not come in,

$$V=16\ R^{\frac{2}{3}} S^{\frac{1}{2}} \qquad (1)$$

$$P=8/3\ Q^{\frac{1}{2}}$$

The second one of these can be written as

$$\frac{Q}{VR}= 8/3\ Q^{\frac{1}{2}} \qquad (2)$$

Multiplying (1) and (2) together

$$Q/R = \frac{128}{3}\ Q^{\frac{1}{2}}\ R^{\frac{2}{3}}\ S^{\frac{1}{3}}$$

$$\text{or } \frac{3}{128}\ \frac{Q^{\frac{1}{2}}}{R^{\frac{5}{3}}} = S^{\frac{1}{2}}$$

$$\text{or } S = \frac{(3)^3}{128} \cdot \frac{Q^{3/2}}{R^5}$$

$$= \frac{1}{77672} \cdot \frac{Q^{3/2}}{R^5}$$

$$\text{or } S \times 10^3 = \frac{1}{77672} \cdot \frac{Q^{3/2}}{R^5}$$

The speaker called it a very simple derivation and it might replace the one given by him on page 290.

The speaker, however, uttered a warning against mixing up the Institute formula with the Lacey formulæ.

In conclusion, the speaker suggested one thing to the author that he should collect data for himself and analyse the same with a fresh mind. The old data and methods are useful as guides but most of them as Mr. Lacey once said had better be chucked into the Ganges.

Mr. G. R. Sawhney congratulated the author on his splendid effort to force on the audience a solution of their difficulties. He said that Mr. Lindley tried to introduce a similar slide rule some years back which did not materialise. He said that proper running of channels depended on momentum MV^2. The MV^2 has to overcome friction and V^2 and sectional area.

The speaker was sure Mr. Lacey would agree to the author's suggestion regarding his constant 2·67 not being rigidly followed in all cases and that it should vary from 2·5 to 2·8. He thought the curves and slide rule should be useful.

He agreed with the author in not allowing the channels to get wide. Author's snake analogy spoiled the paper as silt could be proportionately distributed and advantageously spread over the fields. Silt is doing very useful reclamation work in certain areas. He further said that bad regulation from the Heads can easily be proved to have caused most of the big troubles on the various canals and if this can be guarded against, silt ejectors and bye-paths everywhere were not necessary.

The speaker advised the author to further investigate the trouble in Lahore Branch and he might find some local cause for it. The speaker advocated use of staking and bushing and his bed silt stirring plough for berming up quickly.

Ch. Ali Mohammed said that he wanted to speak as he was in charge of the Sub-Division wherein the author had worked. The Sabraon Branch, before the author took over charge in 1935, was silting but after the author had left, there had been no expenditure on silt clearance since 1935. The author had done bushing in 60 miles of the Branch, resulting in growth of straight berms. Similarly, on distributaries berm trimming into straight lengths was carried out. The speaker showed plan, Long.-Section and X.-Sections of U. B. U. and S. B., which showed the result and work done by the author. He commended the methods employed by the author and said that he had done bushing and staking on the Upper Chenab as well.

Mr. N. D. Gulhati congratulated the author on trying to clarify a much-discussed problem. He said that to solve all questions on the design of channels, the author had produced a magician's wand in the nature of his slide rule. Regarding the author's remarks in first paragraph on page 247 the speaker said that it was not right to ignore the velocity in a channel with respect to its effect on conversion of silt from one grade to another. The author had said on page 248, that the grade of silt entering the U. J. C. are much heavier and the speaker remarked if the size of silt is reduced between Mangla and Rasul *via* the river, why not between the same two points *via* the U. J. C. On page 247, the author had stated that soluble clays and soils of very fine consistency do not effect silt-carrying capacity, and had given no reasons in support of this. The speaker's experiments showed that when water in a distributary became muddy after rains, a large quantity of fine silt displaces coarse silt normally present there. The author deserves great credit for drawing on the Kennedy's diagrams, the two limits of wetted perimeter, thus rendering the diagrams less liable to be misused.

Mr. H. L. Wadhera said that the author's remarks on the so-called staking and bushing done at the Head of Lahore Branch were presumably not based on a full appreciation of facts and circumstances of the case. This staking and bushing was a cheap type of bushwood pitching on the lines of pilchi pitching which was resorted to for protection against side-erosion that was proceeding apace in this reach. The soil in this reach was very soft and the lowering of the crest of fall R. D. 12,500 Lahore Branch had resulted in side erosion in this reach, so much so that on the right side the erosion had reached the District Board Road and threatened to engulf the left bank of Bishniwal Distributary. Steps to protect the sides against further erosion had been taken by means of a cheap type of bushwood pitching, which proved very effective.

R. B. KANWAR SAIN said that he had nothing short of admiration for the author's patience in producing the results that he has done and his untiring energy and courage of conviction in presenting his work to the Congress. At places, the author had been carried away more by heat than light and it reminded him of a Chinese author writing about some American Universities that they would give a Ph.D. for a thesis almost on any subject, made obtruse and unintelligible by a few charts and tables of percentages. The speaker found the paper obtrusive and difficult to follow at places.

The speaker illustrated by taking an example of an actual channel assuming Q=1,000 cusecs, slope=1/6,666 or $\sqrt{5}'$ per thousand, Lacey f=0·9 and Kutter's N=0·0225, and said that from Lacey's diagrams only one section was possible and from author's improved Kennedy's Hydraulic diagrams, three sections were possible. There are three different values of R for these three possible sections and three different values of S or slope from the author's formula $S\,10^3 = \frac{65{\cdot}838\,N^2}{R\ 10/3}$ while the three sections have been given by the author for one slope, *i.e.* 0·15′ per thousand. Thus the author's diagrams do not agree with his own slope formula.

The author's formula on page 283, $S\,10^3 = \frac{1}{1{\cdot}8\,Q}\ \frac{1}{6}$ is the same as Lacey's slope formula if f=1, showing thereby that he has hardly improved upon Lacey. The speaker said what the author had presented in the paper is not any advance on Lacey. Regarding author's reference to Haveli Main Canal the speaker pointed at that Lacey's P formula is not applicable to lined channels or the channels with unerodable bed or sides. Therefore, the author's criticism of the Haveli Main Line is not tenable.

MR. C. C. INGLIS, said that the earlier part of this paper was read with interest, containing, as it does, many observations showing the wide experience and practical knowledge of the author. His proposal to vary the value of 'C' in Lacey's P : Q relation, from 2·5 to 2·8, has been followed at Poona for some time and it is undoubted that this method makes it possible to design a range of channels with considerably different dimensions, which will give fairly satisfactory results ; and his modified Kennedy diagrams will, within these limits and where the bed sand is coarse—so that the bed is relatively flat—be most useful.

Towards the end of the paper, however, the author has made several unjustifiable statements and assumptions, and then juggled with empirical formulæ, so that the clarification of the subject which will result from the earlier part of his paper is stultified by the confusion created towards the end.

Thus one formula is $S^* \propto Q/R^{10/3}$. If this had any physical significance it would mean that the larger the discharge the steeper the slope, which is the opposite of fact.

The author is correct when he says that the explanation of variations in C in the Lacey P : Q relation—normally from 2·5 to 2·8, but in extreme cases from 2·2 to 3·2—are due to "*variations in rugosity* (*i.e.* channel condition which Lacey calls shock) *and the materials of the silt-load,*" adding: "In smoother surfaces C=2·5 and in coarser 2·8"—or in Lacey terminology C is 2·8 where there is shock and 2·5 where there is negative shock.

At the Poona Station the speaker expressed this point as follows:

The shape of a channel in incoherent alluvium depends not merely on the mean diameter as determined from terminal velocities by means of a siltometer but also on the relative quantities of the fine and coarse particles in movement. If there is a normal distribution of the various grades, regime conditions obtain, and the dimensions closely follow the dimensions of a Lacey channel; but if, as is frequently the case—especially in rivers—the bed silt charge is disproportionately high, the width of the channel is disproportionately great, and the depth small. If, on the other hand, the quantity of fine silt relative to the bed sand is high, more berming takes place, and the channel is narrower and deeper, and has a flatter slope than a Lacey channel. Channel shape in incoherent alluvium is, in fact, essentially a balance between bed sand and fine silt in motion.

Coming now to the less happily expressed part of the paper: On page 271, the author says:

> "The Punjab Research Institute's formula $R = \cdot 47Q^{\frac{1}{3}}$ establishes that for any discharge there is a definite R (hydraulic mean depth); So *Nature* has fixed a definite section of the channel with definite P and R and so area of any particular channel."

But why blame Nature? Nature had nothing to do with this statement.

Actually it is known that the hydraulic mean depth *does* depend on the silt grade, as is almost universally accepted by irrigation engineers.

By mathematics the author then produces

See page 283 (3) and (4) (Ishar Das)	Compare Lacey
(3) $S^* = 1/1{\cdot}8\ Q^{1/6}$	$S^* = f^{5/3} / 1{\cdot}84\ Q^{1/6}$
(4) $S^* = 1/2{\cdot}6\ R^{1/2}$	$S^* = f^{3/2} / 2{\cdot}68\ R^{1/2}$

Comparing with Lacey it is found that the author has arrived at his formulæ by the simple expedient of ignoring the silt factor, though it comes into the Lacey formulæ as $f^{5/3}$ and $f^{3/2}$ and into the Punjab Irrigation Research Institute formula as

$$S=2{\cdot}09\ m^{0{\cdot}86}/Q^{{\cdot}21}$$

On page 268 the author says:

"Experience has shown that Kutter's formula, though cumbersome, gives the best results. It has been established that the general value of N found from the observed data of channels in the Punjab is ·0225. Therefore, Kennedy's diagrams based on Kutter's formula with N=·0225 are considered to fit in with actual data very well."

On the other hand on page 281 he says:

"According to the writer, 'f' is a variable and could not and should not form a basis of design as its value is different for any conceivable different discharge and different slopes."

What the author has apparently completely overlooked is that $N_a=0{\cdot}0225\ f^{\frac{1}{4}}$; that is to say, in order to compare errors in N_a with those in 'f', the errors in Na should be raised to the 4th power. The speaker recommends to Mr. Ishar Das to do this and he will then find that he has to change his ideas.

Finally, on page 280, the author says:

"Lacey and his followers fix up the values of 'f' arbitrarily."

If by "arbitrarily" he means "after studying experience on other similar channels and taking into account all factors likely to affect conditions," then this is so. Obviously, this is a much wiser policy than ignoring the silt factor.

One speaker has testified to the practical success of the author in remodelling existing channels. This proves yet again that formulæ like River Models, are merely an aid to Engineering experience and skill which they can in no way replace.

Mr. M. D. Mithal said that he had gone through the manuscript of the paper in 1936, when the author was his S. D. O. and had suggested to him to condense it. He wanted to point out that the staking and bushing on Subraon Branch, mentioned by Ch. Ali Mohammed was not based on the theories of L. Ishar Dass, but was placed to keep the bed width arrived at by keeping Lacey's f=1. If this bushing has resulted in development of good berms; it strengthened Lacey's theory and exploded the author's argument. The work of berm cutting and trimming, also mentioned by Ch. Ali Mohammed, was started under orders of the speaker by the author's predecessor and the author was not helpful in its execution which had to be seen to personally by the speaker.

Mr. Gita Ram Garg, said that he had gone through the paper and the thing which struck him most was the admirable use author had made of Lacey's perimeter equation $P=2\cdot67\sqrt{Q}$. This equation though derived emperically conforms to a fundamental law of hydraulics and is thus of a very great practical utility. The constant used therein is however not absolute, being based on averages and will depend upon the silt and rugosity conditions. The speaker inclined to agree that the limits proposed by the author, *viz.* 2·5 and 2·8 practically cover all the conditions prevailing in the Punjab.

The Kennedy's diagram, which give this easiest and the most practical method of design of channels do present some difficulty in the actual selections of bed width and depth and the superimpositions of the perimeter curves has now rendered the selections very easy. Here in the speaker's opinion lay the usefulness of the author's paper. It is indeed very interesting and the revised diagrams will undoubtedly prove very useful and should be adopted by the Department.

As the coefficient in these perimeter curves take full account of the rugosity and silt conditions generally met with in the Punjab, one need no longer bother about Lacey's silt factor or Kennedy's V in the design of the channels.

As regards the author's formula, the speaker appreciates the great pains taken by the author in deriving a mass of formulæ for different rugosity conditions, but to be frank the speaker was not convinced of the accuracy. It is stated that these have been derived by plotting and correlations, and the speaker thought it better if correlation coefficients had been given.

As regarding the slide rule, it is a commendable achievement but based as it is on Shanta Slope formula, the accuracy of which is doubtful, it cannot be of any practical use.

Mr. Gerald Lacey said, that it is suggested by the author that there are many different ideas and diverse opinions on the subject of silt transport and that the time has come when new formulæ should be evolved for the design of regime sections to canals and for the allocation of the correct regime slope. There are as a fact only two theories of design of regime canals which are now accepted by informed opinion in India, the Lacey theory and what may be termed briefly the Punjab theory. It is true that, such is the inertia of conservatism, the unmformed rank and file of canal engineers will continue to employ the useful approximate solutions of Kennedy until authority, recognizing recent advances, orders the discontinuation of the use of Kennedy's diagrams. This step has already been taken in the United Provinces.

It is necessary first to recognize those respects in which the Lacey and the Punjab theories agree. First, and foremost, the Punjab and the Lacey theories agree that the regime wetted perimeter is given by the equation $P=K\ Q^{\frac{1}{2}}$. This correlation is exceedingly high. It has not been found possible to improve the correlation by introducing either the silt factor or the diameter of the bed silt particle as a variable. It is suggested by Mr. Ishar Dass, as others have suggested before him, that the coefficient might vary from 2·2 to 3·2 depending on the "rugosity" of channels and the "material" of the silt load. For this suggestion there is as yet no statistical warrant. The mention by Mr. Ishar Dass of "rugosity" and "bed material" as independent regime variables should be noted.

The second, and very important agreement, is that between the Lacey and Punjab slope equations. The theory of exaggeration in the vertical scale is deeply involved when attempts are made to evaluate the regime slope in terms of the discharge and the bed silt grade. It is unfortunate that Mr. Ishar Dass has not studied the implications of Professor Reynolds classic pronouncement on this subject:

> "Notwithstanding the general resemblance on the *regime* of the beds of large and small streams running over sand, there is in these a similar difference in vertical scale, the smaller streams not only having a *greater slope* but also having greater depth as compared with their breadth."

The speaker considered the two implications in this statement. The first is that for a given grade of bed material, the competent or regime slope will steadily increase with reduction in the discharge. It follows also as a corollary that for a given discharge the competent or regime slope is a direct function of the size of the bed material, since the rugosity is a function of the bed material. From the first to last the Lacey "silt factor" was always defined as characterising the bed silt grade. In the preface to the Lacey regime diagrams it was specifically stated that they determined for a channel of given *discharge and silt grade* its regime dimensions and *slope*. The Punjab equation goes further since the bed silt grade was actually measured. The second implication of Professor Osborne Reynolds' statement is that for constant silt grade the ratio of the bed-width to depth, or more accurately that of the wetted perimeter to the hydraulic mean depth, steadily diminishes with reduction in the discharge.

The Lacey slope equation in terms of S*, slope per thousand, published in 1930 was

$$S^* = f^{5/3} / 1{\cdot}79\, Q^{1/6}$$

The Bose equation published later after exhaustive research is

$$S^* = 2{\cdot}09\, m^{\cdot 86} / Q^{\cdot 21}$$

It is folly to lay undue stress on the slight differences in these two expressions and to ignore the basic principles, first enunciated by Osborne Reynolds underlying both. More accurate data may lead to modified equations but the basic principles will remain for all time.

The second implication of Professor Osborne Reynolds' statement is borne out by the wetted perimeter and discharge relationship which can be rewritten

$$\frac{P}{R} = K^2 V.$$

This equation in terms of the Lacey 1930 theory reduces to

$$\frac{P}{R} = 5{\cdot}70\ Q^{1/6}\ f^{1/3}$$

and in terms of the Punjab equations to

$$\frac{P}{R} = 6{\cdot}0\ Q^{1/6}$$

It is well to dwell on resemblances first and this procedure will be followed. It is clear that Reynolds' contention that in channels *of the same sand* the ratio of the wetted perimeter to the hydraulic mean depth steadily diminishes with reduction in discharge, that is to say with reduction in scale, has been abundantly confirmed both by the Lacey data and the Punjab data. The difference in the two equations should also be noted, and it is the *only* basic difference between the Lacey general theory, intended to be applied to great variations in the grade of bed material, and the Punjab theory which dealt with canals and variations in silt grade of approximately from 0·20 mm. to 0·40 mm.

According to the Lacey theory the shape, P/R, for a given discharge, is a function of the silt grade, the channel in finer material being narrower and deeper. According to the Punjab theory it has not proved possible, on a statistical analysis of canal data, to include the silt grade as a variable.

According to either theory, from a given grade of silt and discharge, the regime slope can immediately be computed from equations which are basically similar. The wetted perimeter is computed by means of an established equation, which effectively presents the designer with a slope and also a discharge per foot run, or ' q '.

In terms of the Punjab theory the values of V and R are uniquely determined for a given value of ' q ' irrespective of bed silt grade. In terms of the Lacey theory the values of V and R to be adopted are functions of the silt grade, the fine silt demanding a greater hydraulic mean depth and being assigned a reduced velocity.

In the Lacey theory, in terms of laboratory practice, the introduction of coarser material into a flume operating with constant discharge will necessitate, not only a tilting of the flume, but also a reduction in depth and increase in velocity. In terms of the Punjab theory the introduction of the coarser silt will involve tilting, but with the tilting of the flume the cross-section will remain unimpaired and will tilt *with* the flume.

This in the plainest terms is an accurate and faithful summary of the Lacey and Punjab theories. There is thus one, and only one basic difference, not of great importance when the silt grade does not vary within wide limits, but of the greatest scientific interest and importance in all model work. It is important to note that in the Punjab tilted flume the mean velocity should remain unchanged but the velocity distribution should alter with the silt grade and this line of investigation should prove fruitful.

There is clear evidence recently presented to the Congress that "shock" is a new variable which must be considered, that the basic agreement between the Lacey and Punjab theories is high, and that the sole basic difference will find its solution in the laboratory and/or by means of controlled experiments in the field. What is abundantly plain is no regime equations with a scientific backing can be derived from dissertations such as that of Mr. Ishar Dass?

Those who are interested in the subject are earnestly desired to study it first-hand rather than to accept either the Lacey theory, or the Punjab theory at Mr. Ishar Dass' valuation. It is indeed gratifying to read that Mr. Ishar Dass does not deny the great worth of the Lacey or Punjab slope formulæ "in their proper perspective" but it is open to discussion whether Mr. Ishar Dass is competent to paint the perspective to which he refers. The basic differences in modern thories are thus not as great as Mr. Ishar Das asserts, and in his inaccurate presentation of the Lacey and Punjab theories, he creates an element of doubt.

A careful study of the Punjab slope equation, and that of Lacey shows clearly that for a given grade of silt the regime slope *required* will increase with reduction in discharge. If a main canal terminates in two branches the regime slope of the branches *must* be greater than the regim slope of the main canal. Similarly, if the slope throughout a canal system is kept constant the grade of silt appropriate to the small channels must be lower than that appropriate to the large channels. Mr. Ishar Dass, however, complains endlessly that the silt factor will be different for different discharges and for different slopes. The objection appears to arise from sheer lack of appreciation of a physical phenomenon which cannot be avoided.

Among many other equally fallacious complaints against the silt factor Mr. Ishar Dass asserts that it has not been shown that the silt factor is independent of the data of the section of the channel nor of any proposed discharge. The regime silt factor represents silt grade. If for a given silt grade and silt factor the necessary regime slope is *not* available the channel will silt, and must silt unless we can find means to exclude the heavier grades. On any non-regime channel with defective slopes the *computed* silt factor, as determined from the available slope and dimensions, tells us merely the grade appropriate to the *available* slope. This computed silt factor must not be confused with the silt factor which the grade of silt admitted to the channel demands. The *computed* silt factor merely tells us how far we have failed or succeeded in our object.

It is stated by Mr. Ishar Dass over and over again that Lacey and his followers "fix up the silt factor arbitrarily" and then proceed to design the channel. For this grossly incorrect statement there is no warrant. He also asserts that under advice from Lacey higher values of the silt factor are fixed in the upper reaches "arbitrarily". Such values obviously are fixed with reference to the grade of silt admitted, and on the assumption that as much of the coarser silt is excluded as is possible. The principle is as follows: The regime slope is determined from the grade of silt admitted. If the regime slope is less than the slope available falls as necessary are interpolated. If the available slope is insufficient attempts at reducing the grade of silt must be made by improved regulation in the case of a canal head, and in the case of a distributary by improving the head, many of which draw more than their fair share of coarser silt. The subject is dealt with in Regime Diagrams.

When the original part of Mr. Ishar Dass' paper is examined it may be divided into two parts. The first the procedure to be adopted when sufficient slope *is* available, and the second what should be done when sufficient slope is *not* available.

When sufficient slope is available Mr. Ishar Dass' method is fairly simple. He considers the Kutter equation as fundamentally correct and employs the Manning equation as a useful exponential substitute. He then effectively equates the Manning equation with the wetted perimeter equation which he accepts and produces the equation

$$S^{*}=63.70\ N^{2}\ Q/R^{10/3}$$

He assumes that a value of N of .0225 is "safe" for Punjab canals (this involves the assumption that a silt factor of unity is "safe" also) and produces the "thumb rule" for slope

$$S^{*}=1/1.8\ Q^{\frac{1}{6}}$$

This is none other than the Lacey slope equation with the silt factor treated as unity.

Alternatively he uses another thumb rule

$$S^{*}=1/2{\cdot}6\ R^{\frac{1}{2}}=0{\cdot}385/R^{\frac{1}{2}}$$

and this also is none other than the Lacey equation

$$S^{*}=0.383\ f^{3/2}/R^{\frac{1}{2}}$$

with a silt factor of unity.

Thus Mr. Ishar Dass assumes for safety's sake that the silt factor is unity and uses the Lacey 1930 equations and the Manning equation which is tolerably accurate. There is then no great objection to this procedure but it is not original. Having established his "thumb rules" for practical design, Mr. Ishar Dass proceeds to equate nearly all the formulæ extant and produces for "guidance" his Statement No. 6. The component parts of the jig-saw puzzle are thus jumbled together and left to the contemplation of the earnest enquirer.

It will be observed that in the statement the silt factor has disappeared, the size of the silt particle has vanished and one is left to contemplate a variable value of 'N' instead. This is of little assistance and if Mr. Ishar Dass does not assign 'N' arbitrarily he should state how he does assign it. To say that a value of N of .0225 is "safe" is merely to say that a silt factor of unity is safe. Effectively Mr. Ishar Dass can assign 'N' only by measuring V, R and S and relying on computation. The value of the silt factor is determined by identical means. One is left to suspect that by long usage the values of Kutter's N are regarded by Mr. Ishar Dass as justifiably vague.

The paper shows that Mr. Ishar Dass is fully aware that despite all his ingenuity the practical engineer may sometimes be "stumped" by the fact that the available ground slopes will lead to silting. Thus he recognizes that the designer "may be handicapped by the slopes available." He also states that it may sometimes be "*unavoidable* to adopt slopes other than those given by the Lacey and Punjab equations which for a particular discharge and *particular grade of silt* give only one slope and no other." Now excess slope can always be avoided by building falls so clearly Mr. Ishar Dass had in mind insufficient slope, and inevitable silting. Mr. Ishar Dass suggests that under these *non-regime* conditions the Shanta equation provides a guide and some kind of escape or emergency exit. The method is peculiar, and one is assured by Mr. Ishar Dass that this equation provides better means of adjustment than any other.

The Shanta equation is as follows:

$$S^*=63.70\ N^2Q/R^{10/3}$$

The value of Q is fixed for a given problem and the "safe" value of N is equal to .0225. The value of R, from the thumb rule, is fixed also, which leaves Mr. Ishar Dass with a computed value for the slope. This is to be assumed as much greater than the available slope. What then does Mr. Ishar Dass do? He enhances the value of R so that the computed slope may be equal to the available slope. The value of the wetted perimeter he computes from the Lacey equation involved in deriving the Shanta equation. The value of (RV) is thus a constant, and if Mr. Ishar Dass finds that the slope is defective, and that the channel will silt, he deliberately increases the value of R and correspondingly reduces the value of the velocity. Thus the defective critical velocity ratio of his channel will be deliberately reduced still further.

It is obvious to any practical engineer that such a channel with such a reduced velocity would soon silt out of existence, and that Mr. Ishar Dass' equation, designed for flexibility and slope adjustment must be rejected as fundamentally unsound for regime channels transporting silt.

As the Shanta equation is intended mainly to cope with conditions when insufficient slope is available, and Mr. Ishar Dass relies on increased depths and reduced velocities to transport his silt for him, the only strictly original equation which he puts forward appears far from "safe" to employ.

It is a curious comment on Mr. Ishar Dass' methods that when he desires to produce an equation of his own he equates the Lacey critical velocity equation with that of Manning, and that when he wishes to find a stick with which to belabour the silt factor he equates the Lacey critical velocity equation with the fundamental (*sic*) equation of Chezy, $V=C\sqrt{RS}$. He should also have known that the Lacey critical velocity ratio $f^{\frac{1}{2}}$ replaces that of Kennedy's which is only approximately equal to it over a very limited range.

The dissertation of Mr. Ishar Dass on energy of flow is borrowed from elementary textbooks and makes the mistake of ignoring velocity distribution and boundary conditions. We may rest assured that if as Mr. Ishar Dass asserts, the Kutter equation is correct, and universally accepted, that the Chezy equation as Chezy wrote it does not apply to canal systems. It is unfortunate that so many practical engineers, who eschew the Chezy equation in practice, and use any other equation instead, are so prone to revert to Chezy when puzzled by first principles. A study of the work of von Karman, Nikuradse and Prandtl may serve to convince them that they would be well advised to leave the subject to more scientific workers in this field. A careful study of Mr. Ishar Dass' interesting paper leads to the conclusion that although it may prove valuable in provoking discussion it is a faithful record of faulty mental processes rather than a contribution to modern hydraulic science.

The AUTHOR in replying thanked all for the valuable criticism made and said that he proposed to reply first to individual speakers and then sum up the discussion.

The author thanked Mr. Montagu for his learned discourse which he said lacked in facts and figures. It would have been more useful if Mr. Montagu had explained or illustrated as to how he found the author's results false or useless. Mr. Montagu had agreed with the views of the author that the silt excluding and ejecting devices are essential on our canals. The author endorsed Mr. Montagu's remarks that the very channel which Kennedy declared to be in regime was to-day appreciably wider and shallower. The reason is that much coarser silt is now passing these sites than in Mr. Kennedy's time.

Mr. Montagu's enunciation of 'f' is illuminating. The author pointed out that he believed that the misnamed silt factor 'f' is a variable and not a constant. The author had tabulated values of 'f' from Lacey's diagrams and found that these go up as discharge goes up or slope steepens. Mr. Lacey had stated on page 34 of C.B.I. Publication No. 20 that silt factor varies as square root of silt grade. The author like Mr. Inglis had found out that M varies as $Q^{1/10}$ or 'f' varies as Q^{n}. Reference Mr. Montagu's statement that examination of diagrams appended to the paper has failed to disclose any new way of relating the shape of the channel to silt burden, the author said that for coarse silt equation $P=2.8\ Q^{\frac{1}{2}}$ and for fine silt equation $P=2.5\ Q^{\frac{1}{2}}$ should be used.

The author said that he understood Mr. Lacey's theories and had pointed out flaws in these. Mr. Montagu has stated that slope of the channel is determined by the discharge and the silt factor, the shape of the channel having no bearing on slope. The Lacey slope formula is $S=\frac{f^{5/3}}{1844\ Q}$. The author had presented other forms of slope formula involving S/Q/R relationships and advocated that for flow in canals, streams or rivers the fundamental laws are these :

$$V=C_1\ R^{\frac{1}{2}},\ P=C_2\ Q^{\frac{1}{2}} \text{ and } R=C_3\ Q^{\frac{1}{3}}$$

Mr. Lacey evolved certain formulæ by plotting varied data of existing channels, regime or non-regime streams and rivers, and it was not sound to give the coefficients obtained by method of plotting and argumentative analysis, the sanctity of law as was done by Mr. Montagu. Mr. Montagu had stated that if the formula $P=C_2\ Q^{\frac{1}{2}}$ has any fundamental value, the constant must be rigid. The author does not believe in the rigidity of the constant and had proposed zone of selection with curves $P=2{\cdot}5\ Q^{\frac{1}{2}}$ to $P=2{\cdot}8\ Q^{\frac{1}{2}}$ in his proposed Kennedy's diagrams. The author pointed out to Mr. Montagu to enquire the cause of variation of the coefficient in P : Q relationship to 3 times its value in the Mississipi River and he will be satisfied with the author's solution.

Mr. Montagu had condemned the Punjab Research Institute formula from theoretical considerations and the author agreed that these formulæ cannot possibly be the general formulæ and it is dangerous to use these for all cases in the Punjab.

Mr. Montagu has praised immensely the Lacey formula :

$$V=\frac{1.3458\ R^{\frac{3}{4}}}{Na}\ S^{\frac{1}{2}}$$

The author worked value of Na for Mississipi data published on page 65, Vol. 24 of C. B. I. The value of item 7 is ·029 and others near about. Referring to page 35 of C. B. I. Publication No. 20, against Na=0.029 value of m and f by Lacey is given 2.42 and 2.75.

Actual value of observed m is .41 and calculated f =.925 and .462 differently from two formulæ of Lacey.

Mr. Montagu is requested to revise his opinion or contradict the above statement.

The author said that on page 281 of Mr. Lacey's original paper No. 4736 before the Institute of Civil Engineers it has been stated that there must be a direct relationship between the silt factor and Kutter's N and by plotting very approximate values of N against f had been obtained the empirical formula $N = .022 f^{\cdot 2}$. This shows on what basis Lacey's theory is formed to which Mr. Montagu attaches sanctity of Natural Law.

The author said that Mr. Montagu does not bring in any facts and figures in support of accepting Lacey's theory which does not take into account the shape or section of the channel but determines slope from discharge and silt alone. Mr. Montagu appreciates the difficulty in estimating accurately the value of 'f' in a new channel. The author said that process of "guessing" should be avoided as far as possible and suggested to Mr. Montagu the use of his new formulæ based on analysis and conceptions in the paper.

Mr. Montagu has objected to author's equating Manning formula with Lacey's. The author enquired if he had objected to Mr. Lacey using Manning's formula for arriving at his slope formula. The author said that Mr. Montagu's criticism had not moved him from the position taken by him.

In reply to Mr. Khanna the author said that he will find enough in his replies to the criticism of others which amply covers Mr. Khanna's remarks.

Replying to Dr. J. K. Malhotra, the author said it is encouraging to find that Dr. Malhotra regards the author's range of variation for $P = 2.5\, Q^{\frac{1}{2}}$ to $P = 2.8\, Q^{\frac{1}{2}}$ as fairly put. His endorsement of the author's opinion on page 280 regarding change in 'f' on a system is also valuable and should be noted by designers of Haveli Project who fixed arbitrarily one value for the whole system. Dr. Malhotra has also agreed that the coefficients in the Institute formulæ referred to in Chapter VI should not be considered as general to be applied for all cases to be met with in the Punjab.

As regards Dr. Malhotra's remarks regarding relation (6) of page 253, it may be stated that the outcome of the combination are :

(*i*) $P = 2{\cdot}67\, Q^{\frac{1}{2}}$ which supports Lacey's formula and is accepted by the author.

(*ii*) A slope formula connecting S/Q/R which as a matter on fact came as a by-product and latter has found verification from other sources. As a result of this author's fundamental slope formula on the basis of his silt soil factor will be coming in due course.

As regards relationship $R = C_3\ Q^{\frac{1}{3}}$ what the author wanted to show by actual calculations was that for different coefficients in the perimeter equation value of C_3 was different. In his remarks introducing this paper the author showed its general form to be :

$$R = \frac{1}{(C_1\ C_2)^{\frac{2}{3}}} Q^{\frac{1}{3}} \qquad \left(\begin{array}{l} \text{when } C_1 = \dfrac{V}{R^{\frac{1}{2}}} \\ \qquad\ \ C_2 = \dfrac{P}{Q^{\frac{1}{2}}} \end{array} \right.$$

This formula fits in with the actual data admirably well.

As regards data for values of Kutter's N, it was to avoid the length of the paper that the author had not published it. Turning to Chapter XV Dr. Malhotra takes the two Lacey's formulæ for channels in perfect regime and proves :

$$S = \frac{1}{10^3 \quad 77{\cdot}67\ R^5}\ Q^{3/2}.$$ This is to replace one already arrived at by him and given on page 290 of this paper, *viz.*

$$S_{10} = \frac{Q^{3/2}}{80\ R^5}$$

The same S/Q/R relationship is now again proved from the two Lacey's formulæ for perfect regime channels.

With the concluding remarks of Dr. Malhotra the author does not agree. It is of course good to collect fresh data always, but the old data is as good as the fresh. What is required most is the fresh and unbiased mind to solve the unsolved problems with boldness and dash in realism.

The author informed Mr. Sawhney that he was Mr. Lindley's assistant and closely connected with the production of the slide rule which was based on Kennedy's diagrams and Wood's normal data gave B and D for a given Q/S/N/. The slide rule now produced takes hydraulic elements P and R for section for a given Q, S and coefficient of P and is based altogether on different formulæ given in the text.

Mr. Sawhney's Momentum MV^2 is covered in the author's premises in Chapter IV wherein he deals with energy theory of flow. Mr. Sawhney does not favour silt-excluding devices but the author informed him that the coarse sand not fit for crops has only been recommended for exclusion. Mr. Sawhney's view that bad regulation is the main source of trouble may be right to an extent but the author's considered opinion is that silt-excluding devices at Head have greatly helped in keeping out coarse silt.

The author thanked Ch. Ali Mohammed for bringing to the notice of the Congress, the successful results of the author's work in restricting waterway of S. Branch by bushing to widths given by $P=2.67Q^{\frac{1}{2}}$.

In reply to Mr. Gulhati, the author asked him to find fault with his slide rule and claimed that no one except Mr. Lindley has so, far tried to produce one. The author said that the reason for the size of the silt not being reduced *via* the canal is that the velocities in the U. J. C. are comparatively small. The author said that he was not aware of the exchange of grades of silt in muddy water mentioned by Mr. Gulhati. He thanked Mr. Gulhati for appreciating the improvement in the Kennedy's diagrams.

In reply to Mr. H. L. Wadhera, the author said that if the work in question had been done on proper alignment to define section of the channel, all that Mr. Wadhera had in view would have been achieved in addition to improving the hydraulics of the channel.

Replying to R. B. Kanwar Sain, the author said that his criticism was not based on a thorough reading of the paper. Referring to the example of the three different slopes of the channels, quoted by R. B. Kanwar Sain, the author said that in Chapter V, he has taken this very example of a channel of 1,000 cusecs and has stated that for one slope Lacey's diagrams give only one dimension design, but different conditions of rugosity need different sections even on the same slope.

The author said that in formula $S\,10^3 = \frac{65.8\,N^2Q}{R^{10/3}}$ on page 293, S depends not only on the discharge of the channel but also on N, the rugosity of the channel, which may comprise the roughness of its bed and sides and also intensity of silt load.

Replying to Mr. Inglis, the author thanked him for his kind appreciation of the Improved Kennedy's diagrams and expected that after a certificate from a high authority, like Mr. Inglis, they will be adopted by irrigation engineers. Regarding juggling with empirical formulæ, the author stated that Mr. Lacey had also by a similar process arrived at his equation $P=2.668\sqrt{Q}$, which in spite of the wide range of variation of coefficient from 2.0 to 3.2 had been applauded universally. Mr. Inglis has stated that the author has juggled with empirical formulæ so that clarification of the subject in earlier parts is stultified by the confusion towards the end. Thus in one formula S varies as $\frac{Q}{R^{10/3}}$ which means that larger the discharge, steeper the slope, which is the opposite of fact. The author said that this conclusion was wrong and and in support showed graphs for Shanta Slope formula.

The author was glad that Mr. Inglis had accepted author's explanation for variation of coefficient in Lacey's P Q equation but the author entirely disagreed with the explanation that C is 2.8 where there is shock and 2.5 where there is negative shock. Lacey had erred in accepting 2.668 as rigid value for C.

The author continued that he has proved that instead of one rugosity and N=.0225, by his method three different rugosities are represented by Kennedy's curves and coefficient is less than 2.67 in case of finer silts and higher up to 2.8 in case of coarser silts. The author's statement on page 271 postulates the implication of the Punjab Institute Research formula $R=.47\ Q^{\frac{1}{3}}$ from conditions of normal channels in the Punjab, from data of which it was derived. This is subject to influence of silt in changing R which changes co-efficient .47 correspondingly. The hydraulic radius slightly increases or decreases as the silt becomes finer or coarser. The author said that Lacey's formula $N\ a=.0225\ f^{\frac{1}{4}}$ does not hold true always. The author was in agreement with Mr. Inglis that formulæ, like river models, are an aid to engineering skill and it is for this aid that he has put the results of his study and experience before his fellow-engineers.

Replying to Mr. Mithal, the author said that Mr. Mithal had never seen the manuscript of this paper. The author said that bushing and staking was done by him on the basis of his Improved Kennedy's diagrams and not by keeping f=1 as pointed out by Mr. Mithal. The author said, it was finally found by Mr. Mithal that the author's staking and bushing was really effective in growing berms. Mr. Mithal had resorted to berm cutting indiscriminately without reference to the existing and required widths of channels.

The author thanked Mr. Garg for his valuable contribution to the subject. Mr. Garg has accepted the usefulness of the diagrams and has said that the coefficients in the perimeter curves take full account of varying rugosities. The author submitted to Mr. Garg that the slide rule was not based exclusively on Shanta slope formula but on S/Q/R relationship.

The author said that Mr. Blench had communicated to him that his views were sound, 'f' is purely a silt factor and individual channel owes its shape to size of silt on the bed and roughness of sides and that uniform 'f' could not be fixed for a whole canal for design.

In reply to Mr. Gerald Lacey the author said that according to Mr. Lacey there are only two schools of thought on the subject of silt transport, *viz.* those who agree with him and those who still continue to use the approximate solutions of Kennedy. The author said that Mr. Lacey has gone at length to show the agreements between his and the Punjab theory, and has shown that they agree, except for only one basic difference of not great importance. The author invited reference to page 65 of C. B. I. Publication No. 24 for year 1939-40 and said that values of slope worked out by Mr. Lacey's formulæ were 100 per cent. off.

In paragraph 14, Mr. Lacey has practically admitted that the value of 'f' is different for different discharges and different slopes though it may be due to physical phenomenon which cannot be avoided. The author said that his complaint has been this variation in value of 'f'. Mr. Lacey has taken exception to author's statement that value of silt factor 'f' is fixed arbitrarily. The author invited a reference to the Punjab Engineering Congress Paper No. 234 by Mr. S. L. Malhoutra, wherein the value of 'f' for all Haveli channels was reported to have been fixed arbitrarily as .8. The author said that the designed slopes on those channels had not attained. The author said that on the U. B. D. C. the slopes in the main line and branches were very steep, in the neighbourhood of 1/2,500 or even 1/2,000, against the designed slope of 1/6,666 or 1/5,719 and 'f' varied from 1.4 to 1.6, according to Lacey's diagrams which could not therefore be called regime slope diagrams.

The author said that S is connected to Q or R with varying co-efficients under different conditions on pages 284 and 285 for different values of N. For some values of N it tallies with Lacey's equation with f=1 but the fundamental form of the equation is in terms of S/Q/R in all the slope formulæ.

While commenting on Shanta's formula Mr. Lacey over-looked to appreciate the author's fundamental form, $R = C_3 Q^{\frac{1}{3}}$ or $R = \frac{1}{(C_1 C_2)^{\frac{2}{3}}} Q^{\frac{1}{3}}$. So in the formula $S = \frac{Q}{R^{10/3}}$ increase or decrease in R is to be governed by relationship $R = C Q^{\frac{1}{3}}$ which could not be lost sight of. According to Mr. Lacey slope is a function of silt grade and discharge only because $S = f^{5/3} / 1788 Q^{1/6}$ but the author held that slope is a function of Q and R, whereas R is a function of silt and soil and discharge. The author continued that Mr. Lacey does not recognize soil factor. In his scour formula rigid value of 2.67 for all soils is incorporated. So they both differed on fundamentals.

The author said that he has generalized his theory of "Flow of water on basis of silt soil factor." That theory will be shortly published and the author claimed the science of hydraulics has been advanced tremendously with the new orientation on the subject. A synopsis of the new theory based on author's silt soil factor is given in an appendix to this paper.

The author summed up the discussion briefly in the following lines:

(1) Improved Kennedy's Hydraulic Diagrams :

(*a*) These have highly been appreciated by Messrs. Inglis, Garg, Gulhati and others. Not a word has been said by any one against their accuracy.

(*b*) The author's new conception of rugosity in Kennedy's diagrams as distinct from Kennedy's had favourable comments from Messrs. Inglis, Garg and Blench. No one disagreed.

(*c*) Mr. Garg has admirably stated the case of the author in the following words :

The coefficient in these perimeter curves takes full account of the rugosity and silt conditions generally met with in the Punjab. One need no longer bother about Lacey's silt factor or Kennedy's V_0 in the design of the channels.

(2) Punjab Irrigation Research Institute Formula: Dr. J. K. Malhotra, one of the authors of these formulæ, has publicly stated that the objection raised by the author is correct. The author had uttered a note of caution against the general application of these formulæ and that has gracefully been accepted.

(3) The author's case for instituting silt-excluders and silt-ejectors at the head and with head reaches, and not allowing the silt to travel down into the lower reaches of a canal system has ably been supported and strengthened by Mr. Montagu.

(4) (*a*) The author has pointed out that it is a mistake to prescribe generally one value of 'f' for the whole system of a canal as was done in the case of Haveli Canals. This has been agreed to by Messrs. Lacey and Blench and also by Dr. Malhotra.

(*b*) Mr. Lacey has a rigid value of coefficient in his P : Q relationship, *viz.* 2.67, the author's proposal to have fixed the range to a useful zone $P=2.5\ Q^{\frac{1}{2}}$ to $P=2.8\ Q^{\frac{1}{2}}$ has been accepted by Mr. Inglis and others.

(*c*) The natural corollary to (*b*) is that coefficient in Lacey's scour formula will have to be changed because that is based on rigid value of 2.67 in the formula $P = 2.67\ Q^{\frac{1}{2}}$.

(5) In the above four points there has practically been no opposition. The entire opposition in fact centred about the author's Slope formula. The author has stated his case fully in reply to Messrs. Inglis, Montagu and Lacey and in support has attached a chart in reply to Mr. Inglis. Lacey's Slope formula $S = \dfrac{f^{5/3}}{1844\ Q^{\frac{1}{6}}}$ does not take into account the shape of the channels as a factor to determine slope whereas the author's equations for slope are in terms of S/Q/R relationships. The author has by method of correlation analysis found a correlation coefficient of .978 in an S/Q/R relationship and finds that shape of channel represented by R has influence on slope. The author is pursuing this case in his next paper. It is yet to be tested by Engineers what equations are more correct, Lacey's or author's.

APPENDIX A

Punjab Engineering Congress Paper No. 249

Theory of Flow of water on basis of Silt-Soil Factor.
Some Fundamental Formulæ and their application.

Synopsis.

1. Fundamental Equations are :—

(1) $V=C_1\sqrt{R}$

(2) $P=C_2\sqrt{Q}$

(3) $R=C_3Q^{\frac{1}{3}}$

2. From the above the following formulæ are deduced :

1. $C_1P=\dfrac{Q}{R^3/_2}$

2. $C_1C_2=\dfrac{Q^{\frac{1}{2}}}{R^3/_2}$

3. $C_3=\dfrac{1}{(C_1C_2)^{\frac{2}{3}}}$

4. $R=\dfrac{1 \quad Q^{\frac{1}{3}}}{(C_1C_2)^{\frac{2}{3}}}$

5. $V=\dfrac{C_1^{\frac{2}{3}} \quad Q^{\frac{1}{6}}}{C_2^{\frac{1}{3}}}$

6. $A=\dfrac{C_2^{\frac{1}{3}} \quad Q^5/_6}{C_1^{\frac{2}{3}}}$

3. The curves of $C_1C_2=\sqrt{\dfrac{Q}{R^3/_2}}$ and $P=C_2Q^{\frac{1}{2}}$ are plotted and it is on the graph that line of $C_1C_2=\dfrac{Q^{\frac{1}{2}}}{R^3/_2}$ is parallel to the line of $R=C_3Q^{\frac{1}{3}}$ $\therefore$ C_3 is in fact some value of C_1C_2.

The relationship is proved to be—

$$C_3=\frac{1}{(C_1C_2)^{\frac{2}{3}}}$$

From the form of the equation and layout of the curves interdependence of C_1, C_2 and C_3 is shown. The value of C_1 C_2 is in fact silt-soil factor which determines value of R. Hence the important scour formula is presented :

$$R = \frac{1 \cdot Q^{\frac{1}{3}}}{(C_1 C_2)^{\frac{2}{3}}}$$

Lacey's scour formula with rigidly fixed value of $C_2 = 2{\cdot}67$ for all soils, is traced from this general formula. Similarly, the Irrigation Research Institute has value of $C_1 = 1{\cdot}12$ and $C_2 = 2{\cdot}8$ and value of $C_3 = {\cdot}47$, is thus arrived at.

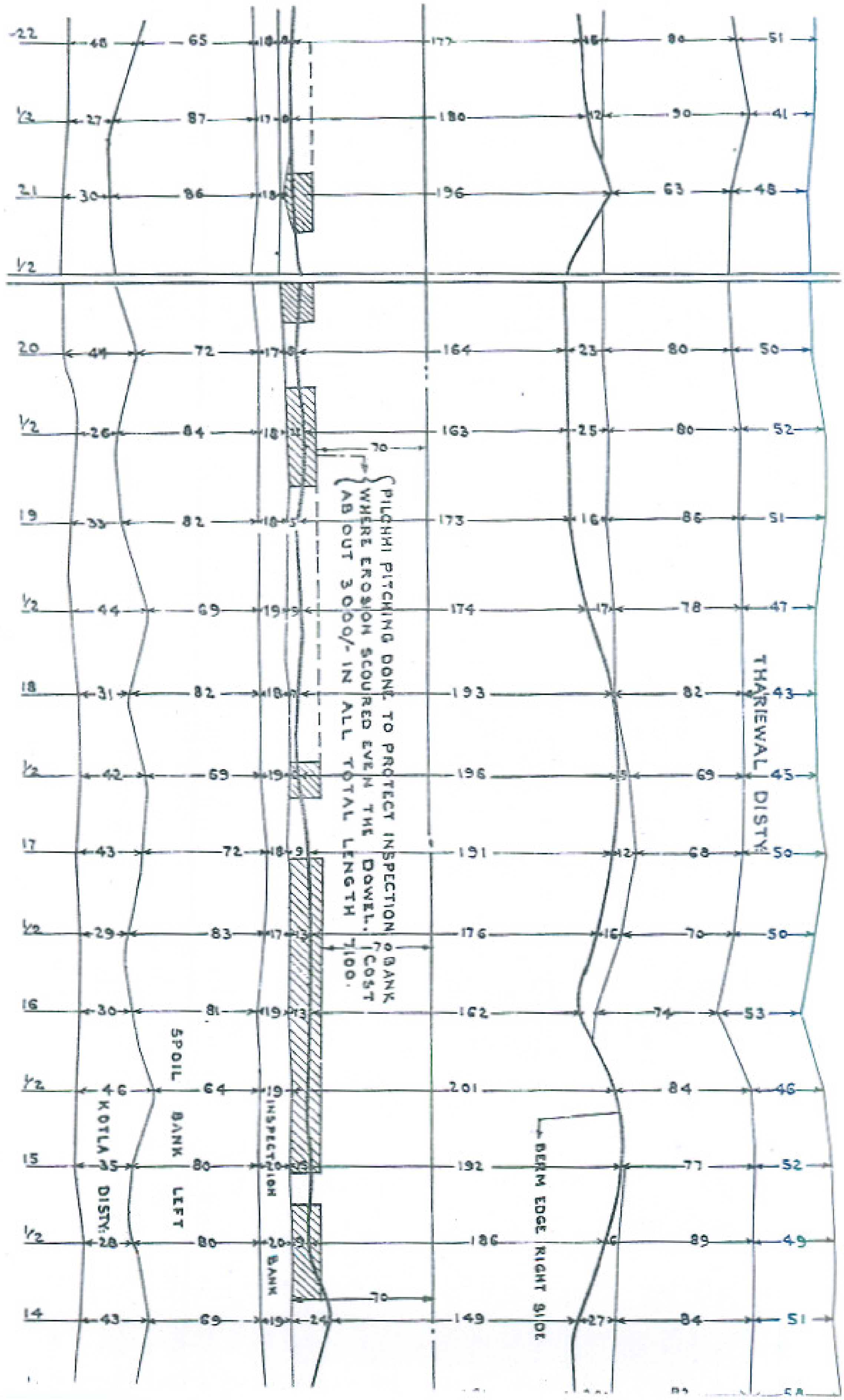
The scour formula now presented is claimed to be universal for all silt grades and soils.

4. Values of C_3, R, V and A are worked out from the published data of the Central Board of Irrigation and the Punjab Research Institute and compared values arrived at by the use of these formulae are found to be extremely accurate.

5. The author has not yet completed his statistical examination of the Slope formulae. The relationships between S the slope with other hydraulic elements Q R M, etc., are being tested. However, the author gives two of such relationships as under :

$$S_{10}{}^{3} = \frac{C_1{}^{3}}{4{\cdot}5} \frac{(C_1 C_2)^{\frac{1}{4}}}{Q^{\frac{1}{3}}}$$

$$S_{10}{}^{3} = \frac{(C_1 C_2)^{5/6}}{6 \quad Q^{1/9}}$$



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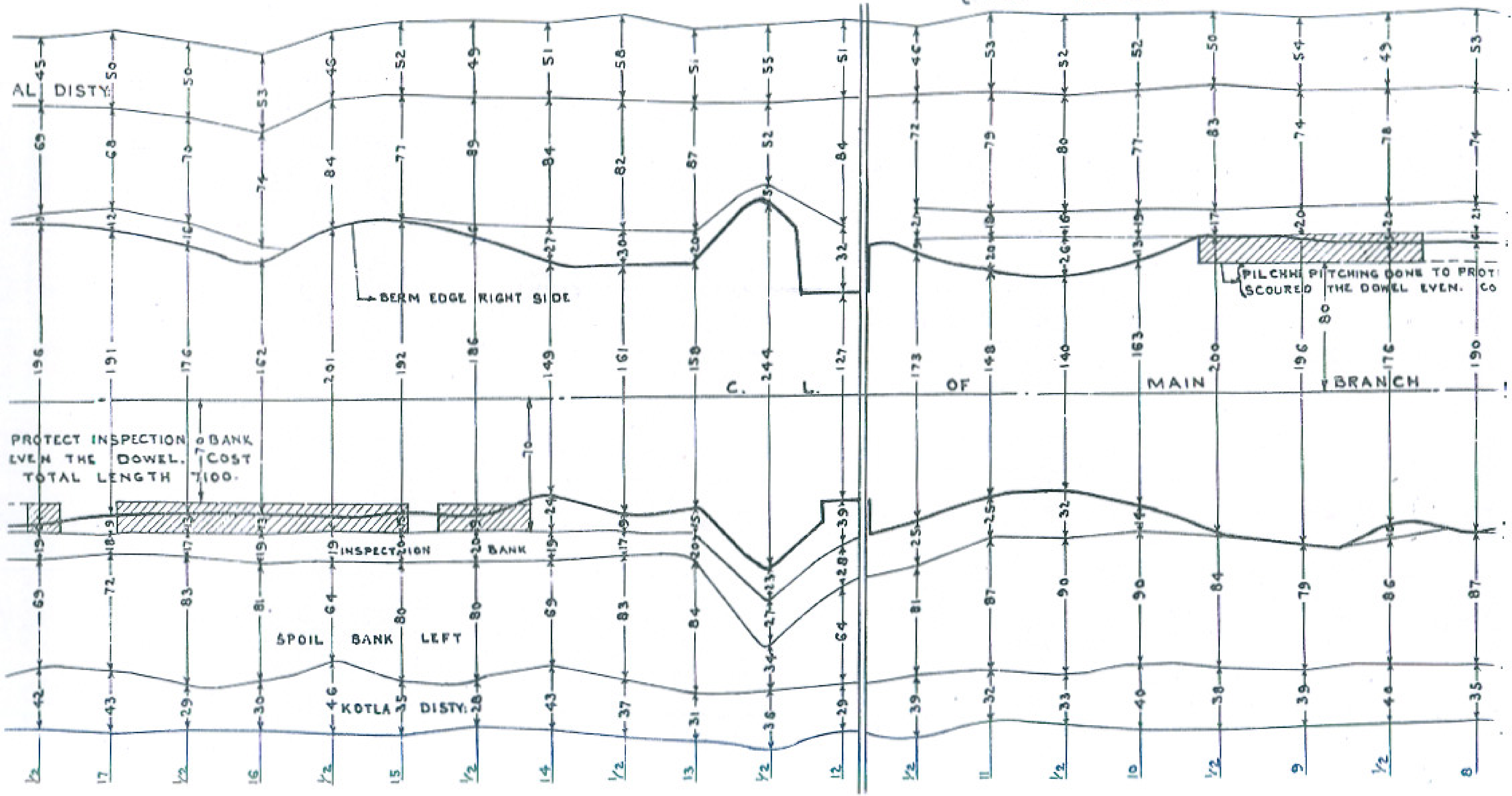

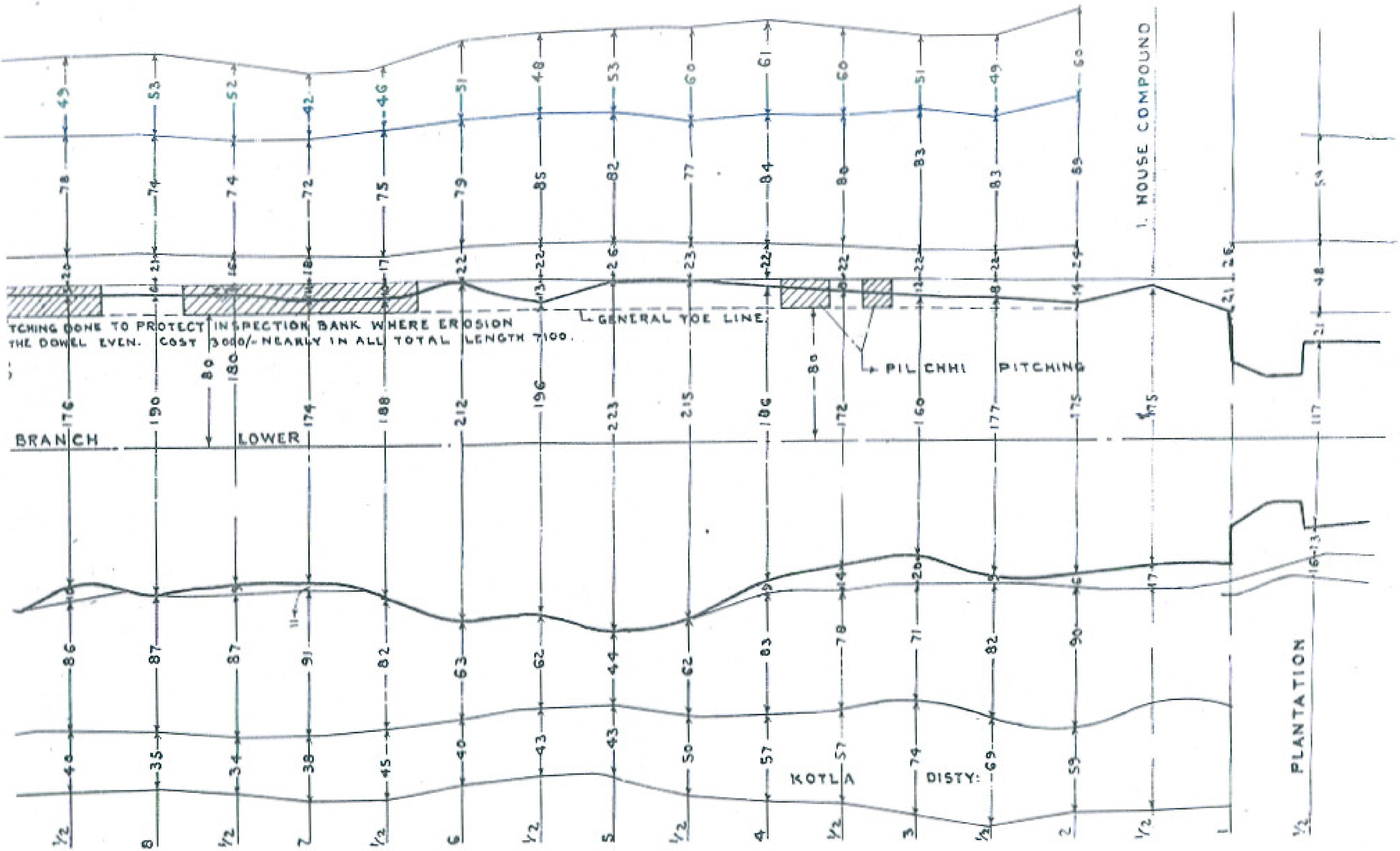
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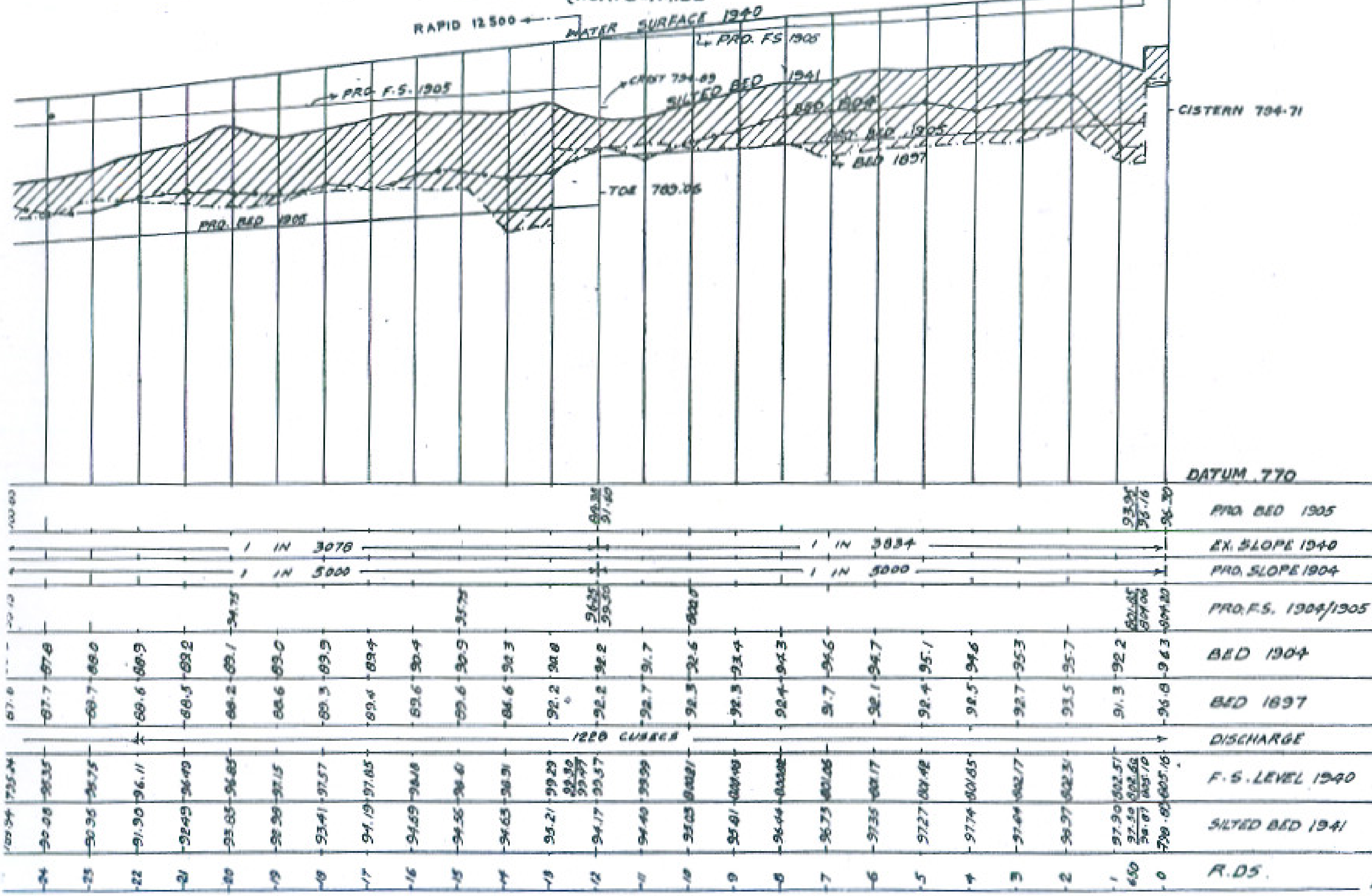

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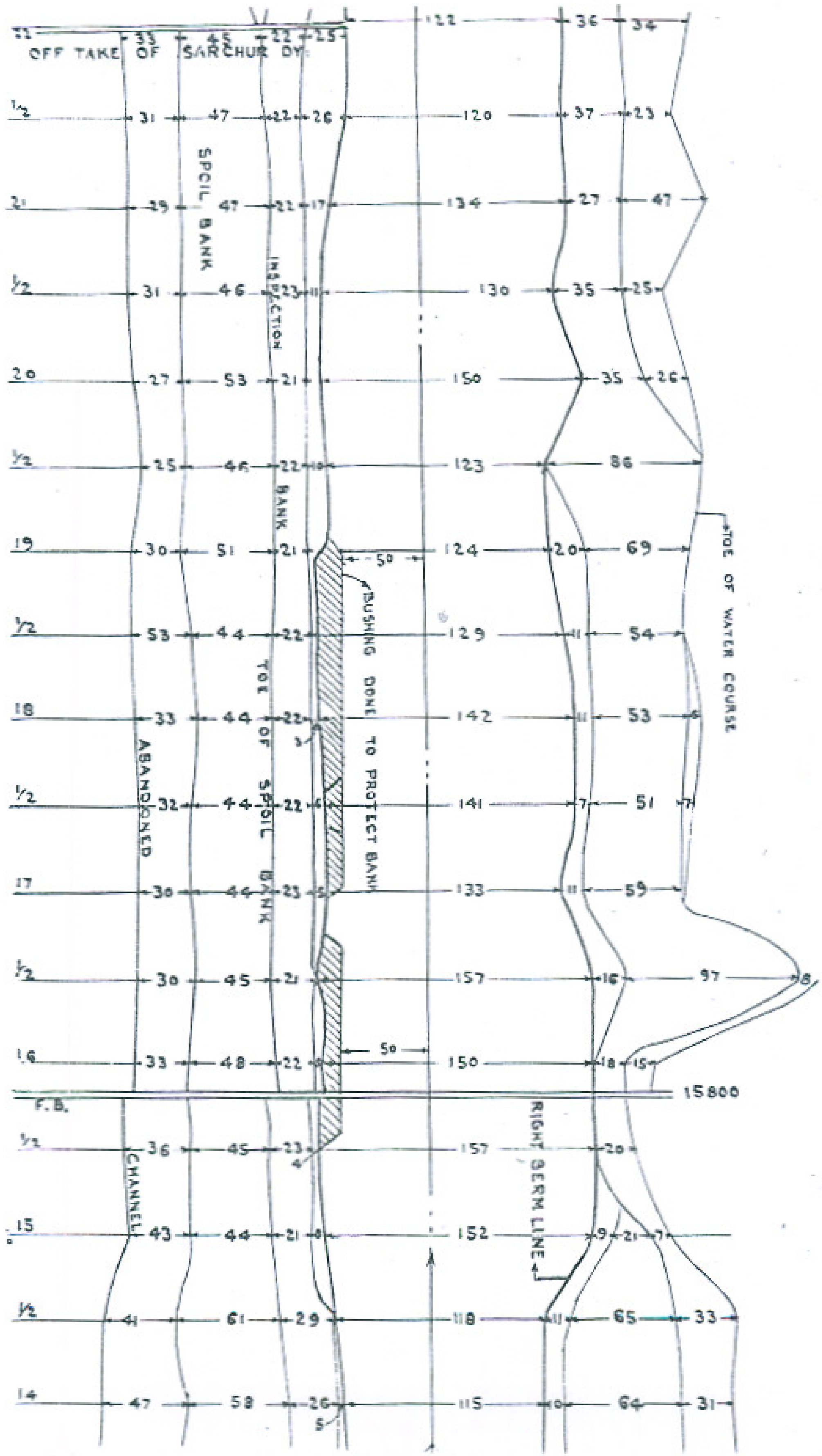
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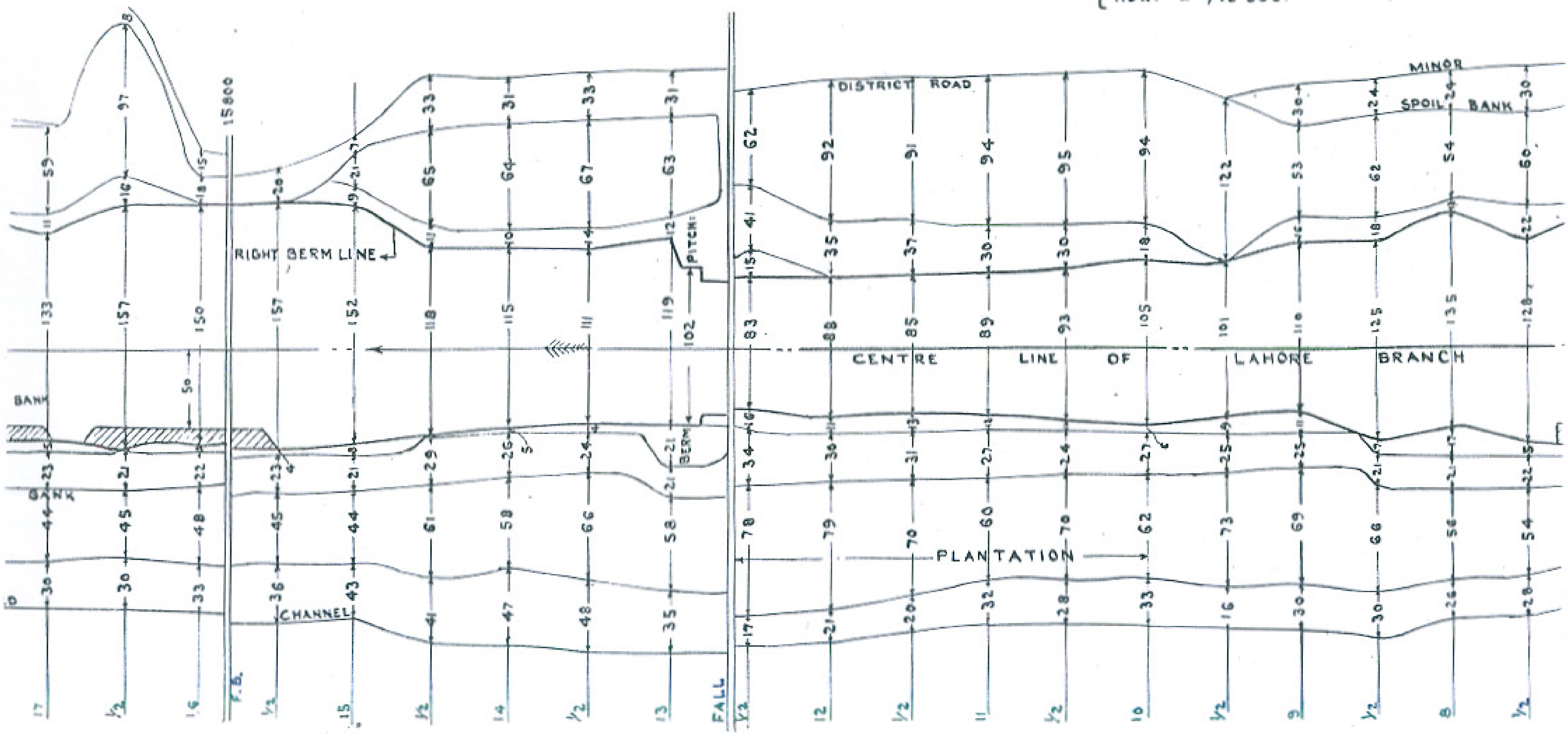

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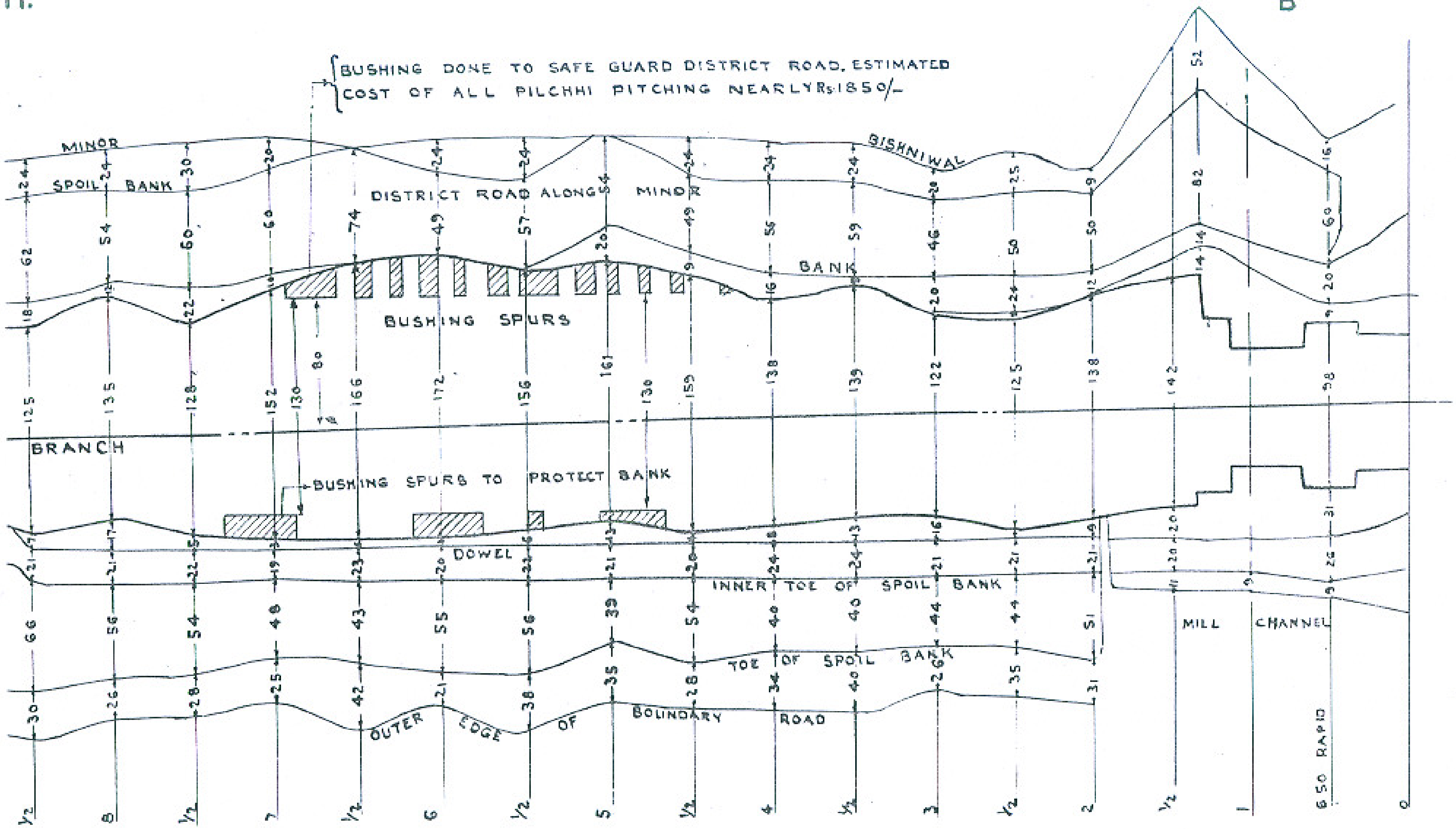

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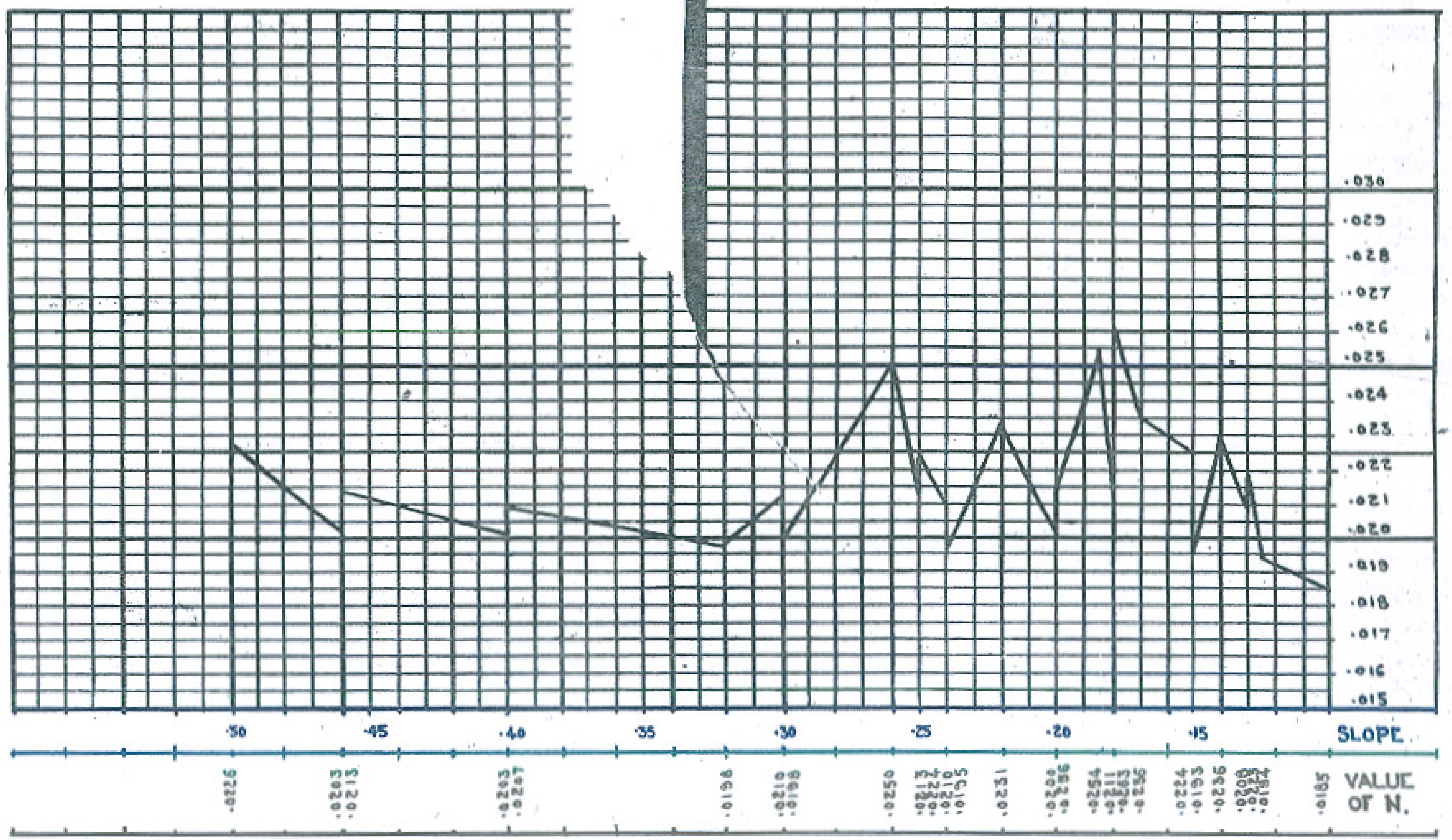

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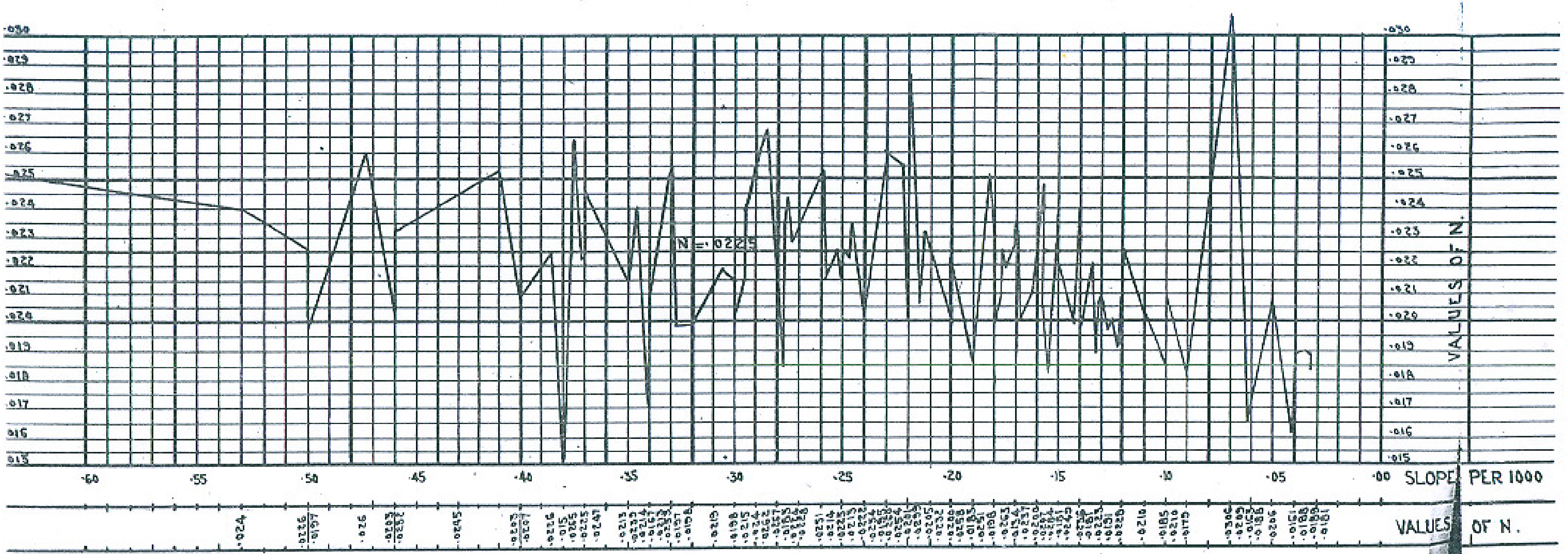

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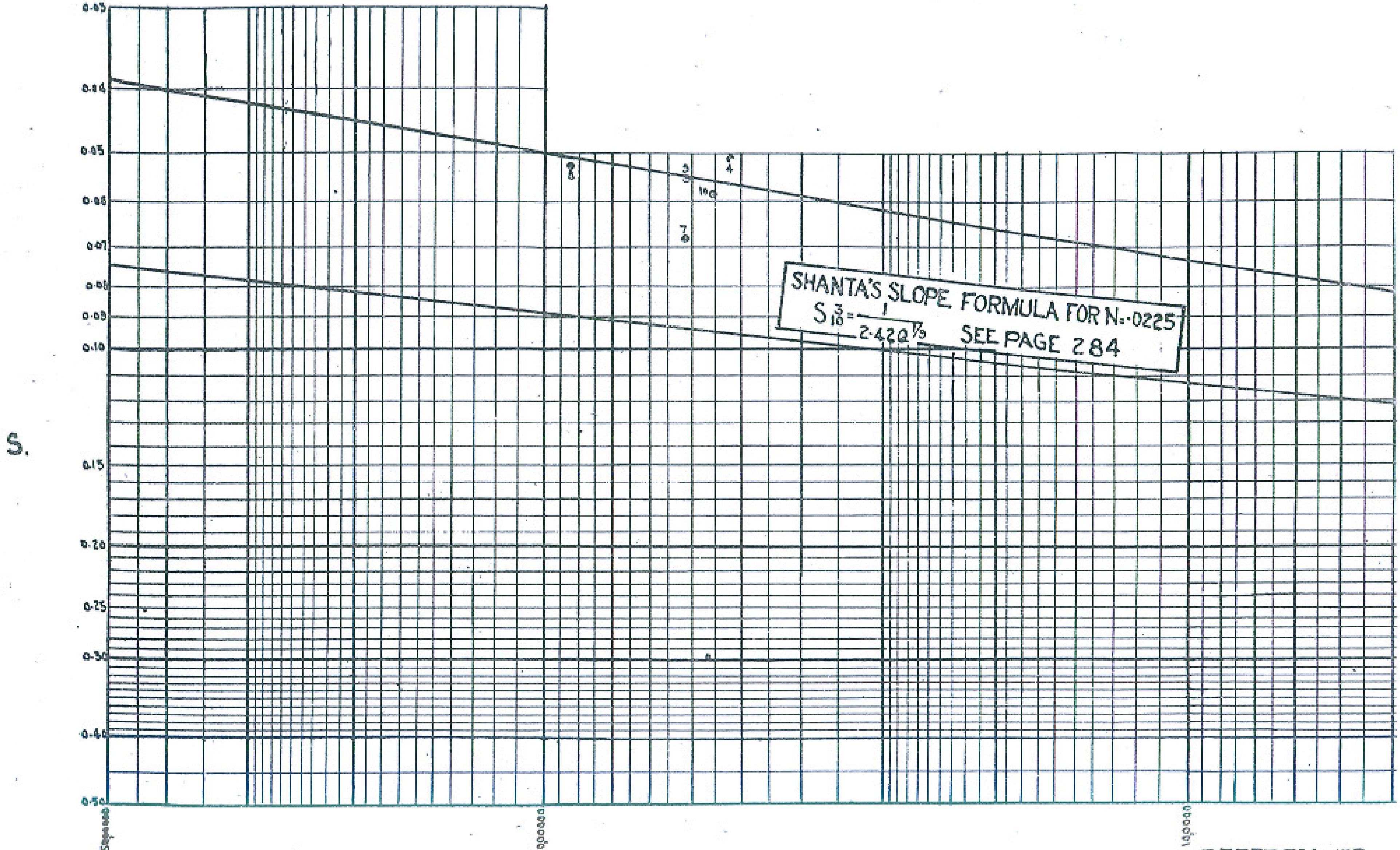

REFERENCES

TABLE SHOWING DISCHARGE ELEMENTS FOR PUNJAB CANALS ON PA

TABLE II DISCHARGE OBSERVATION IN THE MISSISSIPPI RIVER ON PA

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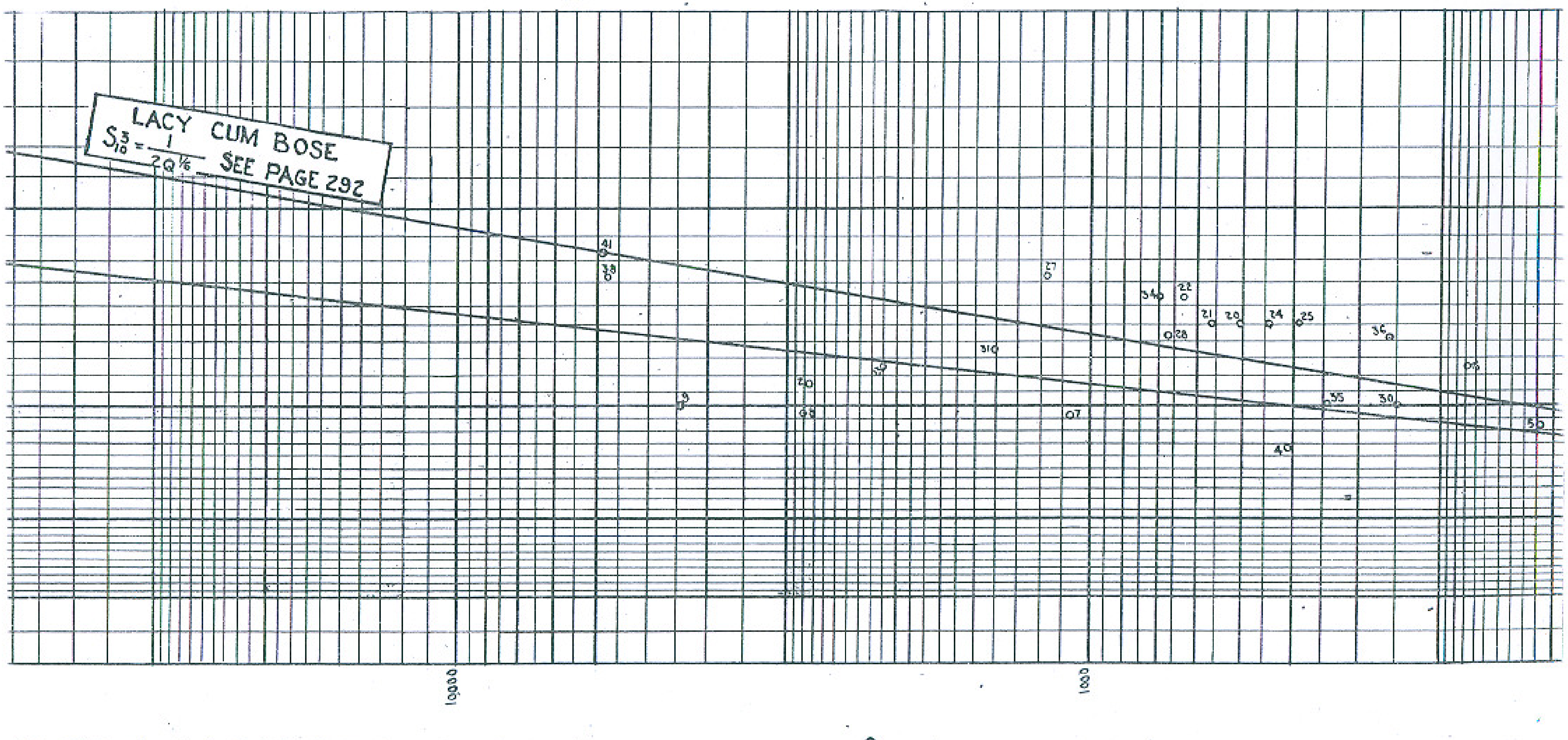
AUTHORS REPLY TO MR. INGLIS



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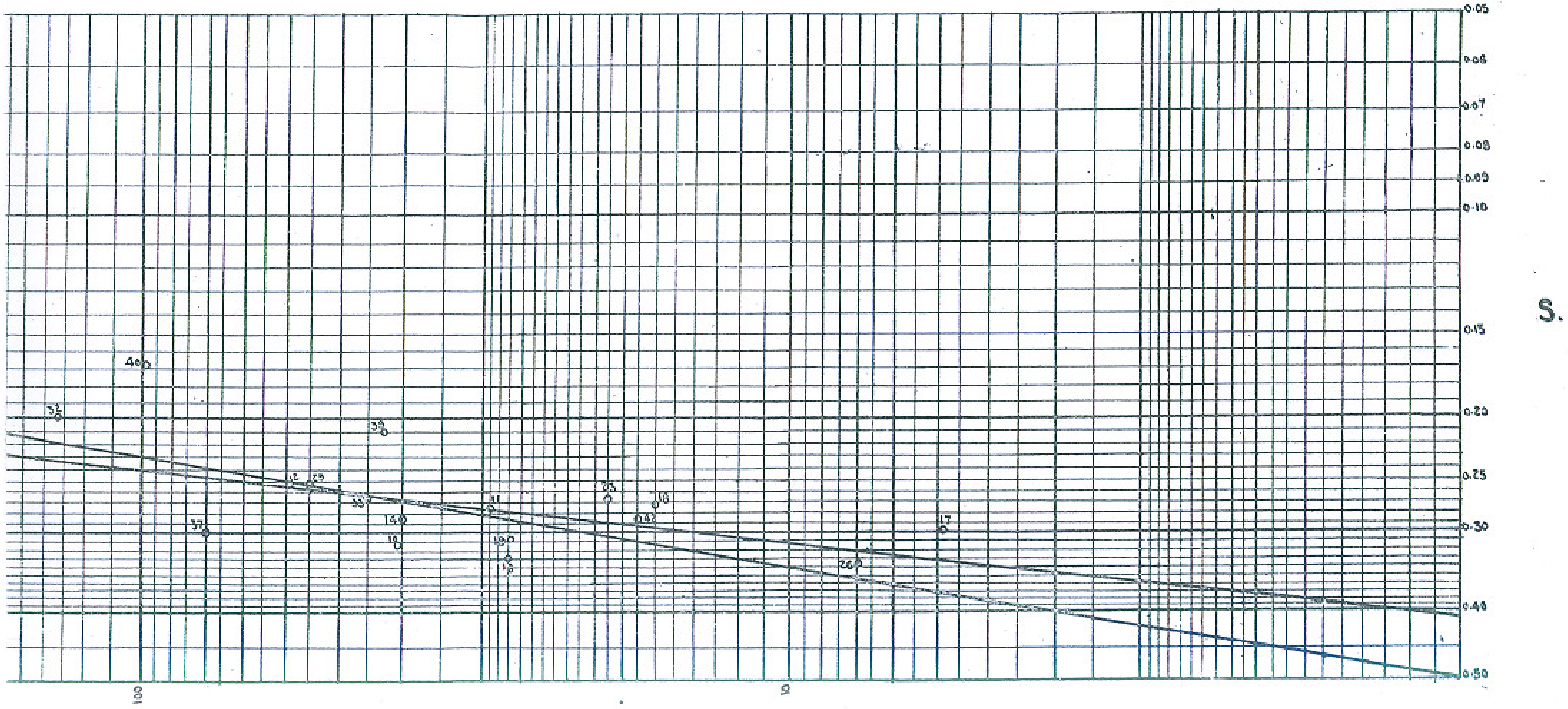

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