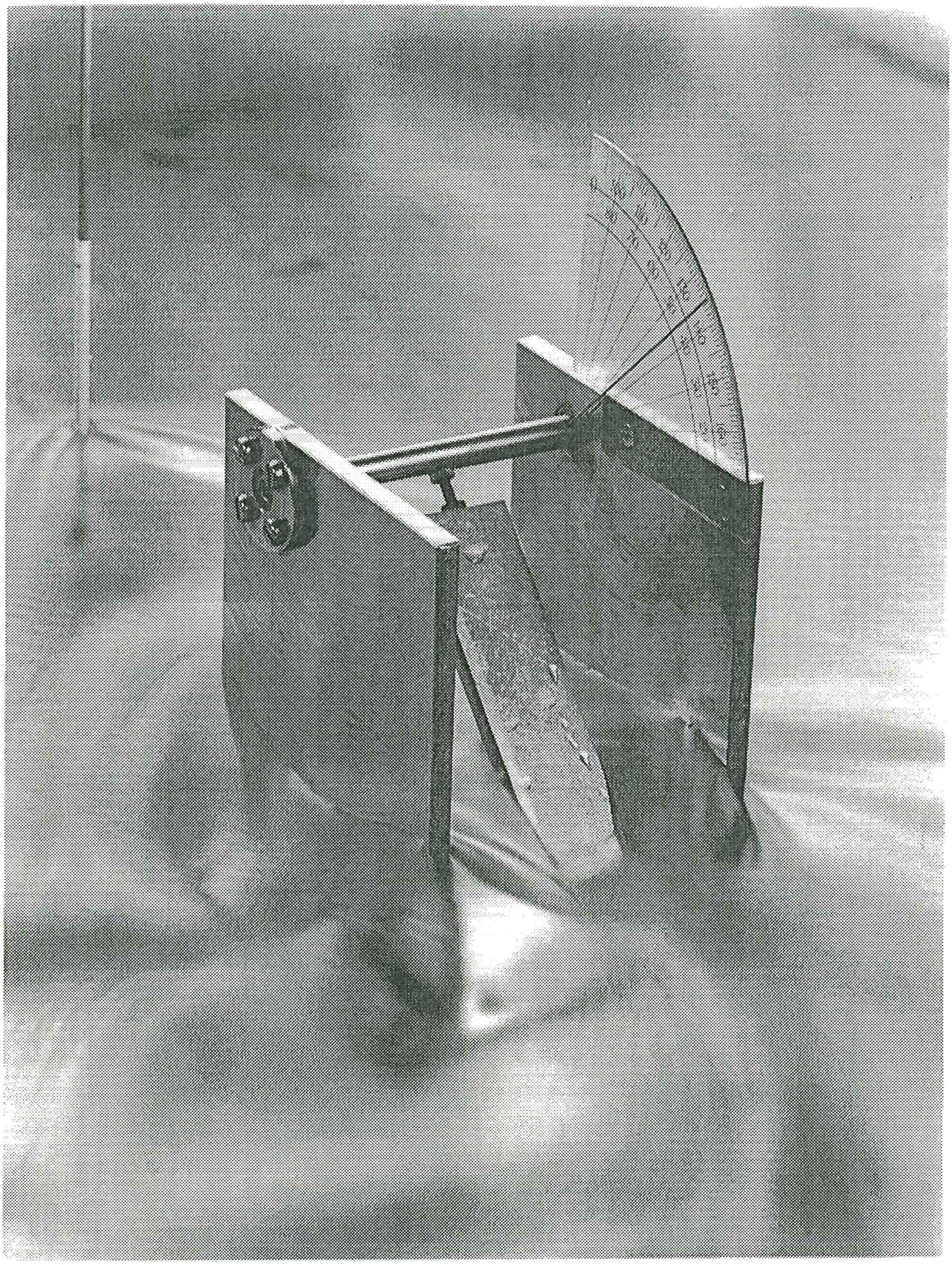


Plate 4 Design 1 - Type 2, dural vane
Velocity = 0.46m/s

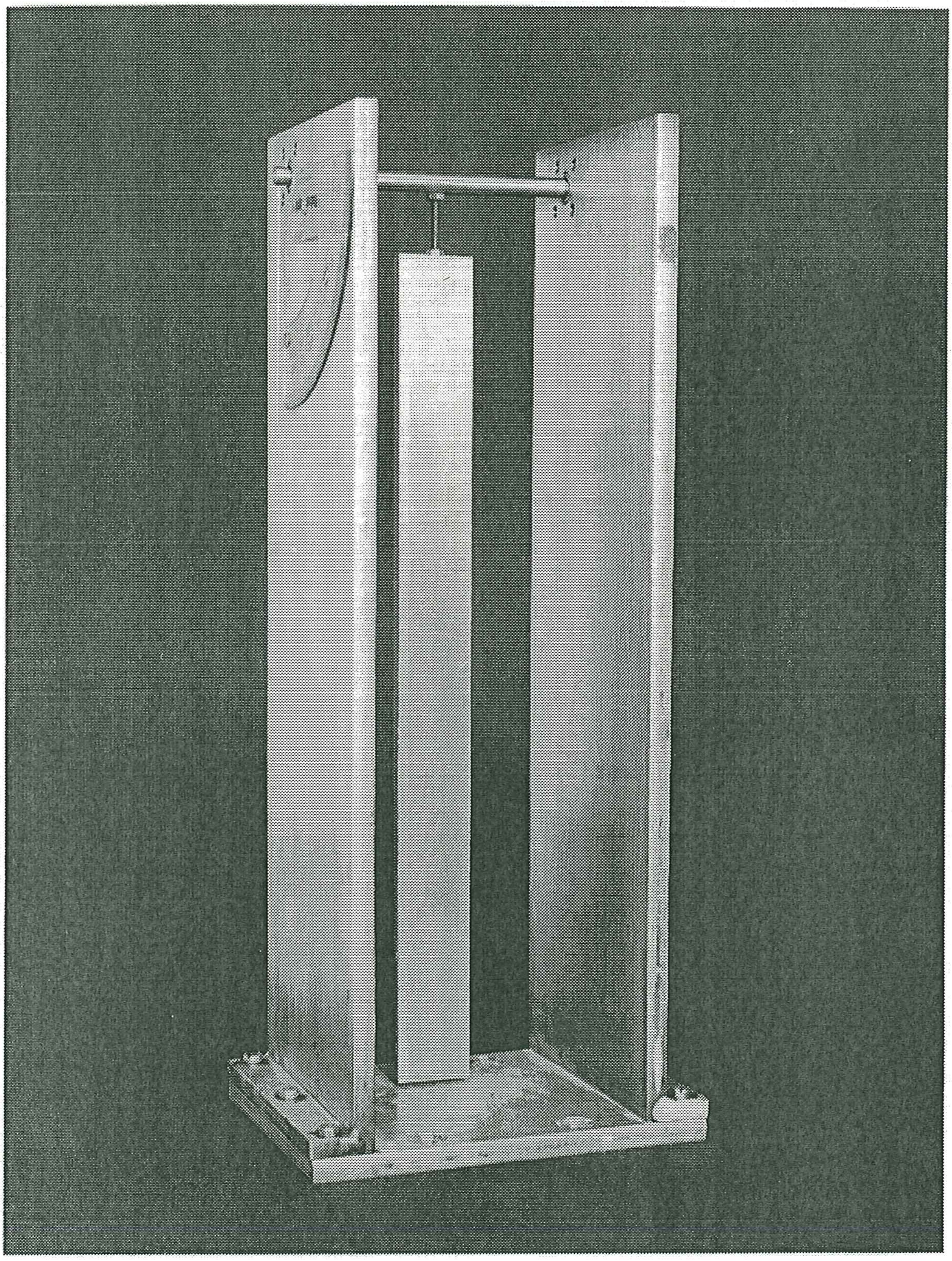


Plate 5   Design 2

APPENDIX

APPENDIX

1 Theory of depth integrating float method

Sargent (1981) states :

" A bouyant float is released from the bottom of the channel, see Fig 20a. Neglecting turbulence, the float will travel with a trajectory determined by the local flow velocity v_x and by its velocity of ascent v_y. Assuming that the float is sufficiently bouyant for it to reach its terminal velocity of rise v_r almost instantaneously and that it accelerates to reach the local flow velocity almost instantaneously, the discharge per unit width q is given by

$$q = \int_0^{tr} v_x . v_r . dt \qquad (1)$$

where tr is the time of rise of the float to the surface. Providing the assumptions are valid, this reduces to

$$q = v_r . L \qquad (2)$$

where L is the horizontal displacement of the float in the direction of flow during its ascent. Turbulence will cause variations in the distance L, but the average position of L will give q, so equation (2) can be rewritten as

$$q = v_r . \bar{L} \qquad (3)$$

where $\bar{L}$ is the mean displacement. Thus, the rising float essentially integrates the velocity profile to which it is subjected and its displacement is proportional to the discharge per unit width at that section. The total discharge Q is then given by

$$Q = \int_0^b q.db \qquad (4)$$

where b is the width of the channel. This is realized in practice in discrete form as

$$Q = \sum_{i=1}^{n} qi.\Delta bi \qquad (5)$$

where n is the number of points across the cross section at which q is determined.

Therefore if the velocity of rise v_r is known and L can be measured for floats rising at several points across the channel, then the discharge can be calculated ".

In respect of using air bubbles as the depth integrating floats they further state :

" The bubbles, on rising to the surface, are carried away downstream forming a semi continuous curve, clearly visible, the upper edge of which represents the points of surfacing. The location of the bubbles on the surface is photographed from the bank. Subsequent analysis of the photographs enables the area A, see Fig 20b, between the air supply line and the surfacing points to be determined from which the discharge Q can then be calculated as

$$Q = \int_0^b q.db = \int_0^b v_r.L.db \qquad (6)$$

$$= v_r \int_0^b L.db = v_r.A$$

so the calculated area is simply multiplied by the bubble rise velocity to give the total discharge ".