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Certified that the attached Thesis Dissertation on....Effect of scale on Coefficient of Discharge over weirs and spillways.

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EFFECT OF SCALE ON COEFFICIENT OF DISCHARGE OVER WEIRS AND SPILLWAYS

by
D. V. VARSHNEY

A Dissertation
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Certified that this dissertation entitled "Effect of Scale on the Coefficient of Discharge over Weirs and Spillways" is a record of the bonafide work done by Sri D.V.Varshney postgraduate student in the course of Master of Engineering (Water Resources Development) in the academic session 1966-67 and 1967-68. Sri Varshney has worked under our guidance on this dissertation from July 1967 to September 1968.

To the best of our knowledge this dissertation has neither been published anywhere nor submitted for the award of any other degree.

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SUMMARY

Coefficient of discharge of weirs and spillways is to be known before head in order to prepare atage discharge curves, regulation charts and correct fixation of crest levels. In order to find out the coefficient of discharge correctly. the usual procedure is to construct a geometrically similar model of the spillway satisfying the Froudian law and to observe the coefficient of discharge on the model.

It was observed at I.R.I.Roorkee (U.P.) and C.W.P.R.S.Poona that these observations of coefficient of discharge involve certain scale effects. At both the places it was observed that the values o coefficient of discharge decreases with the increasing R.F. of the scale i.e. smaller models will have lesser values of the coefficient of discharge. It is therefore difficult to predict correct values o the coefficient of discharge on the basis of model observations. Th usual method followed in the Engineering practice is that the designers adopt suitable value of the coefficient for the geometrical and operational condition of the spillway from standard curves such as U.S.B.R and it is supposed to verify the coefficient of discharge so determined on a model. Suitable safer value is adopted for the prototype and its regulation charts etc. are prepared.

It has so far not been possible to determine the discharge function analytically, and as such the extent of scale effect is not known. On the basis of known parameters entering the discharge equation, a dimensional analysis has been performed to find out the dimensionaless ratios affecting the coefficient of discharge. The dimensional ratios are Reynolds number, Webers number, K/h or 'f' (roughness parameter), P/h (geometrical parameter).

Experimentations have been conducted to evolve relationship between P/h and C in a flume for the adopted spillway profile. The sharp crested weir on the upstream of the flume was calibrated by means of a rating tank of 20'x20'x3'. Five model scales of 1/10, 1/15, 1/20, 1/30 and 1/40 have been chosen for study and with each scale experimentation was done for effective roughness k = .1147, .03646, .0288, .0075 feet.

The data obtained was analysed in such a fashion so that all the dimensionless ratios were attempted to be equated in all the cases. To start with the design head has been taken up for study in which case P/h = 3.33. So values of C for this value of P/h have been read, and next for every scale the value of K/h or 'f' has been plotted against C. In case of prototype N (rugusity coefficient) has been assumed to be equal to .02, and so K/h =.0364. Thus the values of 'C' for each scale for this value of K/h has been determined. Next for these values of C with equal K/h or 'f' and P/h, the values of Reynolds number and Webers number have been determined, and plots have been prepared between C and Reynolds number and C V/s Webers number. These plots have been tried on log-log paper as well in which case almost a straight line has been obtained. The values of C for the values of Reynolds number and Webers number as on prototype have been determined. It has been felt that it is not possible to isolate the effects of Reynolds number and Webers number as the experimentation has been done with water.

On the basis of above studies it has been established that:

1. The values of coefficient of discharge as determined on models involve certain scale effect, and the value of C decreases with the decreasing size of the model.

2. Reynolds number and coefficient of discharge are related with a power law.

3. Webers number and coefficient of discharge are also related with a power law.

CHAPTER ONE

INTRODUCTION

CHAPTER I

INTRODUCTION

1.1 HISTORICAL BACKGROUND

Coefficient of discharge for spillways and weirs for different heads and operating conditions is to be known before hand, in order to prepare the regulation charts and the stage discharge curves. Necessity of a correct regulation chart and stage discharge curve hardly needs any overemphasis. Afflux on weirs and barrages also can not be determined unless the coefficient of discharge is known. On the correctness of the value of coefficient of discharge depends the submergence to be expected on the upstream of structures. However, the coefficient of discharge can only be determined on small workable models in the laboratory from which the expected value of the discharge coefficient (C_d) for the prototype under different conditions of operations can be predicted. This value of coefficient of discharge as determined from the models is very important during the planning and design stages, later the operation of the structure also will be governed by those values, as the actual values of the coefficients of discharge cannot possibly be determined.

Experiments were conducted at Central Water & Power Research Station, Poona on the Effect of Scale in the values of coefficient of discharge over ogee shaped spillways. Their report appeared in the Annual Report of 1939 of the Institute, and their findings find mention in the following pages at relevant place. At Irrigation Research Institute, Roorkee (U.P.) too different values of coefficient of discharge were obtained when the model of Ramganga barrage and spillway were constructed to different scales and the present investigation of the scale effect on the coefficient of discharge over weirs and spillways, has been inspired by those observations which the author had the privilege of being associated with. It is therefore difficult to predict the exact value of coefficient of discharge for prototype spillways, on the basis of model experimentation, since the values determined involve some scale effect.

1.2 COMPLEXITY IN CORRECT DETERMINATION OF COEFFICIENT OF DISCHARGE

It is not easy to estimate the extent of scale effect and to predict the prototype value of the coefficient of discharge from the experimental observations. In order to analyse the problem critically one has to bear in mind that it is the geometry, kinematics, and fluid properties of the flow that influence the value of the coefficient of discharge. In the case of models, only the geometry of flow is made proportional while the other two are not controlled, hence the variations in the values of the coefficient of discharge. It is not possible to equate the kinematic conditions proportionately and also there can be no control over the fluid properties as the experiments are conducted with water. It is mainly for these reasons that a value independent of scale effect can not be determined by performing a single series of experimentation with a particular scale model with a common fluid.

1.3 PROBLEM

An attempt has been made to study the "Effect Of Scale On Coefficient Of Discharge Of Weirs And Spillways" in this dissertation. The study aims at investigating the effect of model scale on the coefficient of discharge of spillways. In case the effect of scale is established, it is aimed to evolve methods so as to estimate the value of the coefficient of discharge over the prototype structure so that correct operation charts and gauge discharge curves could be worked out for it.

1.4 LIMITATIONS

Following limitations were imposed on the study reported here:

(i) Shape of spillway:- Geometrical models of the spillway to different scales were chosen for study, even though it was realized that by constructing a geometrical model of original spillway, the model profile does not actually correspond to that given by the original equation of spillway. The profile though corresponds to U.S.B.R profile for the proportional design head, but yet not the same profile. So it was felt that testing a geometrically similar model amounts to testing a new U.S.B.R. profile each time. Thus in each case the model studies include the shape effect of the spillway.

(ii) Roughness:- Natural materials were chosen for providing roughness. It was not possible to provide roughness larger than 1" shingle on the crest because it would have changed the profile, particularly so in the lower scale models. Moreover the concentration and shape of roughening particles determine the value of 'K' and it was not possible to find the correct value of K. It was therefore decided to provide same shape and concentration of roughening particles in each study and to employ Stricklers formula for determining the value of K.

(iii) Discharge:- Limited supply of discharge in the flume did not permit observations for lower P/h ratios that is for larger heads. The head over the spillway was kept between 1/2" and 6".

(iv) Fluid:- It was further not possible to isolate the effects of Reynolds number and Weber's number, since the experiments were done each time with the same fluid water. Many chemicals were tried which could change the surface tension of water and yet not affect the viscosity of water, however no favourable results were obtained. In these studies therefore the combined effect of the two was considered together.

CHAPTER TWO

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

2.1 INTRODUCTION

In order to analyse the effect of scale, general work on the coefficient of discharge has been studied so as to pin point the causes of discrepancy between prototype and model values of coefficient of discharge. As a matter of fact the sharp crested weir is the simplest form of a spillway. Therefore in order to study the coefficient of discharge over the spillway it has been thought worth while to review the work done on the study of the coefficient of discharge for sharp crested weirs; thereafter the standard work published on the spillways has been reviewed. Very little work has been done on the scale effect, except that it has been experienced and some causes attributed to it. A brief mention of such a work is given in the following pages. No studies are so far available which could predict the coefficient of discharge for prototype based on model observations. Standard curves as proposed by U.S.B.R do not mention the arrangements for which these curves are to be applied, and that is why they have a very limited use and utility.

2.2 Carl E. Kindsvater and W. Carter(1) studied the discharge characteristics of rectangular, thin plate weirs. Their solution is based on a simple equation discharge $Q = CLh^{3/2}$ and experimentally derived coefficients which account for the influence of the fluid properties and the physical characteristics of the weir and the weir channel. The effects of viscosity and surface tension are related to a decrease in the effective head and an increase or decrease in the effective notch width. Thus, the combined effects of the fluid properties are accounted for with adjustment coefficients which are applied to measured values of the head and width. Consequently, the coefficient of discharge is defined as a function of geometric ratios which describe the weir and the weir channel.

However, the authors concluded that the flow pattern for rectangular, thin plate weirs is not subject to complete mathematical analysis. Consequently, an analytical solution for the discharge characteristics has not been developed. They have just provided a comprehensive solution based on dimensional analysis and experiments. Weir discharge is significantly influenced by the physical characteristics of the weir and the weir channel. It is specially dependent on features which control the velocity distribution in the approach channel. For this reason the results of experiments made by different investigators do not agree, and formulae based on a particular set of data reflect the individual characteristics of those data.

2.3 According to a well known weir formula of Rehbock(2) the coefficient of discharge is given approximately by $C = 3.27 + 0.40\ H/h$, where 'h' is the height of weir, Rouse and P.K.Kandaswamy(3) investigated the problem and concluded that the existing weir formula loses its significance as the ratio of head to height of weir becomes great. It is known that the rate of flow over a sill at the end of a channel can be estimated from the basic weir equation by assuming the velocity of approach to have its critical magnitude. This gives rise to a discharge function for sills which meets that for weirs in a sharp peak when the head is about 10 times the weir height. For H/h greater than about 15 the weir becomes a sill. The critical depth of the sections is approximately equal to (H-h). By the critical depth discharge relationship, it can be shown that the coefficient i.e.C is $C = 5.68\ (1 + H/h)^{1.5}$. The transition between weir and sill (between H/h = 10 and 15) however has not yet been clearly defined.

2.4 According to Ven-Te-Chow(4) the effect of approach velocity is negligible when the height 'h' of the spillway is greater than 1.33 Hd where 'Hd' is the design head excluding the approach velocity head. Under this condition and with the design head, the coefficient of discharge C has been found to be Cd = 4.03.

In low spillways with $h/Hd < 1.33$, the approach u velocity will have appreciable effect upon the discharge or the discharge coefficient and consequently upon the nappe profile. For spillways having sloping upstream face, the value of C can be corrected approximately for the effect of the upstream face by multiplying C by a correction factor. Bradley(5) had however developed his curve for finding out the coefficient of discharge at any head based on the empirical relation $C = 3.97\ (He/H_D)^{0.12}$, where 'He' is an operating head and H_D is the design head, including the approach velocity head for a standard profile having a vertical upstream face.

2.5 Since the physical properties of flow are not identical in the models built to different scales the values of the coefficients of discharge do not agree even though the geometrical ratios influencing the flow are the same in all cases. This fact was observed at U.P.Irrigation Research Institute,Roorkee while studying the coefficient of discharge for Ramganga barrage. The model of Ramganga barrage near village Harooli was constructed to a scale of 1/40 in a flume in July 1957 representing only 2 bays out of a total of 17 bays carrying a discharge of 2,14,000 cfs (one full bay and an other half on either side) each one of 59 ft. the coefficient of discharge was observed as 3.12, this model was again constructed to a scale of 1/30 and the coefficient of discharge was observed as 3.26. This led to the conclusion that some scale effect is inherent in the observations made for the coefficient of discharge.

Similar effect of scale was observed at Central Water & Power Research Station,Poona(6) in the coefficient of discharge observations on geometrically similar models, when the problem of Waste Weir at Lake Arthur Hill was under study in 1939. The geometrically similar model of the weir was constructed to the scales of 1/7.5 , 1/6 , 1/4.5, & 1/4 and each time the coefficient of Discharge V/s 'D' (head over weir) curve was plotted. Their conclusive evidence was that with the increasing R.F of model scale the coefficient of discharge decreases. However the reasons attributed to these variations were separation and side wall effect. It was felt by the investigators at Poona that due to the side drag effect the coefficient of discharge was affected to the extent of 4%. So the prototype coefficient of discharge was obtained by extrapolation and increased by 4%. No studies on scale effect followed these.

2.6 The general practice followed so far is to adopt coefficient of discharge for prototype on the basis of standard U.S.B.R curves and then to verify that coefficient on model built to a convenient scale. Realising that the coefficient as obtained on the model is subject to certain limitation a safer value for the prototype is recommended. It has been found in many cases that U.S.B.R curves depart considerably from that obtained in the model specially so under the submerged conditions. So the entire standard of coefficient of discharge curve needs a thorough review.

CHAPTER THREE

THEORETICAL ANALYSIS

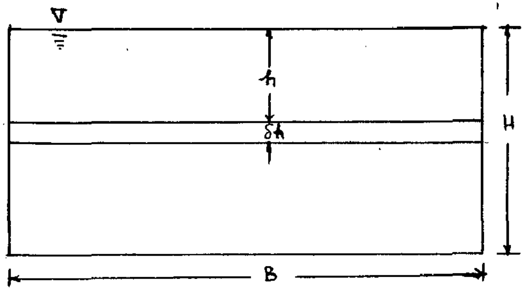
CHAPTER III

THEORETICAL ANALYSIS

3.1 INTRODUCTION.

It is intended to develop the discharge equation from the first principle so that the various parameters affecting the problem could be studied in their correct perspective. It is the coefficient of discharge appearing in the discharge equation which needs a comprehensive analysis, therefore by dimensional analysis various dimensionless ratios affecting the value of coefficient of discharge shall be evolved, and their effects studied on the basis of experimental data.

3.2 Derivation of discharge formula:



Considering a spillway of width B, operating under a head H, assume the discharge passing through a thin slit of thickness ' h' at a depth 'h' from free surface, and of full length B. Theoretical velocity through the slit = $\sqrt{2gh}$

∴ Theoretical discharge through the slit = $\sqrt{2gh} \times B \times \delta h$

∴ Total theoretical discharge through the spillway

$$Q = \int_{v_0^2/2g}^{H+v_0^2/2g} B\cdot\sqrt{2gh}\cdot\delta h$$ where v_0 is the approach velocity.

$$= B\cdot\sqrt{2g}\cdot\frac{2}{3}\cdot\left[\left(H+v_0^2/2g\right)^{3/2}-\left(v_0^2/2g\right)^{3/2}\right]$$

But if the coefficient of discharge is taken as Cd. then actual discharge through the spillway $Q = \frac{2}{3}\cdot\sqrt{2g}\cdot B\cdot C_d\cdot\left[\left(H+v_0^2/2g\right)^{3/2}-\left(v_0^2/2g\right)^{3/2}\right]$

for ideal fluids the coefficient of discharge is a function (P/h ,b/B) where P is the height of spillway, 'h' is the operating head and 'b' is the width of the approach channel while B is the width of the spillway. But in calculating the velocity of approach prior knowledge of the coefficient of discharge is required. Hence it is convenient to ignore the velocity of approach and modify the value of Cd such that

$$\therefore \quad Q = Cd \ 2/3 \ \sqrt{2gh}.h$$

Here Cd = f (P/h, b/B and other fluid properties determining the velocity of approach) where P is the height of the weir, 'h' is the operating head, 'b' is the width of the approach channel and B is the width of the weir.

3.3 DIMENSIONAL ANALYSIS

The geometry of the flow pattern in the case of weirs and spillways is described by the width of the weir, 'b', the width of the approach channel, B, the height of the weir crest above the bottom of the channel, P, and the piezometric head 'h' referred to the level of the crest and measured in the uniform flow section upstream from the weir. The fluid properties involved are the specific weight, γ, the density 'ρ' the viscosity, μ, and the surface tension σ, and K the roughness projection which controls the mean approach velocity. Only one independent flow characteristic is involved, and it can be represented by either the discharge, Q, or the head. However, because 'h' is already involved as an independent geometric variable, Q is conveniently selected as the dependent variable. Thus a complete statement of the discharge function will include both 'h' and as in :

$$Q = f_1(b, B, h, P, K, \mu, \rho, \sigma) \qquad \ldots\ldots (1)$$

From equation (1), non-dimensional ratios which describe the discharge function can be formed as

$$\frac{Q}{bh\sqrt{gh}} = f_2\,(b/B,\ b/h,\ P/h,\ K/h,\ R,\ W) \qquad \ldots\ldots (2)$$

Or K/h could be replaced by 'f' (Darcy's coefficient) in Eq. 2.

in which $g = \gamma/\rho$, the acceleration due to gravity. The dependent ratio in Eq.(2) is a coefficient of discharge. The first three independent ratios describe the geometry of the flow boundaries, and the last two ratios represent the Reynolds and Webers number, which can be expressed as $R = \frac{\sqrt{2\,gh}.h}{\nu}$ and $W = \frac{\sqrt{2g}\;h}{\sqrt{\sigma/\rho}}$

In engineering practice in U.S.A the accelaration due to gravity is commonly included in the definition of the coefficient of discharge. Thus for practical purposes, a convenient definition of the coefficient, C, is

$$C = \frac{Q}{bh^{3/2}} = f_3\,(b/B,\ b/h,\ P/h,\ R,\ W,\ K/h \text{ or } f\,) \quad \ldots (3)$$

from which $Q = Cbh^{3/2}$ ... (4)

The dimensions of C in Eqs. (3) and (4) are the dimensions of $\sqrt{g}$. Because of its obvious simplicity and despite its lack of purity, Eq. (4) is used as the basic discharge Eq. herein.

The discharge function represented by Eq. (3) cannot be evaluated by analytical procedures. Accordingly, the relative influence of each of the independent ratio must be evaluated by experimentation.

3.4 SIGNIFICANCE OF THE GEOMETRIC RATIOS IN EQ. (3).

The ratio b/B signifies the extent of contraction of the channel. But in the present case as the width of the weir is the same as the width of the approach channel. This ratio is insignificant.

The (b/h) ratio is a measure of the shape of the discharge liquid stream in the plane of the weir. The influence of this ratio is believed to be negligible over the full practical range of the other variables. The fact that most of the published results of research on full width weirs ignore the (b/h) ratio indicates that its influence was not evident from the experimental data.

The P/h ratio is a measure of the depth concentration characteristic of the weir. It is complementary to b/B as contraction ratio. Because velocities in the approach channel are proportional to the head, the (P/h) ratio is also a measure of the relative magnitude of the velocity in the approach channel. Since on this ratio depends the velocity of approach channel, it serves to signify the Froude No. of flow. Thus (P/h) ratio is more than merely a geometric parameter in the discharge function. Its variation will change the coefficient of discharge significantly. Hence (P/h) ratio has been chosen as an independent ratio to describe the changes in coefficient of discharge.

The K/h ratio of 'f' is a measure of relative roughness of the crest and the approach channel. In the approach channel it is the main parameter in combination with the Reynolds number to determine the velocity distribution, hence the coefficient of kinetic energy distribution, 'α' will change the effective velocity head and hence also the total head. The velocity distribution is given by ($v = 5.75\ v_c\ \log_{10} \frac{30y}{K}$). Similarly in the crest the values of K/h, determine the profile of the boundary layer, which is given by the Bour's Eq. (7).

$\delta/L = 0.08\ (L/K)^{-0.233}$ for a spillway, in which δ, is the thickness of the boundary layer at a distance L, from the crest, and K is the roughness at the crest so the velocity distribution at the crest is determined by the roughness parameter. Different values of the roughness parameter will lead to different values of 'α' in the approach channel as well as the crest, hence different values of coefficient of discharge.

3.6 Significance of R & W - Influence of Reynolds number and Webers number cannot be precisely estimated. It is, however, known that the relative influence of the two fluid properties increases as the head on the weir and the size of the weir decreases.

The Reynolds number is a measure of the relative influence of viscosity. It is usually expressed as $R = VL/\nu$, in which V is a typical velocity, L is a conveniently evaluated and physically significant length, and ' ' is the kinematic viscosity of the fluid. For large, full width weirs, the most significant length is the head. For small narrow weirs, however, the width of the weirs, as well as the head, are independently significant. Because velocities in the vicinity of the weir crest are proportional to the square root of the head, $\sqrt{h}$ can be substituted for V, whence $\sqrt{2gh}.h/\nu$ signifies Reynolds number. Thus, for a given fluid, the total influence of viscosity on a given weir can be expressed in terms of h or b alone.

The Weber number is a measure of the relative influence of surface tension. It is usually expressed as $W = \frac{V\sqrt{L}}{\sqrt{\sigma/\rho}}$ in which the surface tension, σ , and the density, ρ , are essentially constant for a given liquid. Because 'V' is proportional to $\sqrt{h}$ and because 'h' or 'b' or both can be significant lengths, L, the ratio $\frac{\sqrt{2g}\,h}{\sqrt{\sigma/\rho}}$ will have the significance of the Webers number.

Thus the effects of both viscosity and surface tension for a given weir and liquid are related to the absolute magnitudes of 'h' and 'b', consequently it is impossible to distinguish the separate effects of the two fluid properties from experiments with a single liquid.

Because the Reynolds number for any flow pattern is inversely proportional to a typical viscous shear force the relative influence of viscosity decreases as R increases. Similarly, because the Webers number is inversely proportional to a typical surface tension force, the relative influence of surface tension decreases as Webers number increases. It follows from the foregoing definitions of R and W in terms of 'h' and 'b' that, the relative influence of the combined fluid properties diminish as either 'h' or 'b', becomes larger. Thus, for large heads, on large weirs, the influence of viscosity and surface tension is negligible. This conclusion is substantiated, for example by the observation that coefficient for large weirs is essentially constant, for all heads above a certain minimum. That is, C is independent of the fluid property, parameters for large values of 'h' and 'b'. Hence the distinction between "Small" and "Large" must be based on systematic experimental investigations of the independent relationships between C and h.

The effects of viscosity and surface tension can not be described by exact physical equations. Nevertheless, any procedure whereby those effects are eliminated from the discharge function must be based on a general understanding of the manner in which the fluid properties influence the flow pattern.

3.6 THE INFLUENCE OF VISCOSITY.

A flow pattern which is determined by boundary conditions along is described as a potential motion pattern. The influence of viscosity in a real fluid motion can be illustrated by comparision with its potential motion counterpart.

The principal effects of viscosity on weir flow are those which are associated with flow pattern modifications caused by boundary resistance and separation. Thus as compared with its potential motion counterpart, the vertical trajectory of the nappe is lower. Viscous shear causes the flow to be retarded in the vicinity of the boundaries. This condition can be describe with respect to the potential motion by means of the discharge displacement, boundary layer thickness.

The influence of viscosity has been associated with the occurrence of boundary layer and separation zones. It should be emphasized, however, that the thickness of the boundary layer and the size of the separation zones are not directly proportional to the magnitude of the head or the ~~s~~size of the weir. For this reason, the effects of viscosity are often described as scale effect. This is consistent with the previous conclusion that the relative effects of viscosity diminish as the size of the weir and the head on the weir increase.

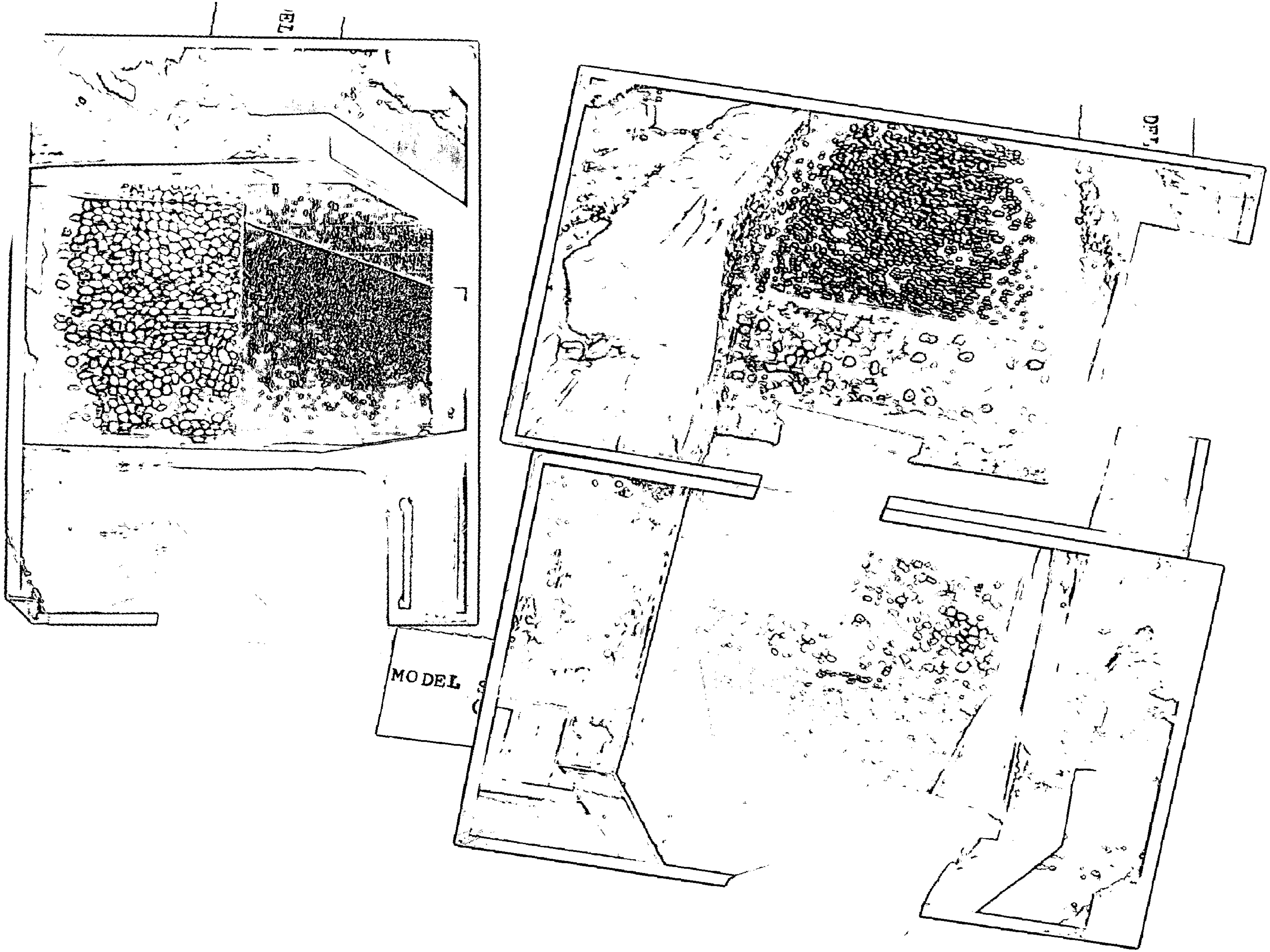
3.7 THE INFLUENCE OF SURFACE TENSION.

Surface tension is seen to have two fold effects firstly it makes the nappe to cling to the top edge of the crest. Thus compared with its potential motion counterpart, a real fluid is characterised by a longer trajectory. The effect of the occurrence is similar to the effect of the rounding the upstream edge. Therefore, the effect on the discharge, is the same as an increase in head.

Secondly the surface tension causes a resultant force 'F' acting in the direction of the centre of curvature of the nappe. Further-more, because the resultant surface tension force has a dominant downward component it has the same effect on the discharge as an increase in head. It should be emphasized, however, that the relative influence of surface tension diminishes as the size of the weir and the head decreases.

SUMMARY

It follows from the foregoing discussions that the relative influence of fluid properties diminishes as the absolute value of 'h' becomes larger so it can be interpreted that coefficient of discharge is independent of fluid properties in prototype, while the fluid properties significantly affect its value in the models the extent of effect depends upon the scale to which the models has been constructed. Hence different values of the coefficient of discharge are obtained when the model is constructed to different scales, and the variance is attributed as the scale effect.


MODEL

CHAPTER FOUR

EXPERIMENTAL PROCEDURE

CHAPTER IV

EXPERIMENTAL PROCEDURE

4.1 INTRODUCTION

The problem mainly involves flow in two directions, hence the experimentation was done in a glass walled flume. The discharge measuring sharp crested weir was calibrated means of a calibration tank built at the downstream of the flume. The entire experimental set-up has been shown in Figure no.11 and described in the following paras:

4.2 ARRANGEMENT

Experimentation work was carried out in a flume 3 ft. wide, 20 ft. long and 2.3 ft high. As the problem involves only 2 dimensional flow studies, the side walls of the flume were rendered hydrodynamically smooth by providing glass plates. A sharp crested weir was provided upstream of the flume for the measurement of flow. However, as the discharge coefficient of the sharp crested weir varies with head, the weir was calibrated by actual volumetric measurements of flow. For calibration of flow calibration tank 20'x20'x3' was constructed downstream of the flume. Thus volume of water collected in a definite time for a certain head over the sharp crest was observed, and a calibration curve between Q and H over the sharp crest was prepared. Since Q and H are related by a power law, this curve was also drawn to log-log scale in which case a perfect straight line was obtained proving that the calibration curve is correct. This calibrated curve was used for subsequent flow measurements. The experimental flume was provided with a gauge pit 12 feet from the spillway crest in which undisturbed and unaffected water levels could be measured. The flume was provided with a moving trolly for observing the water surface profile.

4.3 PROTOTYPE SPILLWAY

For constructing the model a prototype with P = 60", H = 18", H_a (velocity head) = 2" was assumed and the equation of the corresponding spillway profile was determined with the help of U.S.B.R curves provided in "Design of Small Dams" (Chapter on Spillways)(8).

The equation of the spillway works out to

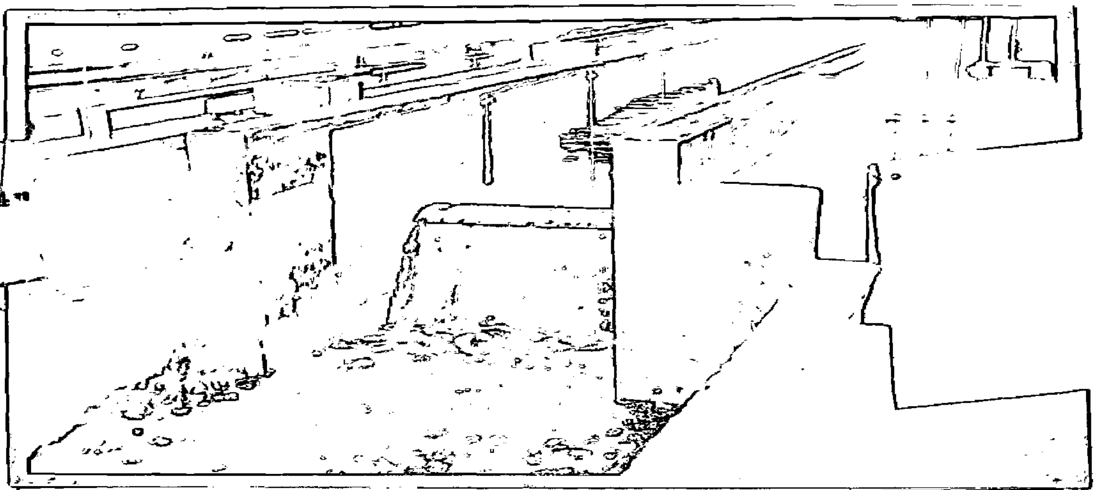
$$y/20 = 0.51\ (X/20)^{1.833} \qquad \ldots\ldots (5)$$

y and X co-ordinates for this spillway profile were determined.

Co-ordinates for a particular scale have been worked out by dividing respective co-ordinates with the scale ratio. Thus geometrically similar models to scales of 1/40, 1/30, 1/20, 1/15 and 1/10 were built. With each 4 different roughness were provided in the approach channel and the crest. For providing roughnesses shingles of 1", 1/2", 1/4" and cement plaster were used. In order to assess the correct value of K (roughness projections) Sieve analysis of the roughening material was got done, so that d_{65} in each case was taken as k_s, the effective roughness. The roughnesses of the roughening materials thus work out to 0.1147, .033, .028 & .0075 respectively in foot.

4.4 Head over the crest was then suitably altered thus changing the value of P/h. For one value of P/h coefficient of discharge was taken as $C_d = \dfrac{Q}{B\,h^{3/2}}$ where B is the flume width and h' is the head over the crest. A plot was next drawn between the dimensionless parameter P/h and C (having the dimensions of $\sqrt{g}$). This curve was smoothened and extended both ways. Thus for each roughness give scale model results were obtained, and for better comparision curves for different scale but for same roughness were super-imposed over each other. Four such sets of curves were prepared which appear from Figure 1 to 4.

4.5 The profile measurements of flow were taken additionally. The temperature at the beginning and end of the experiment of the flowing water was taken. Mean temperature was assumed to previall during the experimentation. Values of ν (kinematic viscosity), and ρ (mass density) and also σ (surface tension) were measured for this temperature. Additional measurements of sediment content were taken of the running water. The concentration of sediment load remain constant nearly during the experimentation. The experimental observations are given in the form of a Table in appendices.



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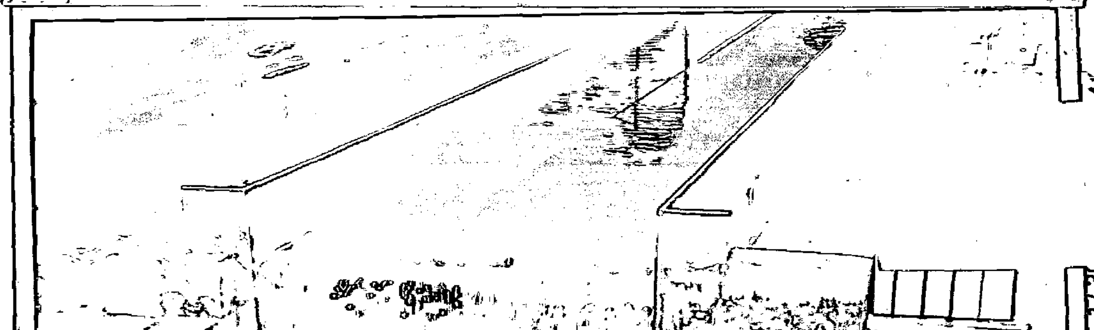

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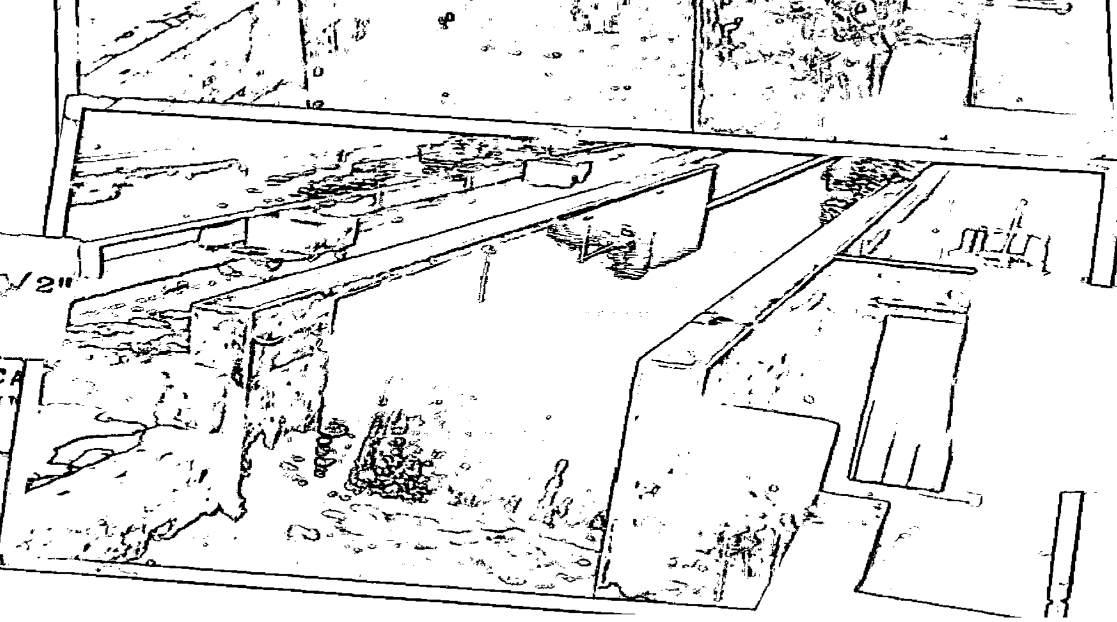

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CHAPTER FIVE

ANALYSIS OF DATA

CHAPTER V

ANALYSIS OF DATA

5.1 INTRODUCTION

For the complete similarity between the model and prototype it is essential that various dimensionless ratios on which the coefficient of discharge is dependent should be the same on the model and prototype. Therefore the data has to be analysed in such a fashion so that the variance of coefficient of discharge against different parameters involved could be studied for different model scales.

5.2 In the first instance effect of geometrical ratio P/h was saught to be eliminated and as such for a particular roughness both in the approach channel and at the crest, full variations of C with P/h were observed for particular scale model. A curve was drawn depicting the variation of coefficient of discharge with P/h. Similar curves were drawn for models on all scales taken for study. These curves so drawn for different scales were next super-imposed over each other so that comparison could be made at a glance. Such a set of curve for each roughness under study was prepared. Curves drawn for different roughnesses appear from Figure 1 to 4. From these curves it was possible to equate the geometric parameter P/h. Study was therefore first limited to design head in which case the value of P/h is equal to 60/18 = 3.33. Therefore values of coefficient of discharge for this value of P/h were found in each scale model for each roughness.

5.3 It was next desired to equate the roughness parameter (K/h) in each case. Since for each scale model four values of (K/h) were available (as there were four roughness under study), for the same geometrical ratio P/h. Thus curves were drawn between (K/h), the roughness parameter and the coefficient of discharge for each scale model, for the fixed value of $P/h_1 = 3.33$. Such a set of curves appears in Figure 5. In the case of prototype the rugosity coefficient 'h' was assumed as .022. From Strickler's formula $'n' = (K)^{1/6}/29.3$ the value of 'K' the roughness projection was computed as .0546 and so the roughness parameter (K/h) for design head for prototype was found as .0364. In each scale model the values of coefficient of discharge for this value of (K/h) was found, in order to eliminate the effect of roughness parameter from the field of study.

5.4 Thus the variation of coefficient of discharge left out after elimination of geometrical and roughness parameters was mainly due to different Reynolds numbers and Webers numbers. However, as explained earlier since it is not possible to study the effect of Reynolds number and the Webers number separately as the experimentation was done with water. At the first instance however the effect of Reynolds number was studied as $R_e = V \; H/\nu$, where V, is the velocity of approach. In this case the velocity of approach was taken into account just to make use of the coefficients of discharge as found out after eliminating geometrical and roughness effects. If the Reynolds number were calculated from its basic $R = \sqrt{2g} \; H^{3/2}/\nu$, the Reynolds number in each case would have been only proportional to the model scale, and the effect of the variation of coefficient of discharge could not have been taken into account. For similar reasons the Webers number was calculated as $W = \underline{V}/\sqrt{h} \; / \sqrt{\sigma/\rho}$ and not from its basic form $W = \sqrt{2g} \; h / \sqrt{\sigma/\rho}$, 'σ', ν' ρ ' being the properties of the fluid which were found out for the temperature at which the experimentation was done.

5.5 Next the Reynolds numbers of approach channel for the specificed values of (P/h), and (K/h) were computed. A curve was drawn between the coefficient of discharge and Reynolds number as shown in Figure 7. It is evident from the curve that Reynolds numbers are significantly effective in the working range of models. After a certain value of Reynolds number ceases to influence the values of coefficient of discharge, which means that the viscous effects are not important after certain values of the absolute head and the height of the weir is achieved. But from the curve it is clear that there is a considerable variation between the values of Reynolds number for the prototype and model and it would need a considerable amount of extrapolation to predict the values of C for prototype from the model results. Moreover it is expected that Reynolds number and Webers number are related to coefficient of discharge by power law. Therefore a plot was tried between the Reynolds number V/s coefficient of discharge on log paper as shown in Figure 7. This was observed that all the five points so obtained lie almost on a straight line and so proving the power law. From this graph the value of the coefficient of discharge against the Reynolds number as existing on the prototype was obtained as 4.06.

5.6 As has been discussed in the preceding paragraphs that it is not possible to separate out the effects of Reynolds number and Webers number if the experimentation is done with the same liquid. It was therefore not possible to study the effects of variation of Eulers number and Webers number on a quantitative basis. However just to complete the qualitative studies it has been attempted to/study the trend of variation of coefficient of discharge with Webers number, so that only the nature of the curve could be known, without eliminating the effects of the Reynolds number. It hardly needs any over emphasis that the curves do not in any case represent the quantitative effects of the Webers number on the coefficient of discharge over weirs and spillway. It is already known from knowledge of the sharp crested weirs that the extent of effect is not very significant as compared to the effect of Reynolds number. Therefore different values of Webers number were computed for the same geometric and roughness parameters, and a plot between coefficient of discharge and Webers number was tried as given in Figure 8. This curve was also tried on log paper as shown in Figure 9 to minimise the extent of extrapolation. The curve obtained is again linear on log-log paper establishing the power law between the coefficient of discharge and the Webers number. The value of coefficient of discharge for the value of the prototype is almost 4.005.

Thus a mean value of coefficient of discharge for the prototype as obtained after equating all the dimensionless ratios involved in the discharge function could be taken as 4.03.

5.7 Similarly the coefficient of discharge could be found for any other operating head that is for any other value of geometric parameter P/h, the roughness parameter (K/h), Reynolds number and Webers number. The value of the coefficient of discharge so obtained shall be more or less independent of the scale effect. Of course there will ~~be~~ still be certain limitations to the correct extrapolation of the value of the coefficient of discharge for the prototype.

5.8 ALTERNATIVE ANALYSIS

In the above analysis it was felt that (K/h) alone does not fully represent the roughness parameter, as the friction losses are a function of R and K/h. It was therefore felt to define roughness with a new parameter 'f' known as Darcy's coefficient and as such

$$C = (P/h , f , R , W)$$

Thus as done earlier coefficient of discharge for the design value of P/h = 3.33 was read for all scale models with all the four roughin approach channel may be influenced by various parameters. It therefore appears reasonable to take a parameter determining the velocity distribution of approach channel. As 'f' is a function of (K/h and Reynolds number) and includes the effects of both the form

ness as well as the surface roughness, it will be more reason-
models as shown in Figure 10. meter than to take K/h which only accounts
K and Reynolds number has been read in thor has presented both the
overall values of C for different scale mod   parameters
separately.

5.10 As the experimental flume was of limited dimensions, it was not possible to measure the velocity profile in the flume correctly. In order to determine the kinetic energy coefficient α, a theoretical velocity distribution (log-distribution) was assumed. The value of Alpha in every case has been calculated on the basis of formula provided in Fluid Mechanics by Dr.Garde$^{(11)}$. Values of Alpha thus calculated are given in appendix. It is clear from these values that with the increasing values of Alpha the values of coefficient of discharge decrease. This may be provide explanation to changing values of coefficient of discharge with changing scales and roughness.

CHAPTER SIX

CONCLUSION

CHAPTER VI

CONCLUSION

6.1 The present studies have established that there does exist a scale effect in the values of coefficient of discharge as determined on the basis of model experiments conducted on geometrically similar model of a weir and spillway. From the perusal of figures 1 to 4 it is evident that with the increasing scale ratio the coefficient of discharge decreases for a particular value of the geometric ratio. Thus the coefficient of discharge as observed on the model will be smaller than the one expected on the prototype which is 1 to 1 scale model. Hence it is safer to adopt the values of coefficient of discharge observed on the model for the prototype. The reasons of this variance could be established from the analysis of discharge function whereupon it is found that it depends upon (i) geometric ratio, (ii) roughness parameters, (iii) fluid properties, and (iv) sediment concentration. However sediment concentration was not taken in the present studies as the entire experimentation was done with the help of clear water. Since the dimensional ratios responsible for the various of discharge function are not the same in model constructed to different scales, same values of the coefficient of discharge are not expected for the same geometrical ratio. Thus the dimensional ratios represented by (K/h) or 'f', Reynolds number and Webers number are not the same in the different scale models, hence the variance in the values of the coefficient of discharge. Apart from these it was found that while constructing geometrically similar models in which every co-ordinate of the prototype is divided by the scale ratio to obtain the corresponding co-ordinate of the model, the original equation of the crest profile is not exactly represented. The model crest thus represents a profile whose equation is not the original equation of the prototype. The new crest profile although corresponds to the equation of the lower nappe for the model head yet is is mathematically a different profile. In the case of U.S.B.R profile of a spillway the model profile will represent a different U.S.B.R profile which corresponds to the model head. Thus testing different scale models of a spillway amounts to testing different U.S.B.R profiles, and so certainly the same values of coefficient of discharge for same geometrical ratio could not be expected, and thus any attempt to estimate the absolute values of the coefficient of discharge independent of all effects viz. of roughness and fluid properties, will have that limitation, since such an affect termed profile effect could not possibly be eliminated.

6.2 It is further possible to predict more approximately the value of coefficient of discharge for the prototype for any operational head. The process lies in conducting a series of experiments for the same scale model with different liquids or alternatively by conducting series of experiments on models constructed to different scales with different roughness in approach channel and crest with the same liquid water. The main idea being to find the discharge function for the dimensional ratios as existing on the prototype. Firstly the geometrical parameters are equated and then the roughness parameters. Finally the effect of fluid properties could be avoided by plotting results obtained on different scale models and finally extrapolating for the prototype conditions.

6.3 It is however, not possible to give ready made general curves from which the correct values of the coefficient of discharge could be read for the prototype on the basis of the value obtained on a particular scale model. However, levelled diagrams for different values of (K/h) could be drawn between C and scale ratio to roughly estimate the percentage effect and this ratio on being multiplied with the value of C obtained on models could give the value of coefficient of discharge on the prototype somewhat approximately.

6.4 Further, it was found that Eulers number and Reynolds number are related by a power law as the plot obtained between the two on log-log paper is linear. Similar is the case with Webers number and Euler number which are also related with power law. Of course the slope of the straight lines obtained on log-log paper.between Eulars number and Reynolds number and that between Eulers number and Webers number will be a function of geometrical and roughness parameters. As such it is possible to find an empirical relationshi between Reynolds number, Eulers number and Webers number and to connect the slope of the line with the geometrical and roughness parameter to generalise such a solution. However, such a solution will not be absolutely true, because it is not possible to isolate the effects of Reynold number and Webers number as complained in the preceding paras. Neither is their effect in the discharge function subject to mathematical treatment. Nevertheless such an empirical relationship derived purely on the basis of experimental results will have limited utility.

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TABLE No. 1

Model Scale - 1/10 L = 3 ft. Shingle used - Cement plaster

Q in cusecs	H in feet	H+P	V=Q/A	$ha=V^2/2g$	Ho=H+ha	$Ho^{3/2}$	$LHo^{3/2}$	P/h	C = $Q/LHo^{3/2}$
0.1196	.058	.558	.0716	.0000803	.058803	.0142	.04242	8.620	2.82
0.3220	.099	.599	.1803	.0005090	.099509	.0313	.09330	5.055	3.45
0.5700	.141	.641	.2992	.0014060	.145406	.0556	.16490	3.550	3.46
0.8920	.180	.680	.4550	.0032250	.183225	.0984	.29160	2.780	3.06
1.2250	.219	.719	.3760	.0051950	.224195	.1062	.31400	2.285	3.90
1.6300	.251	.751	.7360	.0084900	.259490	.1320	.38950	1.993	4.17
2.0700	.286	.786	.8960	.0125400	.298540	.1635	.48150	1.750	4.20
2.3800	.311	.811	.9999	.0166200	.326620	.1868	.54850	1.150	4.34

TABLE NO. 2

Model Scale -1/15 $L = 3$ ft. Shingle used - Cement plaster

Q in cusecs	H in feet	H+P	$V=Q/A$	$ho=V^2/2g$	$Ho=H+ha$	$Ho^{3/2}$	$LHo^{3/2}$	P/H	$C= Q/LHo^{3/2}$
0.1196	.055	.388	0.1027	.000216	.055216	.0130	.03886	6.066	3.080
0.3220	.096	.429	0.2515	.009890	.105890	.0342	.10200	3.469	3.155
0.5700	.135	.468	0.4090	.002615	.137615	.0509	.15140	2.466	3.762
0.892	.169	.502	0.5990	.005605	.174600	.07320	.21720	1.970	4.110
1.225	.204	.537	0.7715	.009310	.213300	.0980	.29000	1.633	4.220
1.630	.238	.571	0.9650	.014600	.252600	.1270	.37500	1.400	4.340
2.070	.269	.602	1.1670	.021350	.290350	.1570	.46300	1.238	4.460
-	.281	.614	-	-	-	-	-	-	-

TABLE NO. 3

Model Scale - 1/20 L = 3 ft. Shingle used - Cement plaster.

Q in cusecs	H in feet	H+P	V=Q/A	$h_a=V^2/2g$	Ho=H+ha	$Ho^{3/2}$	$LHo^{3/2}$	P/h	C= $Q/LHo^{3/2}$
0.1196	.054	.304	.1313	.000271	.054270	.0127	.0380	4.630	3.142
0.3220	.092	.342	.3158	.001558	.093558	.0287	.0856	2.717	3.760
0.5700	.129	.379	.5050	.003990	.132990	.0485	.1442	1.938	3.950
0.8920	.166	.416	.7220	.008170	.174170	.0730	.2166	1.505	4.120
1.2250	.198	.448	.9235	.013350	.211350	.0971	.2878	1.262	4.260
1.6300	.230	.480	1.1480	.020600	.250600	.1257	.3713	1.087	4.390
2.0700	.259	.509	1.3710	.028450	.287450	.1540	.4520	0.965	4.570
2.4750	.283	.533	1.577	.038800	.321800	.1824	.5365	0.884	4.610

TABLE NO. 4

Model Scale - 1/30 L= 3 ft. Shingle used - Cement plaster

Q in cusecs	H in feet	H+P	V=Q/A	ha=$V^2/2g$	Ho=H+ha	$Ho^{3/2}$	$LHo^{3/2}$	P/h	C= $Q/LHo^{3/2}$
0.1196	.054	.220	0.19350	.000585	.054585	.0128	.03830	3.0850	3.15
0.3220	.089	.255	0.4235	.002790	.091790	.0277	.08275	1.8720	3.89
0.5700	.126	.292	0.6565	.006750	.132750	.0473	.14080	1.3210	4.06
0.8920	.156	.322	0.9335	.013610	.169610	.0694	.20600	1.0670	4.33
1.2250	.189	.355	1.1630	.021180	.210180	.0963	.28550	0.8815	4.29
1.6300	.219	.385	1.4280	.031750	.250750	.1259	.37100	0.7610	4.39
2.0700	.254	.420	1.6720	.043700	.297700	.1620	.47700	0.6560	4.32
2.3950	.273	.439	1.8500	.053500	.326500	.1868	.55000	0.6100	4.35

TABLE NO. 5

Model Scale - 1/40 L = 3 ft Shingle used - Cement plaster

Q in cusecs	H in feet	H+P	V=Q/A	$h_a=V^2/2g$	$H_o=H+h_a$	$H_o^{3/2}$	$LH_o^{3/2}$	P/h	$C = Q/LH_o^{3/2}$
0.1196	.052	.177	0.2260	.000798	.052798	.01215	.0363	2.4020	3.292
0.3220	.081	.206	0.5246	.004310	.085310	.02500	.0746	1.5420	4.315
0.5700	.122	.247	0.7760	.009410	.131410	.04770	.1424	1.0220	4.010
0.8920	.150	.275	1.0915	.018680	.168680	.06920	.2056	0.8335	4.350
1.2250	.178	.303	1.3620	.029100	.207100	.09400	.2787	0.7020	4.390
1.6300	.202	.327	1.6860	.044500	.246500	.12270	.3630	0.6190	4.480
2.0700	.228	.353	1.9820	.061350	.289350	.16350	.4830	0.5470	4.290
2.3800	.242	.367	2.1950	.075500	.317500	.17900	.5280	-	-

TABLE No. 6

Model Scale - 1/10 L = 3 ft Shingle used - 1/4" (approx)

Q in cusecs	H in feet	H+P	V=Q/A	$h_a=V^2/2g$	$H_o=H+h_a$	$H_o^{3/2}$	$LH_o^{3/2}$	P/h	$C= Q/LH_o^{3/2}$
0.1196	.057	.557	0.0717	.0000805	.570805	.0138	.0412	8.770	2.910
0.3220	.100	.600	0.1801	.0005080	.100508	.0319	.0960	5.000	3.390
0.5700	.138	.638	0.3050	.0014200	.139420	.0519	.1542	3.592	3.695
0.8920	.179	.679	0.4270	.0028500	.181850	.0770	.2282	2.790	3.920
1.2250	.217	.717	0.5780	.0052200	.222220	.1046	.3087	2.302	3.960
1.6300	.254	.754	0.7330	.0084000	.262400	.1346	.3963	1.969	4.120
2.0700	.290	.790	0.8910	.0123800	.302380	.1664	.4915	1.723	4.220
2.4800	.322	.822	1.0270	.0165300	.338530	.1970	.5770	1.553	4.290

TABLE NO. 7

Model Scale - 1/15 L = 3 ft Shingle used-1/4"(Approx)

Q in cusecs	H in feet	H+P	V=Q/A	$h_a = V^2/2g$	Ho=H+ha	$Ho^{3/2}$	$LHo^{3/2}$	P/h	$C = \frac{Q}{LHo^{3/2}}$
0.1196	.066	.386	0.1028	.000164	.056164	.0134	.0402	5.890	2.970
0.3220	.097	.427	0.2525	.000995	.097995	.0308	.0921	3.405	3.493
0.5700	.135	.465	0.4130	.002650	.137650	.0510	.1517	2.445	3.760
0.8920	.172	.502	0.5990	.005600	.177600	.0748	.2215	1.919	4.030
1.2250	.211	.541	0.7660	.009170	.220170	.1035	.3060	1.565	4.070
1.6300	.236	.566	0.9750	.014850	.250850	.1312	.3874	1.398	4.210
2.0700	.277	.607	1.1580	.020900	.297900	.1625	.4780	1.192	4.320
2.3500	.301	.631	1.2670	.025150	.326150	.1865	.5475	1.095	4.280

TABLE No.8

Model Scale - 1/20   L = 3 ft   Shingle used - 1/4" (Approx)

Q in cusecs	H in feet	H+P	V=Q/A	$h_a = V^2/2g$	$H_o = H + h_a$	$H_o^{3/2}$	$LH_o^{3/2}$	P/h	$C = \frac{Q}{LH_o^{3/2}}$
0.1169	.053	.303	0.1320	.000272	.053272	.0123	.0368	4.685	3.246
0.3220	.094	.344	0.2138	.001540	.095540	.0294	.0578	2.615	3.667
0.5700	.131	.381	0.5030	.003950	.134950	.0495	.1475	1.856	3.868
0.8920	.167	.417	0.7215	.008140	.175140	.0731	.2195	1.426	4.065
1.2250	.202	.452	0.9162	.013150	.215150	.0998	.2950	1.162	4.160
1.6300	.234	.484	1.1400	.020300	.254300	.1282	.3790	0.983	4.315
2.0700	.267	.517	1.3580	.028800	.295800	.1608	.4730	0.847	4.380
2.5080	-	-	-	-	-	-	-	-	-
2.1800	.276	.526	1.4070	.030850	.306850	.1705	.5030	0.514	4.325

TABLE NO. 9

Model Scale - 1/30 $L = 3$ ft Shingle used - 1/4"(Approx)

Q in cusecs	H in feet	H + P	$V=Q/A$	$h_a=V^2/2g$	$H_o=H+h_a$	$H_o^{3/2}$	$LH_o^{3/2}$	P/h	$C=\frac{Q}{LH_o^{3/2}}$
0.1196	.051	.21776	.1840	.000528	.051528	.0117	.03499	3.262	3.418
0.3220	.090	.25667	.4215	.002770	.092770	.0282	.08410	1.850	3.822
0.5700	.126	.29267	.6450	.006510	.132510	.0482	.14330	1.322	3.975
0.8920	.159	.32567	.9240	.013320	.172320	.0717	.21300	1.047	4.180
1.2250	.191	.35767	1.1550	.020800	.211800	.0972	.28800	0.872	4.250
1.6300	.221	.38767	1.4230	.031650	.252650	.1259	.37180	0.753	4.390
2.0700	.252	.41867	1.6760	.044000	.296000	.1610	.47400	0.661	4.375
2.4250	.276	.44267	1.8600	.054100	.330100	.1910	.56200	0.603	4.320

TABLE NO. 10

Model Scale - 1/40 $L = 3$ ft Shingle used - 1/4" (Approx).

Q in cusecs	H in feet	H + P	V=Q/A	$ha=V^2/2g$	Ho=H+ha	$Ho^{3/2}$	$LHo^{3/2}$	P/h	$C = \frac{Q}{LHo^{3/2}}$
0.1196	.049	.174	0.229	.00082	.04982	.0110	.0329	2.5520	3.632
0.3220	.870	.212	0.509	.00405	.09105	.0276	.0824	1.4370	3.910
0.5700	.122	.247	0.786	.00967	.13167	.0475	.1413	1.0250	4.040
0.8920	.156	.281	1.071	.01783	.17383	.7250	.2153	0.8020	4.150
1.2250	.186	.311	1.330	.02760	.21360	.0990	.2935	0.6720	4.180
1.6300	.218	.343	1.582	.03920	.25770	.1302	.3850	0.5730	4.230
2.0700	.252	.377	1.865	.05430	.30630	.1692	.4990	0.4965	4.115
2.4000	.275	.400	2.039	.06500	.34000	.1980	.5860	0.4550	4.080

TABLE NO. 11

Model Scale - 1/10 L = 3 ft Shingle used - 1/2"(Approx)

Q in cusecs	H in feet	H+P	V=Q/A	$h_a=V^2/2g$	Ho=H+ha	$Ho^{3/2}$	$LHo^{3/2}$	P/h	$C = \frac{Q}{LHo^{3/2}}$
0.1196	.053	.553	0.0723	.0000817	.0530817	.0122	.03645	9.950	3.280
0.3220	.095	.595	0.1817	.0005150	.0955150	.0295	.08800	5.260	3.660
0.5700	.136	.636	0.3018	.0014200	.1374200	.0510	.15150	3.680	3.762
0.8920	.175	.675	0.4460	.0031200	.1781200	.0750	.22200	2.858	4.020
1.2250	.211	.711	0.5820	.0053200	.2163200	.1100	.32450	2.370	3.780
1.6300	.249	.749	0.7390	.0085200	.2575200	.1307	.38550	2.060	2.060
2.0700	.283	.783	0.8550	.0114200	.2944200	.1600	.47000	1.767	4.410
2.4500	.310	.810	1.0320	.0167000	.3267000	.1860	.54600	1.613	4.480

TABLE NO. 12

Model Scale - 1/15 L = 3 ft Shingle used - 1/2" (Approx)

Q in cusecs	H in feet	H+P	$V=Q/A$	$ha=V^2/2g$	$Ho=H+ha$	$Ho^{3/2}$	$Lho^{3/2}$	P/h	$C = \frac{Q}{LHo^{3/2}}$
0.1196	.055	.385	0.1037	.0001682	.055168	.0129	.03859	6.000	3.100
0.3220	.095	.425	0.2541	.0010090	.096009	.0298	.08890	3.475	3.645
0.5700	.137	.467	0.4120	.0026558	.139650	.0520	.15470	2.308	3.690
0.8920	.173	.503	0.5990	.0056150	.178615	.0755	.22400	1.905	3.982
1.2250	.208	.538	0.8225	.0105500	.218550	.1025	.30830	1.585	4.040
1.6300	.245	.575	0.9620	.0145000	.259500	.1320	.38960	1.345	4.185
2.0700	.283	.613	0.1540	.0208000	.303800	.1670	.49000	1.166	4.230
2.3800	.305	.635	0.2750	.0254000	.330400	.1900	.55800	1.080	4.265

TABLE NO.13

Model Scale - 1/20 L = 3 ft Shingle used - 1/2"(Approx)

Q in cusecs	H in feet	H+P	V=Q/A	$ha=V^2/2g$	Ho=H+ha	$Ho^{3/2}$	$LHo^{3/2}$	P/h	$C=\frac{Q}{LHo^{3/2}}$
0.1196	.055	.305	0.1310	.000268	.055268	.0131	.03917	4.5400	3.058
0.3220	.093	.343	0.3141	.001543	.094540	.0292	.08690	2.6870	3.710
0.5700	.132	.382	0.5020	.003950	.135950	.0499	.14820	1.8950	3.841
0.8920	.167	.417	0.7225	.008160	.175160	.0734	.21680	1.4980	4.115
1.2250	.202	.452	0.9170	.013120	.215120	.1000	.29590	1.2380	4.150
1.6300	.237	.487	1.1320	.020150	.257150	.1305	.38450	1.0550	4.235
2.0700	.273	.523	1.3430	.028250	.301250	.1653	.48700	0.9165	4.250
2.5000	.304	.554	1.5360	.036800	.340800	.1990	.58500	0.8230	4.270

TABLE NO.14

Model Scale - 1/30 L = 3 ft Shingle used - 1/2"(Approx)

Q in cusecs	H in feet	H + P	V=Q/A	$h_a=V^2/2g$	Ho=H+ha	$Ho^{3/2}$	$LHo^{3/2}$	P/h	$C=\frac{Q}{LHo^{3/2}}$
0.1196	.049	.2150	0.1860	.000541	.049541	.0110	.03289	3.400	3.639
0.3220	.091	.2576	0.4190	.002740	.093740	.0285	.08490	1.842	3.790
0.3700	.124	.2900	0.6600	.006830	.130830	.0471	.14000	1.335	4.070
0.8920	.160	.3260	0.9310	.013600	.173600	.0720	.31380	1.038	4.180
1.2250	.191	.3570	0.1162	.017700	.208700	.0950	.28200	0.870	4.350
1.6300	.226	.3920	1.4090	.031100	.257100	.1305	.37900	0.735	4.310
2.0700	.263	.4290	1.6770	.043900	.306900	.1700	.50200	0.632	4.120
2.3750	.295	.4610	1.7500	.047800	.342900	.2010	.59100	0.563	4.020

TABLE NO.15

Model Scale - 1/40 L = 3 ft Shingle used - 1/2" (Approx)

Q in cusecs	H in feet	H+P	V=Q/A	$h_a = V^2/2g$	$H_o = H + h_a$	$H_o^{3/2}$	$LH_o^{3/2}$	P/h	$C = \frac{Q}{LH_o^{3/2}}$
0.1196	.060	.175	0.2285	.000816	.050816	.0114	.03402	2.5000	3.510
0.3220	.088	.213	0.5070	.004020	.092920	.0280	.08350	1.4210	3.858
0.5700	.123	.248	0.7730	.009300	.132300	.0483	.14370	1.0160	3.940
0.8920	.157	.282	1.0660	.017780	.174780	.0730	.21680	0.7965	4.115
1.2250	.188	.313	1.3230	.027350	.215350	.1000	.29600	0.6650	4.135
1.6300	.220	.345	1.5970	.039900	.259900	.1326	.39100	0.5670	4.165
2.0700	.250	.375	1.8700	.054700	.304700	.1675	.49250	0.5000	4.210
2.4200	.276	.401	2.0500	.065700	.341700	.1990	.58700	0.4530	4.120

TABLE NO. 16

Model Scale - 1/10 L= 3 ft Shingle used - 1"(Approx)

Q in cusecs	H in feet	H+P	V=Q/A	$ha=V^2/2g$	Ho=H+ha	$Ho^{3/2}$	$LHo^{3/2}$	P/h	$C=\frac{Q}{LHo^{3/2}}$
0.1196	.054	.554	0.0722	.0008170	.0540817	.01270	.03800	9.265	3.142
0.3220	.093	.593	0.1820	.0005180	.0935180	.02870	.08555	5.375	3.760
0.5700	.134	.634	0.3020	.0014250	.1354250	.04990	.14840	3.735	3.840
0.8920	.174	.674	0.4475	.0031350	.1731350	.07465	.22130	2.870	4.030
1.2250	.211	.711	0.5835	.0053200	.2182200	.10100	.29830	2.370	4.110
1.6300	.247	.747	0.7390	.0085500	.2555000	.12880	.37980	2.027	4.290
2.0700	.283	.783	0.8990	.0126200	.2956200	.16070	.47300	1.767	4.370
2.4700	.312	.812	1.0370	.0168000	.3288000	.18850	.55350	1.603	4.470

TABLE NO. 17

Model Scale - 1/15 L = 3 ft. Shingle used - 1"(Approx)

Q in cusecs	H in feet	H + P	V=Q/A	$ha=V^2/2g$	Ho=H+ha	$Ho^{3/2}$	$LHo^{3/2}$	P/h	$C=\frac{Q}{LHo^{3/2}}$
0.1196	.053	.383	0.1046	.0001706	.0531706	.0122	.03525	6.280	3.390
0.3220	.095	.425	0.2542	.0010100	.0960100	.0299	.08620	3.510	3.720
0.5700	.133	.463	0.3998	.0019990	.1349990	.0497	.14300	2.505	3.990
0.8920	.170	.500	0.6010	.0056400	.1756400	.0734	.21000	1.962	4.250
1.2250	.207	.537	0.7705	.0092900	.2162900	.1070	.31620	1.610	3.870
1.6300	.242	.572	0.9650	.0145300	.2565300	.1300	.38400	1.377	4.240
2.0700	.277	.607	1.1570	.0209000	.2979000	.1625	.47700	1.203	4.330
2.4300	.302	.602	1.3120	.0270000	.3290000	.1888	.55400	1.104	4.380

TABLE NO.18

Q in cusecs	H in feet	H+P	V=Q/A	$ha=V^2/2g$	Ho=H+ha	$Ho^{3/2}$	$LHo^{3/2}$	P/h	$C=\frac{Q}{LHo^{3/2}}$
0.1196	0.051	.301	0.1324	.000274	.051274	.0116	.03467	4.910	3.446
0.3220	0.090	.340	0.3265	.001621	.091640	.0277	.08260	2.778	3.890
0.5700	0.128	.378	0.5060	.004015	.132150	.0481	.14500	1.952	3.932
0.8920	0.164	.414	0.7260	.008260	.173260	.0718	.21320	1.523	4.180
1.2250	0.199	.449	0.9215	.010320	.209320	.0957	.28380	1.257	4.330
1.6300	0.235	.485	1.1380	.020200	.255200	.1290	.28120	1.063	4.270
2.0700	0.266	.516	1.3570	.028750	.294750	.1602	.47300	0.940	4.370
2.4900	0.298	.548	1.5410	.037150	.335150	.1938	.57000	0.839	4.360

TABLE NO.19

Model Scale 1/30 $L = 3$ ft   Shingle used - 1"(Approx)

Q in cusecs	H in feet	H+P	$V=Q/A$	$h_a=V^2/2g$	$H_o=H+h_a$	$H_o^{3/2}$	$LH_o^{3/2}$	P/h	$C=\frac{Q}{LH_o^{3/2}}$
0.1196	.050	.216	0.1861	.000535	.050536	.0113	.03378	3.320	3.540
0.3220	.089	.255	0.4230	.002800	.091800	.0278	.08290	1.865	3.932
0.5700	.124	.290	0.6620	.006850	.130850	.0473	.10070	1.337	4.050
0.8920	.162	.328	0.9170	.013150	.175150	.0732	.21720	1.025	4.115
1.2250	.193	.359	1.1510	.020700	.213700	.0987	.29250	0.860	4.190
1.6300	.225	.391	1.4115	.031150	.256150	.1300	.38400	0.737	4.245
2.0700	.256	.422	1.6610	.043200	.299200	.1640	.48350	0.648	4.280
2.3000	.274	.440	1.7730	.049200	.323200	.1837	.54150	0.605	4.250

TABLE NO.20

Model Scale - 1/40 L = 3 ft Shingle used - 1"(Approx)

Q in cusecs	H in feet	H+P	V=Q/A	$h_a=V^2/2g$	$H_o=H+h_a$	$H_o^{3/2}$	$LH_o^{3/2}$	P/h	$C = \frac{Q}{LH_o^{3/2}}$
0.1196	.052	.177	0.2260	.000798	.052798	.0122	.0365	2.405	3.275
0.3220	.087	.212	0.5090	.004050	.091000	.2074	.0810	1.437	3.937
0.5700	.122	.247	0.7760	.009420	.131420	.0476	.1415	1.020	4.030
0.8920	.159	.284	1.0600	.017500	.176500	.0808	.2400	0.786	3.720
1.2250	.990	.316	1.3130	.026900	.216900	.1012	.3000	0.658	4.070
1.6300	.222	.347	1.5900	.039500	.261500	.1338	.3950	0.564	4.130
2.0700	.258	.383	1.8315	.052500	.310500	.1733	.5120	0.484	4.045
2.3000	.277	.402	1.9420	.059000	.336000	.1947	.5725	0.451	4.020

TABLE No. 21

$h = 1.5$ ft.

Scale	C from curve for K/h =.0364	$Q = C.H^{3/2}$	$R = \frac{q}{\nu}$	$W = \frac{q}{(H+p)^{1/2}\sqrt{\sigma/\rho}}$	Remarks
1/10	3.550	0.2070	0.1852×10^5	5.070	Reynolds number for prototype $= 7.44 \times 10^6$
1/15	3.430	0.1088	0.0973×10^5	3.266	
1/20	3.330	0.0670	0.0600×10^5	2.319	Webers number for prototype = 164.
1/30	3.198	0.0358	0.03205×10^5	1.673	
1/40	2.905	0.02107	0.01883×10^5	1.146	

TABLE No. 22

f = .026 P/h = 3.33

Scale	C as read from curve	Reynolds number	Webers Number	Remarks.
1/10	3.60	1.95×10^4	5.19	Reynolds number for prototype = 7.44×10^6
1/15	3.52	1.08×10^4	3.52	Webers number for prototype = 164
1/20	3.45	6.80×10^3	2.56	
1/30	2.98	3.10×10^3	1.64	
1/40	2.72	1.74×10^3	0.95	

TABLE NO.23

$P/h = 3.33$

Scale	$4 R \times 10^{5}$	$4\frac{(P + H)}{(K)}$	'f' as read from curve	C	K	Webers number	α
1/10	.77800	90.220	.0415	3.730	.02880	5.310	1.0676780
1/15	.40040	60.200	.0480	3.530	.02880	3.340	1.0794316
1/20	.26600	45.120	.0520	3.490	.02880	2.562	1.0873148
1/30	.13608	30.120	.0620	3.295	.02880	1.615	1.1018872
1/40	.08668	22.560	.0700	3.370	.02880	1.185	1.1157758
1/10	.81400	71.240	.0450	3.912	.03645	5.580	1.0735194
1/15	.56280	47.560	.0500	3.650	.03645	3.480	1.0856200
1/20	.26480	35.640	.0550	3.490	.03345	2.580	1.0955072
1/30	.13760	23.800	.0700	3.430	.03645	1.630	1.1117942
1/40	.08520	17.840	.0800	3.280	.03645	1.165	1.1264970
1/10	.81800	22.660	.0700	3.930	.11470	5.610	1.1137780
1/15	.43600	15.120	.0920	3.843	.11470	3.660	1.1365000
1/20	.28600	11.340	.1300	3.770	.11470	2.760	1.1551270
1/30	.14200	7.560	.1750	3.540	.11470	1.680	1.1876790
1/40	.08780	5.668	.2000	3.380	.11470	1.198	1.2121790
1/10	.77800	346.400	.0250	3.730	.00750	0.310	1.0429688
1/15	.41192	230.800	.0200	3.630	.00750	3.460	1.0504570
1/20	.26400	173.600	.0320	3.480	.00750	2.560	1.0557666
1/30	.12480	119.680	.0360	3.112	.00750	1.485	1.0630638
1/40	.36600	86.680	.0450	2.960	.00750	1.050	1.0794164

APPENDIX - II

The following symbols have been used in this dissertation:-

C_d - Dimensionless Coefficient of Discharge.

C - Coefficient of Discharge with Dimensions of $\sqrt{g}$.

K - Roughness Projection.

h - Head over the crest excluding Velocity Head.

R - Reynolds number.

W - Webers number

L - Length of Spillway.

Q - Discharge through the Spillway.

Ho - Total Head over Spilling Crest.

g - Acceleration due to Gravity.

P - Height of Spillway above the bed of channel.

f - Darcy's coefficient.

V - Velocity of Approach.

δ - Thickness of Boundary Layer.

ρ - Mass density of Liquid.

μ - Dynamic Viscosity.

ν - Kinematic Viscosity.

σ - Surface tension.

ha - Velocity head.

n - Rugosity coefficient.

FIGURES

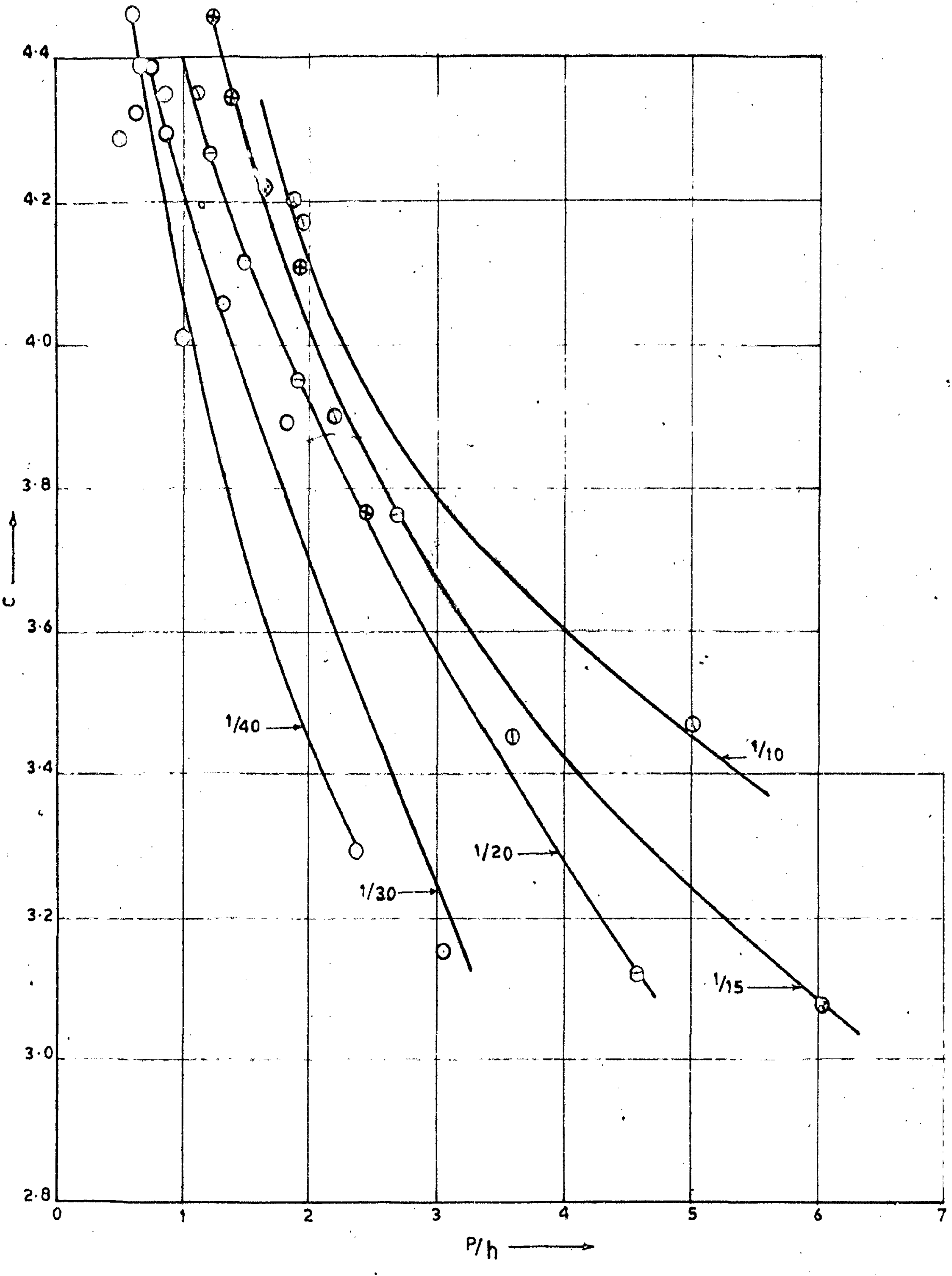


FIG.1 CEMENT PLASTER ROUGHNESS IN APPROACH CHANNEL AND CREST CURVE SHOWING VARIATION OF C WITH P/h

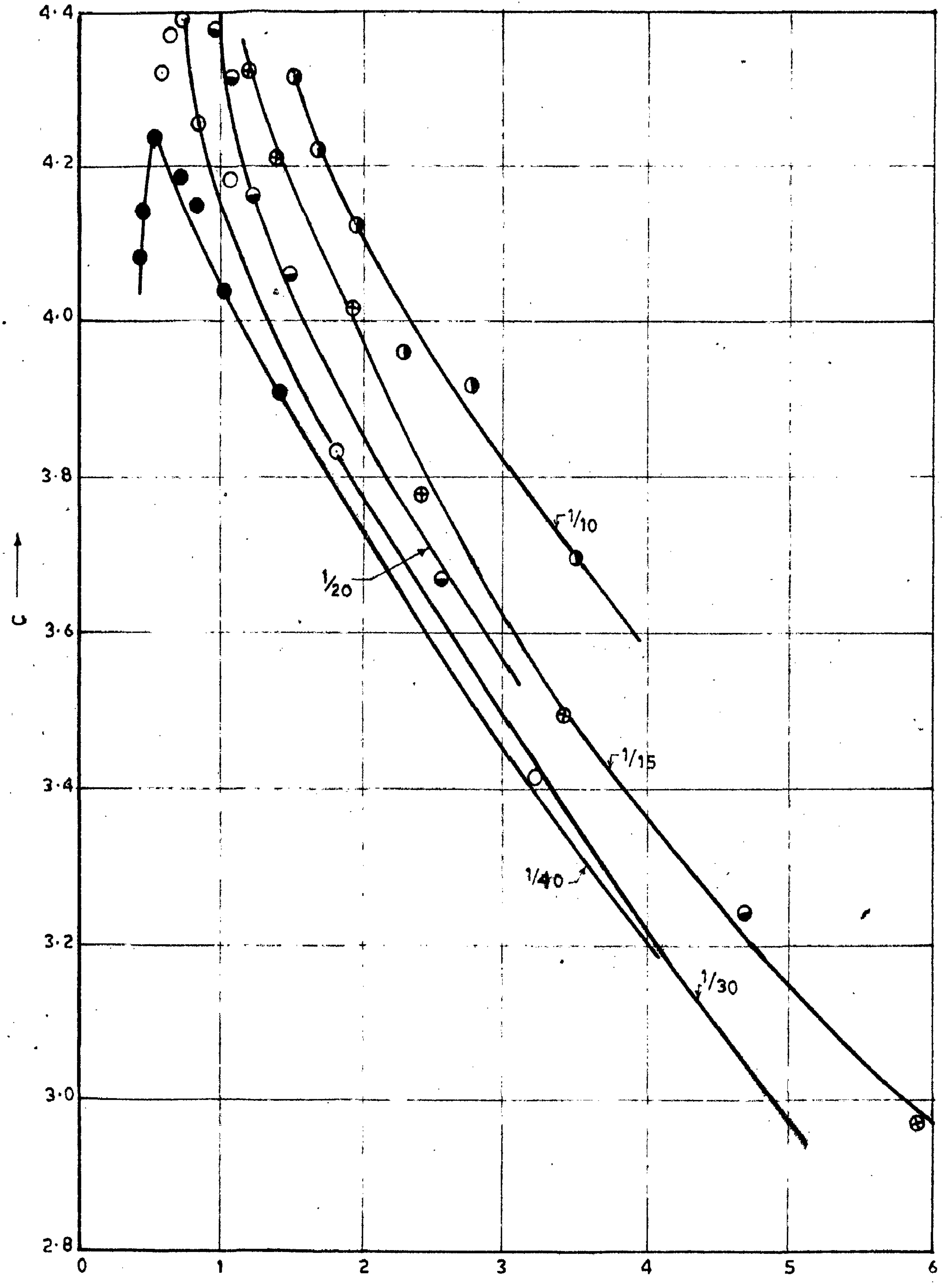
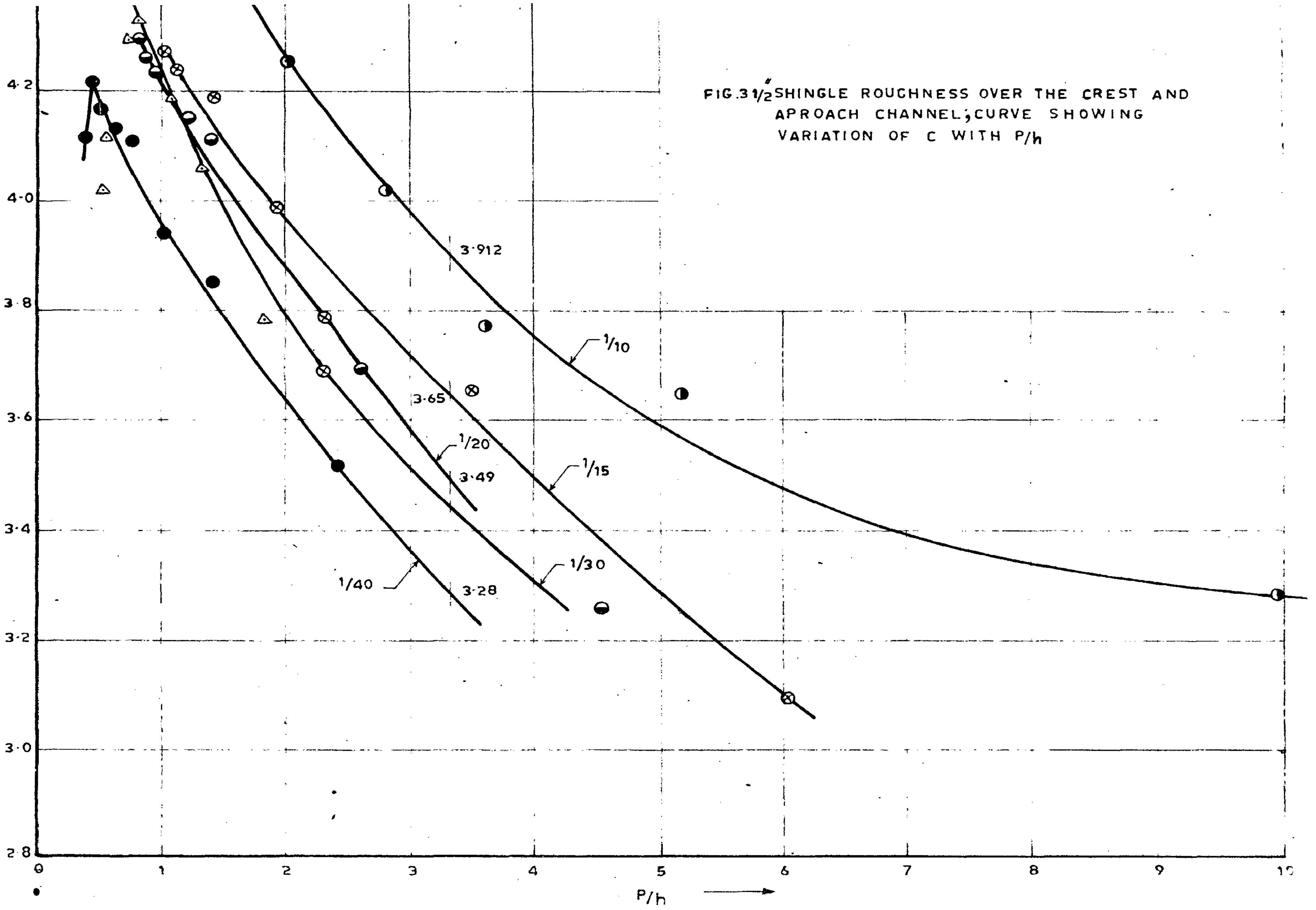


FIG.2. 1/4" SHINGLE ROUGHNESS IN APROACH CHANNEL AND ON THE CREST CURVE SHOWING VARIATION OF THE C WITH P/h

FIG.3 1/2" SHINGLE ROUGHNESS OVER THE CREST AND APROACH CHANNEL; CURVE SHOWING VARIATION OF C WITH P/h



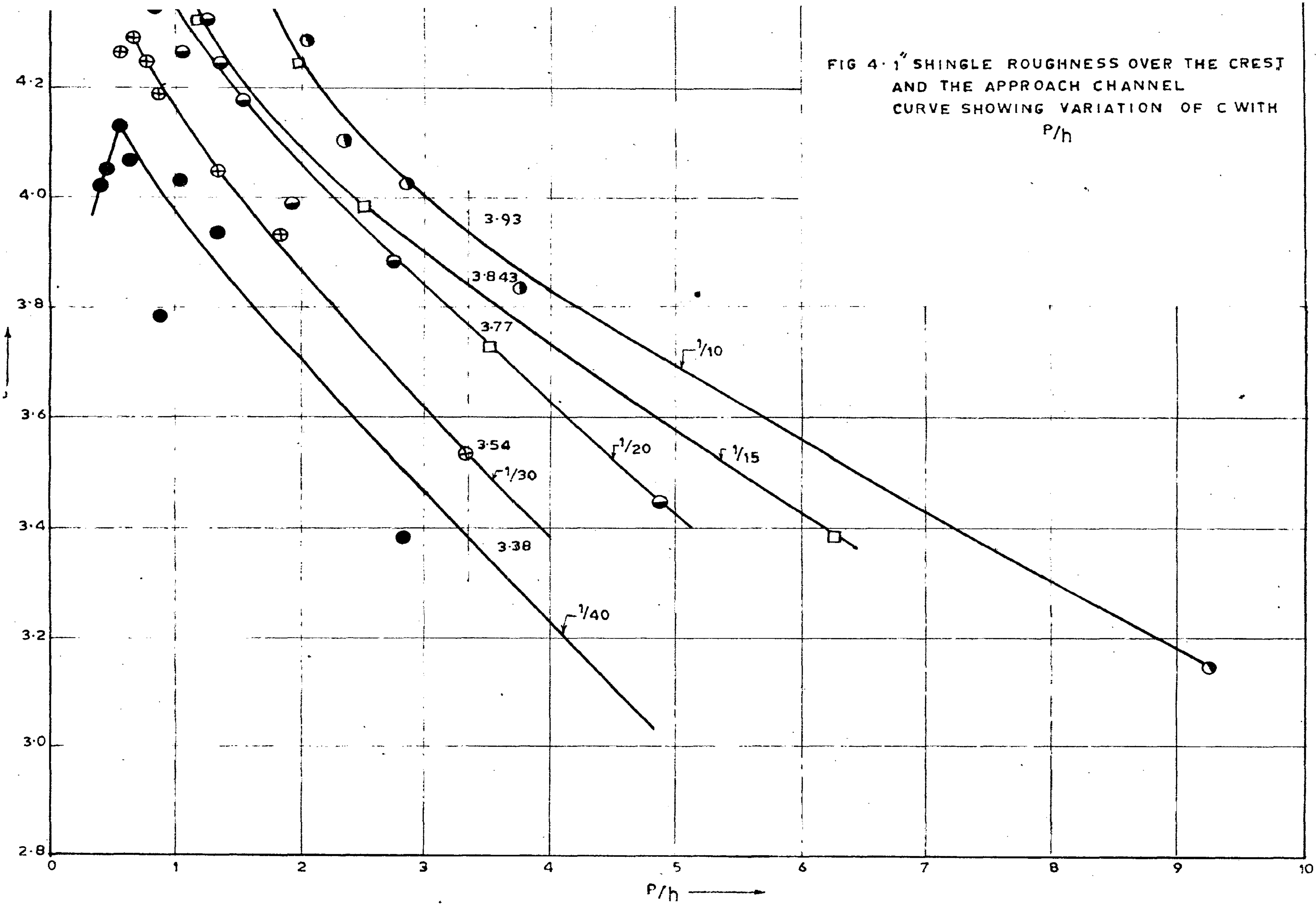


FIG 4·1" SHINGLE ROUGHNESS OVER THE CREST AND THE APPROACH CHANNEL CURVE SHOWING VARIATION OF C WITH P/h

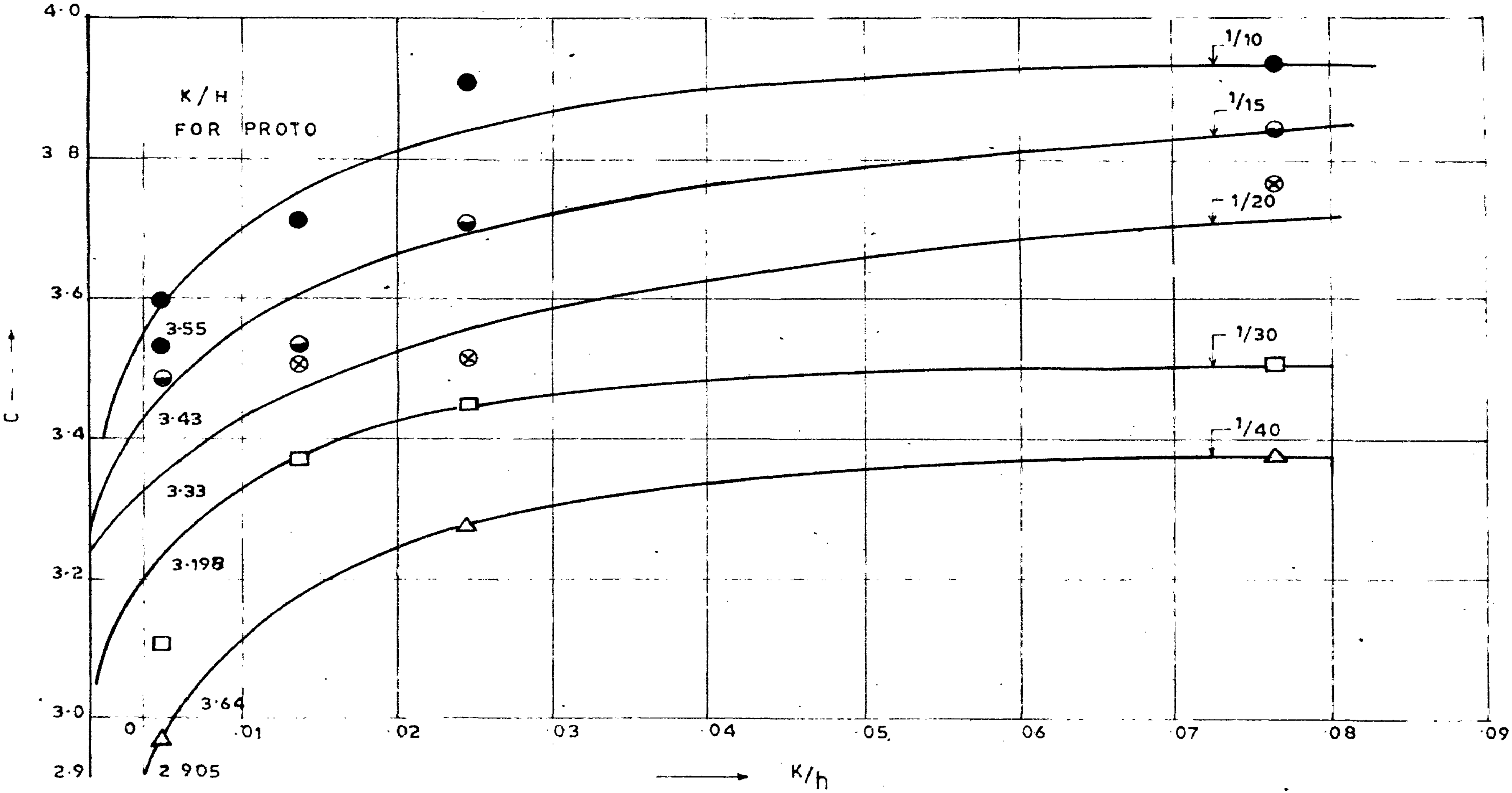


FIG.5 GRAPH BETWEEN K/h AND C FOR P/h = 3·33

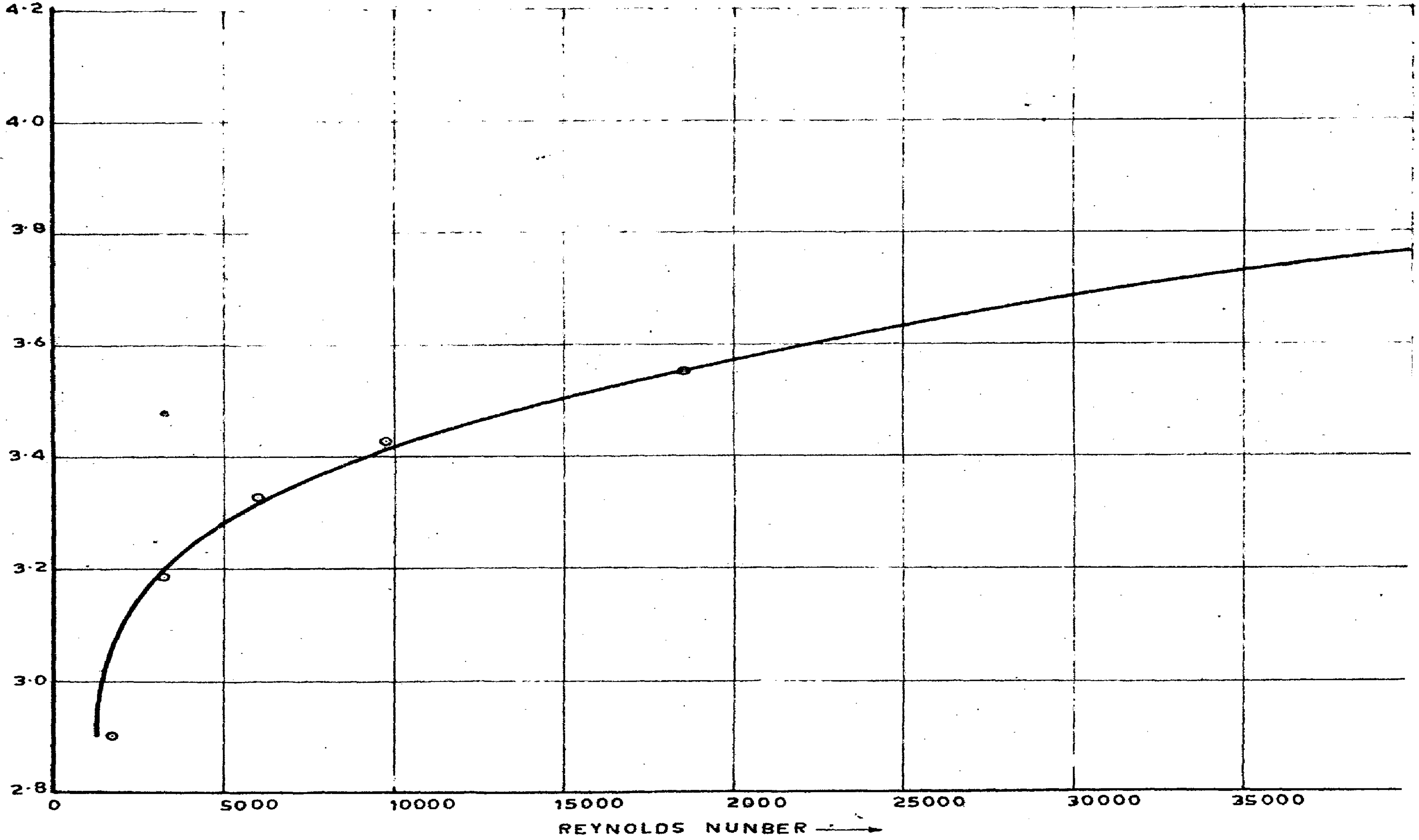


FIG. 6:- CURVE SHOWING VARIATION OF C WITH REYNOLDS NUMBER FOR CONSTANT K/h AND P/h

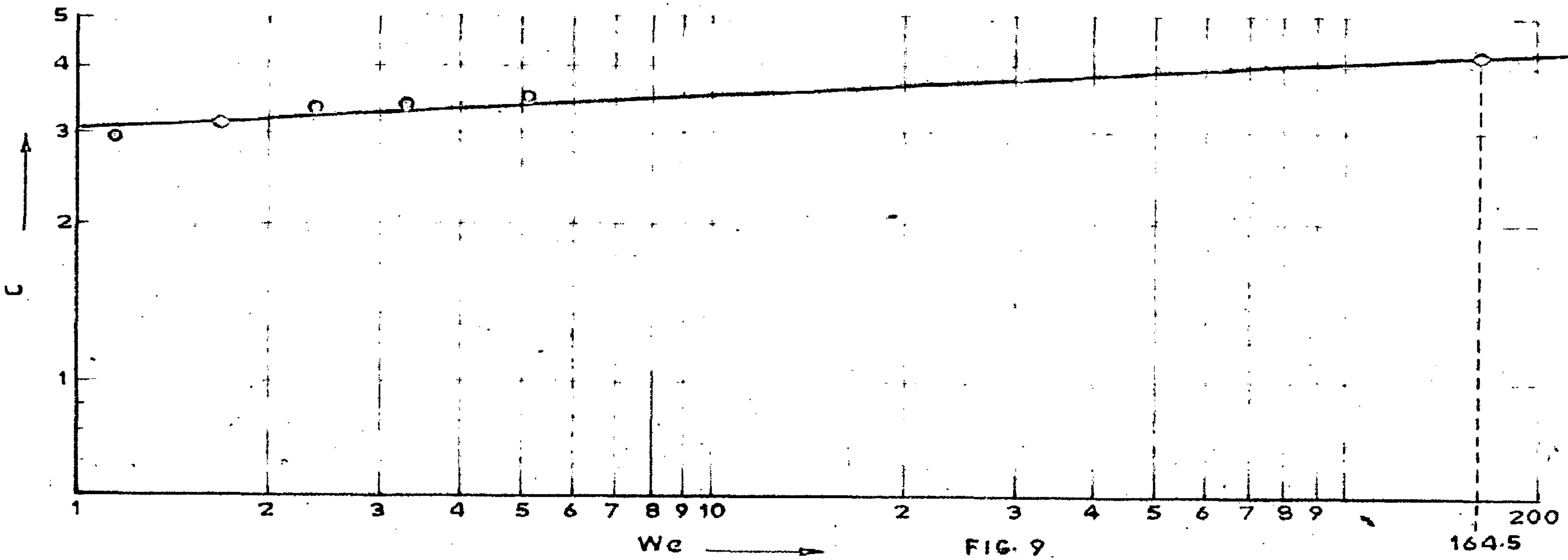
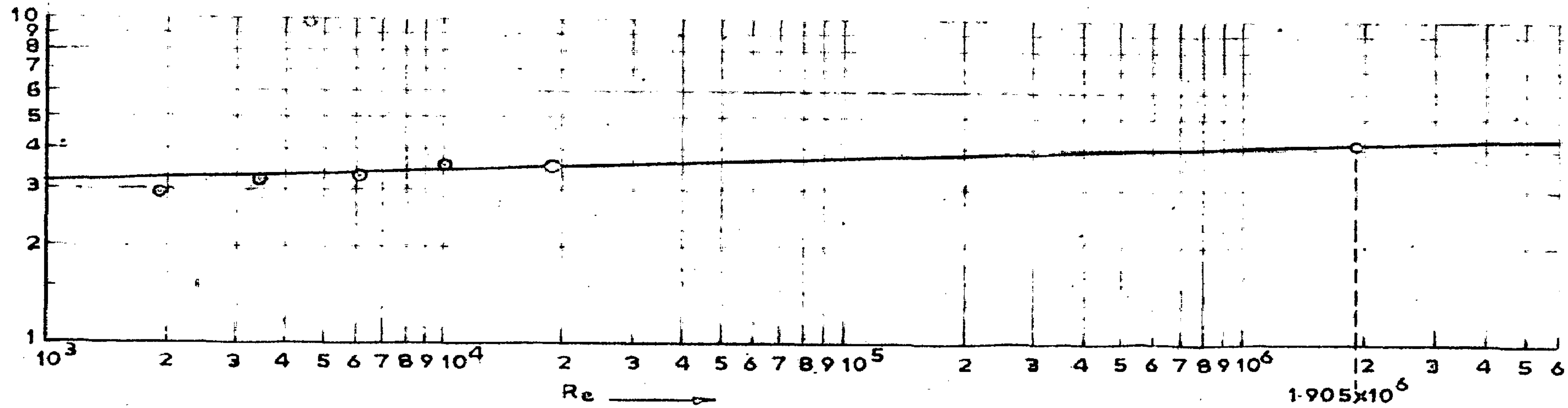


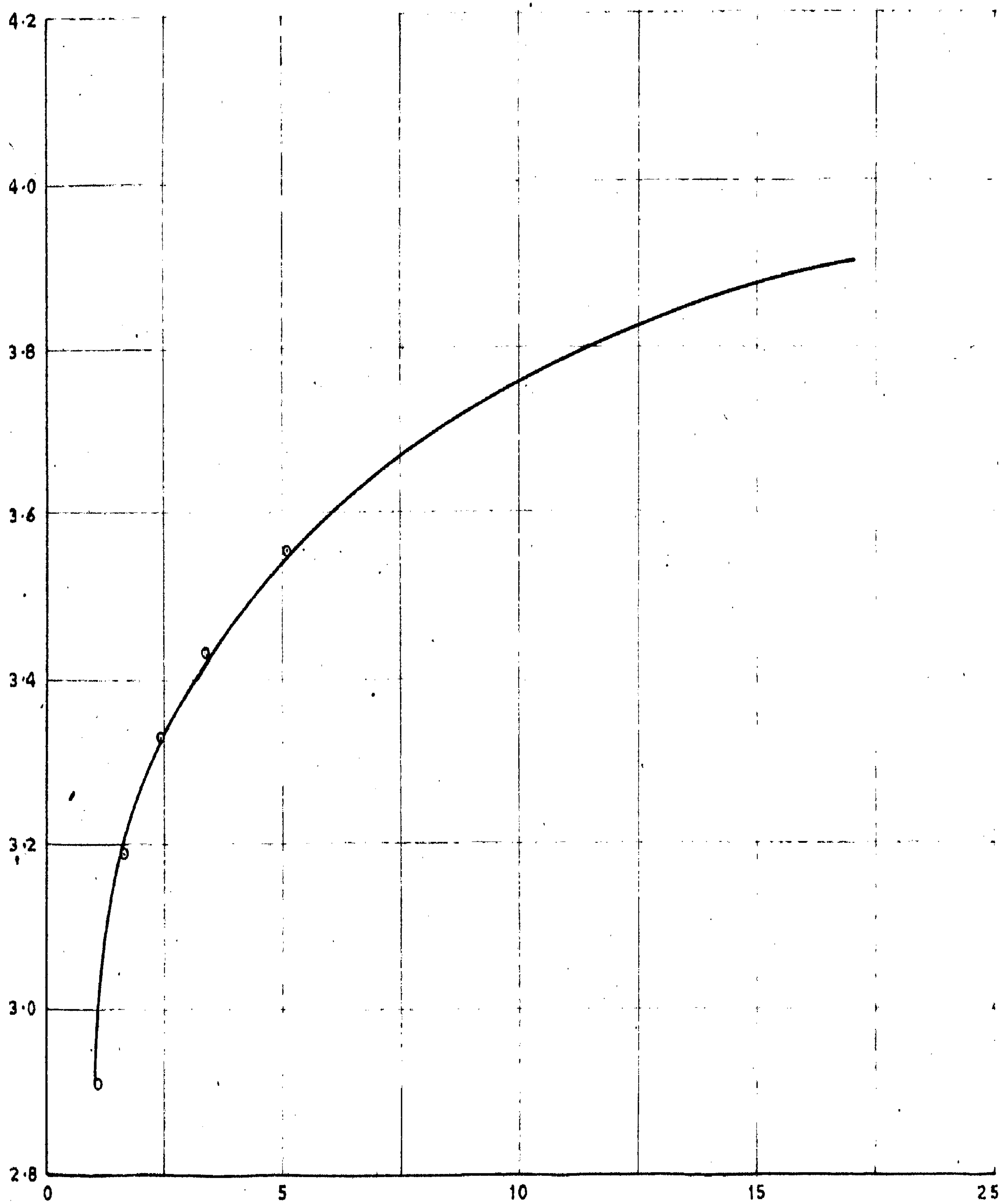
FIG. 9

CURVE SHOWING VARIATION OF C WITH WEBERS NUMBER



CURVE SHOWING VARIATION OF C WITH REYNOLDS NUMBER

FIG. 7



CURVE SHOWING VARIATION OF WEBERS NUMBER WITH C FOR CONSTANT VALUES OF P/h & K/h

FIG. NO. 8

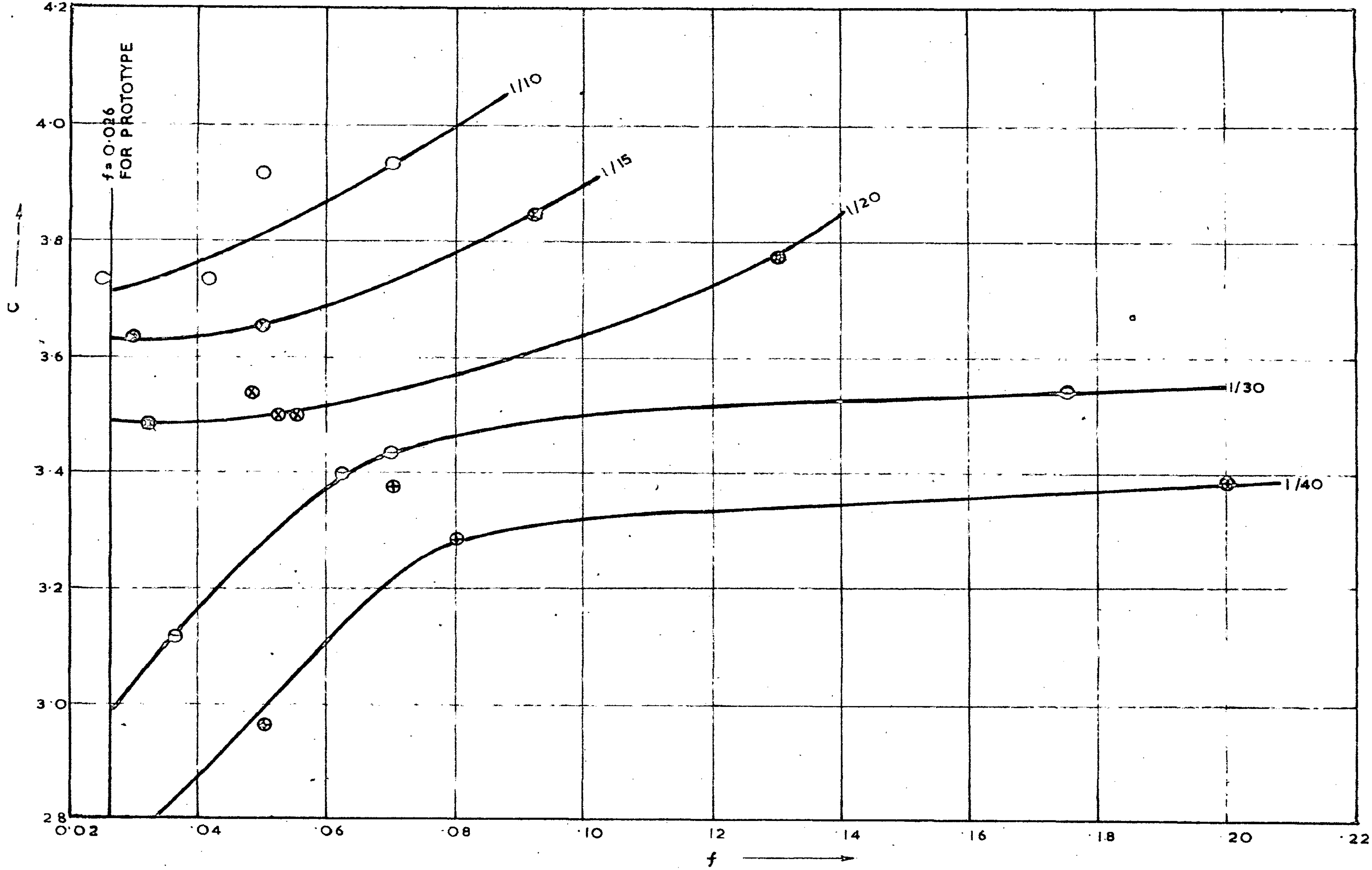


FIGURE 10 :— CURVES SHOWING VARIATIONS OF C WITH f FOR DIFFERENT SCALES FOR CONSTANT P/h

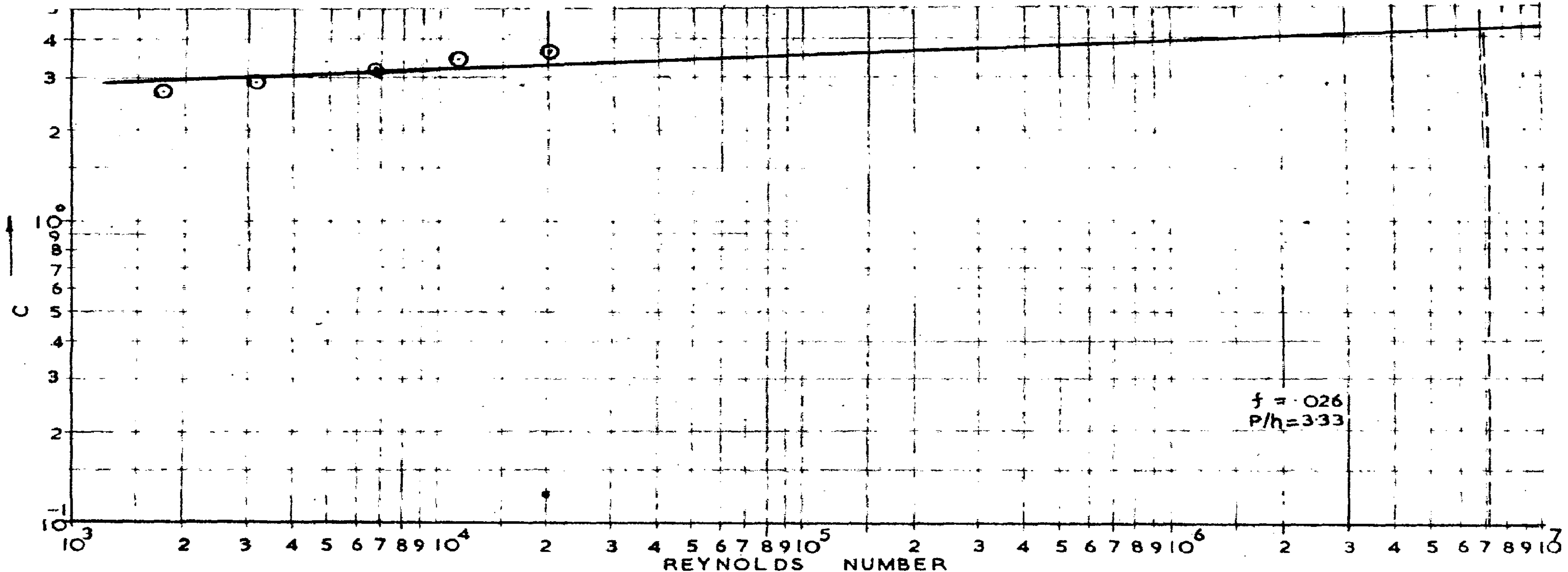


FIGURE. 11 :— CURVE SHOWING VARIATION OF REYNOLDS NUMBER WITH C FOR CONSTANT f AND P/h

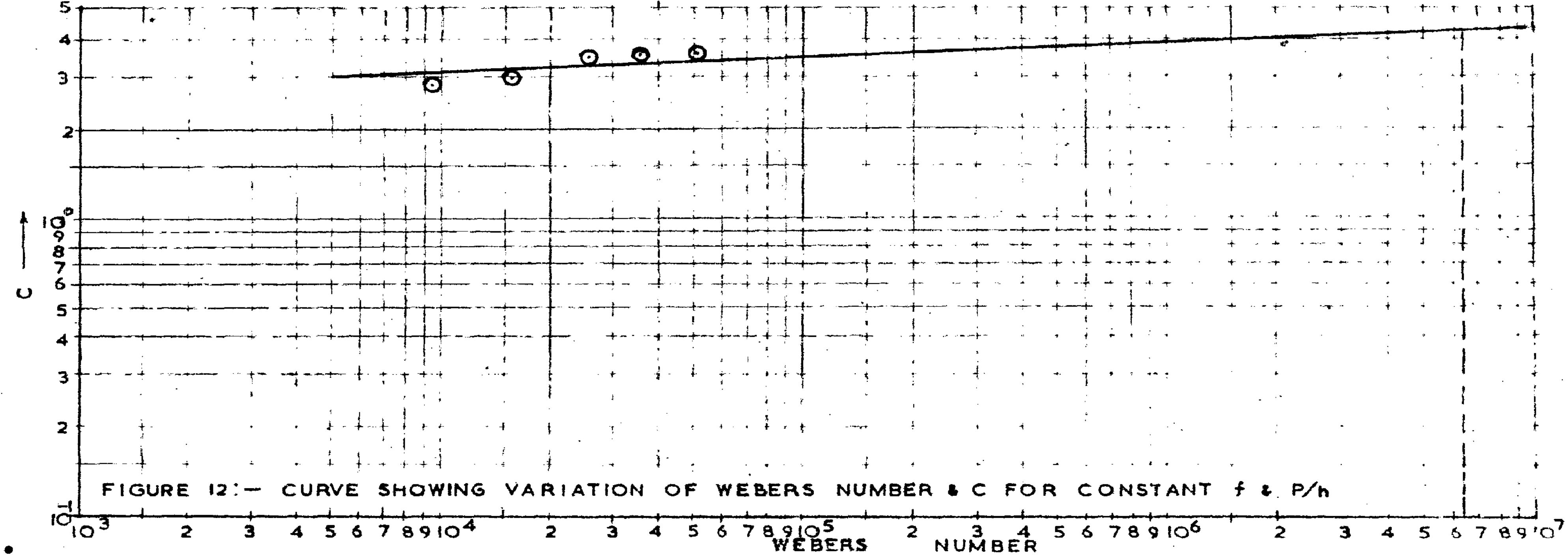


FIGURE 12:— CURVE SHOWING VARIATION OF WEBERS NUMBER & C FOR CONSTANT f & P/h

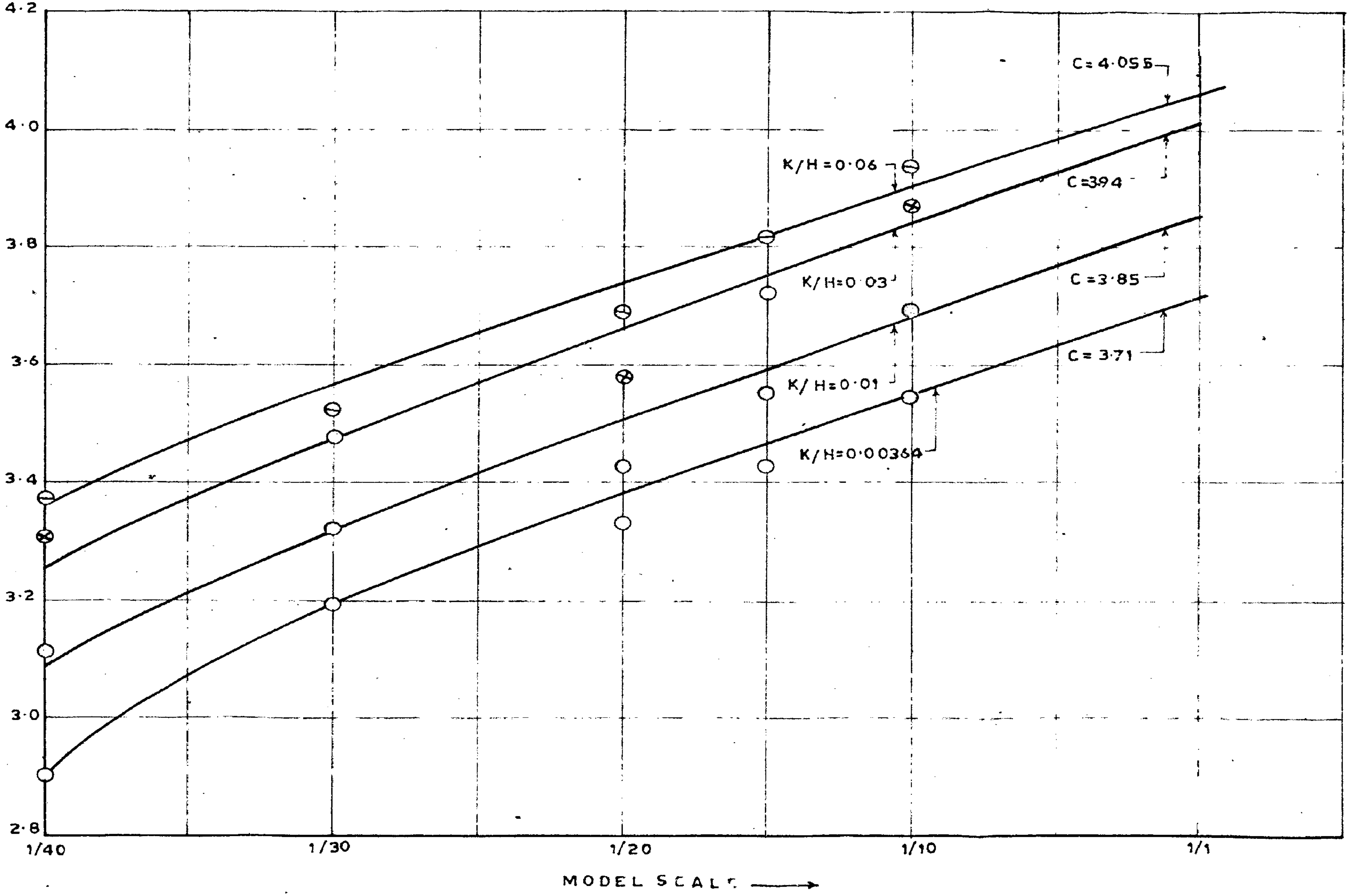


FIG.13. CRAP BETWEEN C AND MODEL SCALE FOR FIXEDK/H VALVE