STUDY ON RIVER COURSE SHIFTING PATTERN IN BANGLADESH

A Thesis

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED BY MD. MONAYEM DAD ENTITLED STUDY ON RIVER COURSE SHIFTING PATTERN IN BANGLADESH BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ENGINEERING (WATER RESOURCES)

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ABSTRACT

An attempt has been made to study the shifting pattern of the reach of the Ganges from the point of its entry into Bangladesh upto Goalundo by analyzing the data available with the Bangladesh Water Development Board.

The Ganges is an irregular meandering river and the thalweg shifts continuously from one position to another within the bank lines. The shifting of thalweg is due to the movement of the sand bars, mid-channel islands and aggradation.

The shifting of bank lines is erratic and gradual and it is due to the frequent shifting of thalweg in different years.

The relationship between sinuosity and width-depth ratio, and sinuosity and bed slope indicate that the reaches of the river with low sinuosity (i.e. more or less straight) have wide and shallow cross-sections and steeper slopes.

It was observed that the thalweg sinuosities in the reach of the river under consideration were 1.19 and 1.15 in 1968 and 1969 respectively and its value reduced to 1.09 in 1976. The river is gradually becoming straight and developing braiding.

Analysis of the data also show that the river is gradually becoming flatter, wider, shallower and the braided pattern is emerging in some reaches in place of meandering pattern.

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LIST OF SYMBOLS

Symbols	Definition	Unit
D	Average depth of river	ft.
F	Froude number	–
g	gravitational acceleration	$ft^2/sec.$
L	Meander length (wave length)	ft.
LR	Length along river bend	ft.
LV	Straight length along chord	ft.
m	Weighted mean diameter of bed sand	ft.
q	Discharge per foot width	$ft^3/sec.$
R	Radius of center line of bend	ft.
$\mathcal{R}$	Feynolds number	–
S	Slope of river	–
v	Velocity	ft/sec.
W	Surface width of river	ft.
ν	Kinematic viscosity	$ft^2/sec.$
σ	Gradation of bed material	–
ρ_s	Density of sediment	$lb\text{-}sec^2/ft^4$
ρ	Density of water-sediment mixture	$lb\text{-}sec^2/ft^4$
μ	Apparent viscosity of water-sediment mixture	$lb\text{-}sec/ft^2$

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CHAPTER I

INTRODUCTION

General

For a long time people have flocked together to build townships and homesteads on the banks of rivers. In early days the rivers served as main arteries for travel and trades. The floodplains of rivers are fertile resulting in intensive agricultural activities. River system in a region control environmental and ecological balance.

Again the rivers cause havoc when it floods the flood-plain. Another source of misery is erosion of banks which brings in destruction of lives and properties, damage of engineering works etc. Bank erosion results in river course shifting. As such attemps are made by Engineers to control the bank erosion which is also necessary to maintain the navigability of the river. However, before a river can be controlled it should be studied in sufficient detail, so that its response to the controls can be anticipated.

Rivers flowing in alluvial materials, under a given set of climatic, hydrologic, geologic, and geomorphic conditions, exhibit a similarity of pattern and shape that implies cause and effect relations. It is, of course, very important to understand the behavior of rivers under diverse conditions and to identify the complex and interdependent variables which are responsible for the geomorphic and hydraulic character of a stream. However, the nature of a change of river character may be clearly apparent to the trained observer but the reasons therefore often are obscure or, if suspected cannot be proved. This is because there are many interdependent variables influencing a river and rarely can one be isolated and its effects studies. For example, Lane (1957) stated there is nearly infinite variety in stream forms, if considered in detail. No stream is exactly like any other stream and no part of any stream is exactly like any other part of the same stream. There is because stream channel forms are the result of a great many factors, and the same combination of these factors is never exactly repeated. However, stream channels, forms and shapes are the results of physical laws and if the conditions controlling the shape of any part of a stream were exactly reproduced, the same form of a stream would result.

Variables Affecting Alluvial Rivers

A great many factors affect stream channel forms. Some affect the form directly, and others affect it because of their influence on the directly affecting variables.

According to Lane (1957), the most important variables affecting alluvial streams are: (1) Stream discharge, (2) Slope, (3) Sediment load, (4) Resistance of banks and bed to movement by flowing water, (5) Vegetation, (6) Temperature, (7) Geology and (8) Works of man. Undoubtedly, other factors are involved, but Lane believed these eight to be major. They are not all independent, however, as many depend to a greater or less extent on the others. The interrelation between slope, sediment load, and resistance of the banks and bed to movement is particularly close and complex.

Simons (1970) stated that "variables affecting alluvial channel forms are numerous and inter-related. Their nature is such that, unlike rigid boundary hydraulic problems, it is not possible to isolate and study the role of an individual variable". For example, if one attempts to evaluate the effect of increasing channel depth on the average velocity, additional related variables respond to the changing depth. Similarly, not only will the velocity respond to the change in depth but also the form of bed roughness, the position and shape of alternate, middle, and point bars, the shape of cross-section, the magnitude of sediment discharge, and so on. Consequently, the mechanics of flow in alluvial channels and the response of channel geometry is not as well understood and explained as many other areas of fluid mechanics and hydraulics.

Simons (1970) gave the list of the most important variables which influence the geometry of river channels. That list includes the following variables:

$$\phi\left[V, D, S, \rho, \mu, g, d, \sigma, \rho_s, S_p, S_R, S_c, f_s, C_T\right] = 0 \quad \ldots . \quad (1)$$

in which

V = Velocity

D = Depth

S = Slope of energy grade line

ρ = Density of water-sediment mixture

μ = Apparent viscosity of water-sediment mixture

g = Gravitational constant

d = Representative fall diameter of the bed material

σ = Gradation of bed material

ρ_s = Density of sediment

S_P = Shape factor of the particles

S_R = Shape factor of the reach of the stream.

S_C = Shape factor of the cross-section of the stream

f_s = Seepage force in the bed of the stream

and C_T = Concentration of bed-material discharge.

The majority of these variables were discussed in the analysis of forms of bed roughness by Simons and Richardson (1962).

Using V, D, and ρ as the repeating variables and applying the Pi-theorem

$$\phi_1\left[S, \frac{VD}{\mu}, \frac{V}{\sqrt{gD}}, \frac{d}{D}, \sigma, \frac{\rho_s}{\rho}, S_P, S_R, S_C, \frac{f_s}{\rho V2}, C_T\right] = 0. \quad (2)$$

Equation 2 gives the list of the nondimensional parameters which are important in the study of alluvial river characteristics.

Objective

Bangladesh is a land of rivers interlaced by the numerous channels of the three great river systems of the world viz. the Ganges-Padma, the Brahmaputra-Jamuna and the **Meghna.** Average flood during monsoon and low discharge in winter are recurring features in this country. These three great rivers are alluvial in nature and as such have high shifting tendency.

It is essential to know the probable behaviour of a river reach i.e. its erosion pattern, its shifting tendency and direction of movement, formation of bars and shoals on its bed before any important engineering project can be undertaken on or besides this rivers. This study attempts to study the shifting characteristics of the Ganges and takes up a 80 miles reach from its point of entry into Bangladesh to Goalundo between latitude from 23° 42'N to 24° 12'N and longitude from 88° 45'E to 89° 46'E as a case study.

The objectives of this research are to:

a. investigate the cause of shifting, directions and rate of bank movement as well as to document the morphologic characteristics of the Ganges.

b. establish the effect of slope on river morphology and also to study how the morphological parameters of the river reach change from year to year.

History of the Ganges River

The Ganges is an international river, with its basin spread over China, Nepal, India and Bangladesh. Figure 1 shows the Ganges basin. Rajshahi, Pabna, Kushtia, Jessore, Faridpur and Khulna districts in Bangladesh are situated on the banks of the Ganges and its major distributaries. The area served by the Ganges river system in Bangladesh covers approximately 20,000 square miles. About ¼th of the total cultivable area of the country lies in these districts, ⅓rd of the population of Bangladesh or about 25 million people live in the Ganges basin and depend on the Ganges water for their subsistance (BWDB, 1976).

The Ganges, rises in the gangotri glacier of the Himalayas at an elevation of 23,000 ft, west of the Nanda Devi Range, and quite close to the sources of the Indus and the Tsangpo. It has a length of 1370 miles upto Goalundo, and 1570 miles to the mouth of the Meghna and a drainage area of 3,77,400 sq. miles upto Goalundo. It is bordered in the north by about 700 miles of the Himalaya Range and in the south by the Vindhya mountains.

The average gradients of the river are: from Allahabad to Benaras 1:10,500, from Farakka to Rampur Boalia 1:18,700, from Rampur Boalia to Hardinge Bridge 1:22,200, and from there to Goalundo 1:28,000. The river, since ancient times, has meandered extensively. Often, it leaves the old bed and seeks a new channel. New islands are washed away or attach themselves to the mainland. Many ruins of old towns and cities are evidence of such changes.

It has a maximum recorded discharge of 2,585,000 cusecs and a minimum of 41,421 cusecs at the Hardinge Bridge. The lowest river level is usually recorded in April, after which melting snow increases the flow. Rainfall in the foothills of the Himalayas and in the plains is abundant during the monsoon months (June-September) and the river rises to its maximum usually in July or August.

The Kosi, which carries a considerable volume of flood water joins the Ganges within a short distance of the Bangladesh border. Another important affluent of the Ganges is the Gorai, taking off near Kushtia and flowing to the sea via Madhumati and Baleswar. The Ganges joins the Brahmaputra to form the Padma at Goalundo.

Prior to the sixteenth centuary, the Ganges passed most of its discharge to the sea via the Bhagirathi-Hoogly, Jalangi and Mathabhanga Channels. Thereafter the Ganges main discharge moved steadily to the east developing various channels such as the Ichamati, Nabaganga, Bhairab, Kumar and Gorai in its progress, and causing repeated flood devastation in these areas. Flood embankment was constructed at that time on the Nabaganga, but has since been abandoned as flooding decreased. The Padma was originally a small channel which passed down the Arial Khan to the sea, and later this became the eastern limit of Ganges spill channels. After the main Brahmaputra joined the Ganges, the Padma developed as the main river and joined the Meghna near Chandpur.

From 1810 to 1830, under backwater effect of the Brahmaputra, which had joined the Ganges at Goalundo, the Ganges was halted in its eastern movement. It commenced to develop so strongly south down the Gorai-Madhumati, that from 1857 to 1865 it was feared that the entire Ganges would pass this way. There was much ponding up of floods in the low Faridpur area, until the Madhumati developed as a strong outlet to the sea. The Bhairab, which had been closed, reopened in 1874, but later closed again. However, the Ganges stopped favouring the Gorai-Madhumati and moved north-east, to pass its main discharge, along with the Bhrahmaputra, down the Padma and then, neglecting the Arial Khan, straight east to the Meghna.

It is supposed that very long ago the Baral, an offtake of the Ganges below Rajshahi together with Atrai and the Jamuna, once had a common channel along the Dhaleswari to the Meghna.

CHAPTER II

RIVER PATTERNS

General

The pattern of a river is defined as the appearance of a reach in a plan view. If plan views of most of the major rivers are examined, they can generally be grouped into three types: straight, meandering and braided. (Leopold-Wolman 1964). These types are shown diagrammatically in Fig.2. Although, these three types represent the major divisions, it should be realised that a continuous gradation exists between one type and another. In any single river, therefore, it is common to find more than one type of pattern existing along its length.

Straight rivers are those which have, at the bank-full stage, a negligible sinuosity over a distance many times the channel width. (Fig.2B).

Meandering rivers show more or less regular inflections in the direction of the channel and are quite sinuous in plan (Fig. 2C).

Braided rivers are those marked by successive divisions and rejoinings of the flow around alluvial islands (Fig. 2A).

It should, however, be borne in mind that all channel forms in the field are not covered by these three categories and this classification is not comprehensive. For example, the distingnishing characteristic of a braided stream is the interlacing of its multiple channels. On the other hand, the distinguishing characteristic of a meandering river is a tortuous alignment. Thus, whereas the terms straight and meandering refer to direction, braiding refers to multiplicity of channels.

Straight Rivers

In a straight river, the thalweg (line of maximum depth) is generally sinuous in plan, moving from one bank to the other. As a result, lateral bars are formed and are arranged alternately along the banks (Fig. 2B). The longitudinal profile of such a stream therefore shows alternation between deep pools (Opposite the lateral bars) and shallow riffles (between the lateral bars). This type of stream, although quite distinctive, is essentially transitional, showing features comparable to both meandering and braided streams. The riffles correspond to a semi-braided reach and the lateral bars and pools to a meander loop. Steep river gradients, large variations in stage, a periodic floods, and small bedload (although it might be quite coarse) are characteristic of straight rivers.

Meandering Rivers

The term meandering is generally applied to any river having a sinuous course, with bends of either regular or irregular shape and small or large curvature. In fact, any river which is not straight is generally termed meandering.

Meanders can be classified as either of regular or irregular shape and as either simple or compound, as shown on Fig.3. Regular meanders are a train of bends of the same curvature and frequency, while irregular meanders are deformed in shape and may vary in amplitude and frequency. Simple meanders have one dominant amplitude and frequency, while compound meanders have bends of different amplitudes and frequencies. Compound meanders may develop if a stream has more than one dominant discharge, each of which could independently influence meander characteristics. Irregular meanders may occur because of variation in discharge along the channel by additions from tributary streams, withdrawals by branches, lakes etc.

Meandering river consists of a series of bends connected by crossings. In the bends deep pools are carved adjacent to the concave bank by the relatively high velocities. The centrifugal force in the bend causes a transverse water surface slope and helicoidal flow in the bend. These transverse currents, with a magnitude of about 15% of the average channel velocity, flow toward the convex bank. In so doing they sweep the heavier concentrations of bed load toward the convex bank where they are deposited to form the point bar. The bends are connected by crossings (short straight reaches) which are shallow compared to the pools in the bendways. The scour in the bend causes the bend to migrate downstream and sometimes laterally. Much of the sediment eroded from the outside bank is deposited in the crossings and at the point bar in the next bend downstream.

Meandering streams tend to migrate rapidly, rates upto 2,500 feet a year have been recorded in Bangladesh. Because of the flow in a meander loop, however, it is relatively easy, even with a limited amount of information, to predict both rate and direction of movement with a moderate degree of accuracy.

Braided Rivers

The river channel is wide, the banks are poorly defined and unstable. There are two or more channels that cross one another giving the river bed a braided appearance at low flow. Between sub-channels there are numerous sand bars and islands. These sub-channels and sand bars rapidly change position with time and stage and in an unpredictable manner. The result of this constant change in cross sectional area is rapid cutting and filling along the banks. Thus the bank lines of most braided rivers are indistinct. As a result of the studies on the design of stable rivers in irrigation canals, Lane (1957) concluded that there are two primary causes of braiding streams. These causes are: (i) overloading i.e. the stream may be supplied with more sediment that it can carry and part of it may be deposited and (ii) steep slopes causing a wide, shallow channel in which bars and islands readily form.

Slope-Discharge Relations

Effects havebeen made to distinguish between meandering and braided streams on the basis of slope-discharge relations. For example, Lane (1957) made a plot showing the relationship between slope and discharge for sand bed meandering stream. He obtained a line described by the equation

$$S = \frac{0.0017}{Q^{\frac{1}{4}}} \qquad (3)$$

Observing that this form of equation fits a large amount of data from meandering sand streams, Lane expressed the equation in the following form

$$S = \frac{K}{Q^{\frac{1}{4}}} \qquad (4)$$

where K = 0.0017 for all meandering streams in sand under equilibrium conditions.

By using only data from sand streams having steep slopes he made a quantitative comparison of the slope-discharge relations for braided streams. The slope-discharge relations for braided streams can be approximately represented by a line having an equation.

$$S = \frac{0.01}{Q^{\frac{1}{4}}} \quad \text{i.e., } K = 0.01 \qquad (5)$$

This represents a slope of about six times as steep as that for meandering sand streams.

Relationship Affecting River Pattern

Meander Characteristics - The most important parameter defining meander geometry is the sinuosity of the curved channel. Sinuosity was defined by Leopold-Wolman as the ratio of thalweg length (length along the line of maximum depth) to valley length, by Friedkin as the ratio of thalweg length to air line distance, and by Leopold-Wolman in their subsequent contribution as ratio of arc distance to wave length in a single meander. The first definition appears to be preferable because of its simplicity, requiring less judgement in measurement.

The sinuosity ratio determines the shape of meanders. Sinuosity is usually measured over a reach including several bends. Other terms describing a meander are defined by the sketch presented in Fig. 4.

River Characteristics - Wide, shallow rivers are usually associated with lesser tortuosity (Chitale, 1970). When distortion is used in hydraulic models, flow lines are found to follow sharper curvature than in the prototype, indicating that deeper and narrower rivers produce more acute bends.

The valley slope provides the force which helps the river straighten its course. The steeper the slope, the higher the mean velocity, requiring a flatter curvature for negotiating a curve. The relationship of channel slope to valley slope can be expressed by river channel slope=valley slopes X length along valley/length along river. The slope of the river, S, is, thus, an important parameter which must be considered.

The size of bed material m is also a pertinent factor. Acute bends are associated with relatively fine bed material, whereas coarser bed material is associated with rivers. having low tortuosity.

Relation for Meander Sinuosity - Chitale (1970) gave the following relationships. The relationship between the sinuosity ratio and other parameters can be expressed as

$$\frac{LR}{LV} = f\,(\,W, D, S, m\,) \qquad (2)$$

in which

LR = length along river bend

LV = straight length along chord

W = surface width of river

D = average depth of river

S = slope of river.

This can be reduced to the dimensionless equation

$$\frac{LR}{LV} = f\left(\frac{W}{D}, S, \frac{m}{D}\right) \qquad (3)$$

If mean velocity and discharge per foot of channel width are assumed as two more relevant parameters eq. (3) can further be modified as $\frac{LR}{LV} = f\left(\frac{W}{D}, S, \frac{m}{D}, R.F.\right)$ (4)

in which $R = \frac{q}{\nu}$ = the Reynolds number,

$F = \frac{V}{\sqrt{gD}}$ = the Froude number,

q = discharge per feet width;

ν = kinematic viscosity;

v = mean velocity, and

g = gravitational acceleration.

Factors Affecting Meandering - To study the effect of parameters $\frac{W}{D}$, S and m/D individually on meander sinuosity, plots of LR/LV against these three parameters are shown in Fig. 5. This figure indicate that rivers with low sinuosity ratio, i.e. more or less straight rivers, have wide and shallow cross-sections, steeper slopes and relatively coarser bed material. A value of LR/LV equal to one indicates straight rivers. If LR/LV $\leq$ 1 is adopted as the limit, the data indicate that channels having W/D $>$ 400, slope $>$ 1/1000 and m/D $>$ 0.16 may be expected to be straight. All braided rivers would also be seen to have LR/LV nearly equal to one.

According to Chitale (1970), with gradual reduction in the value of all three parameters W/D, S, and m/D, the sinuosity ratio increases, indicating that meanders become more and more acute. When the value of W/D becomes less than 50, the value of S $<$ 2.75/10,000 and the value of m/D $<$ 0.02. Fig. 4 suggest that LR/LV may be expected to be greater than 1.7. Thus sharp bends are formed when the river section is narrow and deep, its slope flat, and the bed material of relatively small size.

CHAPTER III

RIVER COURSE SHIFTING

Wandering of the Thalweg

In a river highly charged with sediment, the bed configuration changes drastically under differing flow regimes. Deposition of sediment in one locality causes deepening by scour in another locality. Thus the thalweg tends to wander continuosly from one position to another within the river bank lines. This is generally characterized by two distinct types of movements, a gradual and transverse movement and sudden shifts from one position to another.

In the low-water stage, prior to the passage of the flood, the river is subdivided into numerous small channels with one of these generally serving as the main channel and carrying a larger portion of the flow. This channel is commonly situated near one of the river banks and is slightly curved, moving from one bank to the other. With the onset of the flood, the initial reaction is for the river to seek a path with little curvature. As a result, the thalweg tends to move toward the inside portion of the curvature. The rise in flood stage, however, is quite rapid, and the river must widen and deepen to accomodate this large increase in discharge. The usual result is for the bank to be undercut, slumping then occurs and the migration of the thalweg in a transverse direction is initiated. This type of river shifting takes place gradually, usually over an entire month, but it may attain considerable amplitude.

The second type of shifting of the thalweg can be related to the movements of the sand bars and mid-channel islands. As flood water subside, an excess of sediment is carried as bedload in suspension, velocities diminish, causing this material to be deposited. Deposition of the material results in a corresponding change in local flow direction and the thalweg is in a state of constant movement. It is during this period that bed aggradation is the greatest and many new channels are formed, function for a short time, and are then abandoned. As the flood continues to subside, one of the channels becomes dominant and the rate of wandering of the thalweg diminishes (Coleman, 1964).

Deposition and Erosion of the river bed

Rates of deposition and erosion are quite high in rivers carrying large quantity of sediment. The constant shifting of the thalweg adds to the magnitude and complexity of deposition and erosion patterns. During rising stage the velocity increases abruptly to a maximum, then fluctuates in response to differences in discharge. Scour depth, however, increase slowly and do not reach maximum at the same time as velocity. The greatest amount of scour occurs during the latter part of the flood, at which time the velocity declines sharply. Once the velocity diminishes, the maximum amount of deposition takes place. This generally occurs just before or during the falling stage. The river widens with the passage of the flood and suddenly diminishes during falling stage. (Coleman, 1964).

Formation and Movement of Sand Bars

The initial location and formation of the sand bars are determined during the flood, they are possibly the result of the formation of the water scour channels hugging each channel bank. The hydraulic conditions that cause this erosion and deposition are essentially unknown. However, the area of deposition in the central part of the channel is undoubtedly caused by slack water conditions. During the flood this area receives deposition and the bed is aggraded significantly. Since the flood waters subside rapidly, there is not enough time for this material to erode, and hence it is soon exposed as a shoal. After exposure and drying of the surface, wind activity modifies it slightly, piling sand into various types of aeolian dunes.

During the next flood, the island is once more inundated. In some cases it is completely removed by erosion, but move commonly it suffers erosion on its upstream face and deposition on its downstream end. This generally causes the island to migrate in a downstream direction. In some instances, however, whole islands disappear or new islands form that were not present in the previous year. Thus, during flood the sediment is shifted as bed load, causing the islands to migrate (Coleman, 1964).

Reasons for river shifting

The characteristics and direction of flow are determined by various opposing factors within the stream; for instance; the oncoming load versus the sediment-carring capacity of the flow, and the erosive resistance of the bank against the bank-caving capacity of the flow. The existence and development of these various factors contribute to the shifting of the river channel. Probably the major controlling factor, however, is the amount of sediment and the inability of the river to transport it. The aggradation constantly causes the main current to seek better gradients, new alignments and paths of least resistance. A new channel thus formed is at first narrow and deep; with time; however, it, too, will begin to aggrade, and the whole process is repeated. In this manner the river is in a state of constant migration, eroding and redepositing sediment of its own making as well as older deposits of previous channels.

Although the aggradation of the river bed is one of the major factors responsible for the wandering of a river course, it also creates conditions under which other factors manifest their influence. During low stage, the river-width is excessive for the amount of water it must attain, and the channel forms complicated patterns of pools and riffles. Some areas receive excessive deposition, causing scour in an adjacent area. Thus, the river spreads its sediments across the entire valley. Under such conditions the channel is able to remould freely its bed configuration, thus maintaining a cross sectional area in keeping with flow regime. In addition, a number of factors, including the high susceptibility to erosion of the bed material, the large variability of the flow, and the abrupt rise and fall of the river stage, have a strong bearing in determining the migration patterns. Both rate and amplitude of channel shifting become larger when the above factors exist. (Coleman, 1964).

CHAPTER IV

DATA COLLECTION AND ANALYSIS

Collection of data

All field data i.e. cross-sections, longitudinal profile, discharge data, stage data, etc. were collected from the Surface Water Hydrology Directorate and River Morphology, Research and Training Directorate of Bangladesh Water Development Board. Bangladesh Water Development Board is responsible for collection of these data for all the rivers of Bangladesh.

For the reach under investigation the Board maintains a discharge station at Hardinge Bridge since 1934 and gage record station at Hardinge Bridge since 1910. The Board takes cross-section along the river at 21 places and these sections are denoted by G # 0-1 through G # 18. These sections are taken only during low water period. Information available from the Surface Water Hydrology and River Morphology, Research and Training Directorate of Bangladesh Water Development Board is not sufficient for investigation the characteristics of the rivers, because of lack of continuity in data. Complete set of data were available for the year 1967, 1968, 1969 and 1976 and as such data of these years only have been used in this study. Ganges river course were traced from the maps prepared by the survey of Bangladesh in 1956 and this is taken as index map.

Analysis of Data

The cross-section of the Ganges river from G # 18 located at the point of entry into Bangladesh to G # 0-1 located at Goalundo have been plotted with the help of the co-ordinates of the respective B.M. pillars of all the cross-sections in the course map shown in Fig. 6. With the maximum depth at each cross-section for respective years, the thalweg were determined for the abovementioned years. The locations of right bank and left bank were drawn by studying all the cross-sections. This bank line movement was superimposed on thalweg movement (Fig. 6) to get a clear understanding of the relationship between bank movement and the thalweg.

Sinuosity i.e. length along river bend/straight length along chord was computed from the thalweg (Fig. 6) of respective years. Sinuosity ratios were determined at various places in the reach under study for respective years. After that two curves, one for 1976 and another for 1969 were drawn to get the relationship between sinuosity and channel shape (Fig.9).

In a similar way, relationship between meander length (wave length) and average width of the channel (Fig. 11), relationship between average depth and average width (Fig. 12), relationship between sinuosity and slope (Fig. 10), relationship between sinuosity and year (Fig. 13) and also relationship between minimum bed elevation and meandering length (Fig. 8) were plotted.

As a means of investigating the short term changes of river banks, comparative bank line studies were done. In the study of bank line migration, measurements were made at all cross-sections whose locations are shown in Fig. 7. Shifting of banklines for 1968, 1969 and 1976 were studied with reference to the bankline of 1956. Fig. 7 shows the rates of migration in feet per year that have occured on both banks for respective years.

All the cross-sections for the years 1967, 1968, 1969 and 1976 were superimposed shown in Fig. 14 through Fig. 32 to study the shifting of sand bars and shoals. The reasons of bank erosion, the rate of erosion and the direction of bank movement and also the changes in thalweg position predicated with the help of these figures (From Fig.14 to Fig. 32).

Rating curves and hydrographs for several years have been drawn for the Ganges at Hardinge bridge and these are shown in Figures from 33 to 35.

Hardinge bridge is the only discharge measuring station for the reach of the Ganges under study.

CHAPTER V

RESULTS AND DISCUSSIONS

To determine the shifting characteristics of the reach of the Ganges the thalweg and the bank lines of different years were investigated carefully. The superimposed cross-sections for different years were studied to quantify the movement of sand bars and shoals, and the resulting changes in the cross-section.

<u>Thalweg movement.</u>

Fig. 6 shows that the thalweg for the years 1967, 1968, 1969 and 1976 shifts continuously from one position to another within the river bank. It has been found that the thalweg passes through the almost same location at Hardinge bridge in the abovementioned years. It is because that the Railway department stabilized that reach of the Ganges at the Hardinge bridge with groynes and boulders. From the rating curves (From Fig. 33 to 35), it can also be said that channel is stable at Hardinge bridge and as a result it acts as control section for the deep water channel in the reach of Ganges. It is observed that the thalweg for different years has meandering pattern and moves through various locations at each section in a different path.

In cross-section G # 15 (Fig. 17), it was observed in the year 1969 that the thalweg moved near the right bank, but in the year 1976, that portions were silted up and consequently the thalweg was shifted towards the left bank causing the erosion of left B.M. pillar. Similar case was happening in other years also.

Again in cross-section G #= 17 (Fig. 15), it was observed that the deepwater moved from one position to another in different years due to the movement of sand bars. In this case thalweg for 1976 moved near the right bank. It can be said that the flow in Ganges is certainly capable of shifting sand bars at moderate flow regimes and of causing frequent and intense changes in channel sections and configurations during floods.

It is observed from the Figure 6 that the low flow in the Ganges moves in quite sinuous channels which are separated by numerous bars, whereas the high flow takes a comparatively straight course. The channel configuration thus moulded at one time will be destroyed and subject to modification once there is a large change in discharge. The variability of the flow in the Ganges thus results in the river's constantly changing its shape from low flow to flood flow and from flood flow back to low flow. Thus it can be said by studying the cross-section (Figs. 14 through 32) that the shifting of thalweg is due to movement of sand bars and mid-channel islands.

The location and formation of sand bars are determined during the flood; they are possibly the result of the formation of the two scour channels hugging each channel bank. In most cases (From Fig . 14 to Fig. 32), the total area of the island remains approximately the same from one flood to another and only its position and shape change. In some instances (Figures 17, 28, 29, and 32), however, whole islands disappear or new islands form that were not present in the previous year. Thus during flood the sediment is shifted as bedload causing the islands to migrate and as such the thalweg also move with time.

Sinuosity

Figure 13 shows the variation of thalweg sinuosity from 1968 to 1976. It appeared from Table IV and Fig. 13 that the thalweg sinuosity between cross-section G # 18 to G # 1 varies from 1.41 to 1.14, 1.36 to 1.04, and 1.17 to 1.02 in 1968, 1969, and 1976 respectively. Thus the thalweg sinuosity of the reach of the Ganges under consideration is decreased gradually, which means that the river is developing straight-braided pattern.

Sinuosity and slope

Fig. 10 shows the relationship between sinuosity and slope for the years 1969 and 1976. It appears from the figure that the channels with low sinuosity have steeper slopes.

Sinuosity is also unity at steeper slopes but the channel is braided in this case.

Braided channel developes at higher velocities. At higher velocities the flow cut through the bars and the channels became very wide and shallow and alluvial islands readily formed in such a channel. Because of the higher inertia of motion associated with a faster moving mass of water, the flow have a tendency to follow a straight path and as a result it cut throught the bars. Alluvial islands develop in a braided channel due to the deposition of some of the coarser materials which the flow could not transport. Finer material are trapped among the coarser particles and the bars increase in size. Finally the flow take place in a number of interlaced channels separated by these islands.

Sinuosity and channel shape

Fig. 9 shows the relationship between sinuosity and channel shape for the year 1969 and 1976. It appears that channels with low sinuosity have wide and shallow cross-section. It has already been stated that the value of sinuosity in 1969 was higher than 1976 i.e., the value of sinuosity has a tendency to decrease over the years under study. From the curves it can be said that channels are gradually silting up with increasing width.

Thus the present study verified chitale's (1970) observations that the channels with low sinuosity (i.e. more or less straight channels) have wide and shallow cross-section and steeper slopes (Fig. 5).

Meander length (Wave length) and width of the channel

The relationship between meandering length (wave length) and average width of the channel (Fig. 11) shows that the meander length rapidly increases with a small increase of the width of the channel. In this case also it can be said that river pattern gradually becomes straight.

Average width and average depth

The relationship between average width and average depth (Fig. 12) shows that the width of the channel increases rapidly with a small increase in average depth of the channel.

Bank movement

From Fig. 7 it is observed that the bank lines in different years throughout the reach are shifting gradually. In some cross-section (Fig. 7, Figs. 21 through Fig. 25) shifting is more than others. If the bank line of 1956 is compared with the bank line of 1976, it is seen that at the left bank, the maximum amount of deposition was 919 ft per year (Fig. 7 & 9) at cross-section G # 9 and the maximum rate of erosion was 666 ft per years (Fig. 7) at cross-section G # 3 and at right bank, the maximum rate of erosion was maximum amount of deposition was 550 ft. per year (Fig.7) at cross-section G # 2. In some cross-section (Fig. 7) at G # 18, 17 & 9 both banks of the river were retreating rapidly. At several cross-sections (Fig. 7) G # 15, G # 6, G # 5, G # 3, G # 2, G # 1 one bank is cutting and the other is depositing at a similar rate. Thus, within the period, bank line migration was not predicatable but rather it was erratic. It might be noted that a slightly higher number of cross-section on the left bank showed erosion than on the right bank. Similar conditions can be documented (Fig. 7) for the years 1968 and 1969.

These rates give some indication of the magnitude of movement that can occur in a relatively short period of time. The illustrations also point out the erratic nature of the shifting. The sudden and erratic shifting of the channel results in rapid deposition of sediment. The overall effect, however, is the formation of blanket sand bodies with considerable lateral continuity. Such type of erratic movement of bank lines may be due to the frequent shifting of the thalweg in respective years which results in the movement of sand bars and shoals.

Ganges at Hardinge bridge

From the rating curves (Fig. 33 through Fig. 35) it appears that the channel is suitable at Harding bridge. In every year, stage gradually increases with the increase of discharge (Fig.33 through Fig. 35) The phenomenon is almost similar in all other years. Hence Hardinge bridge is a stable section and acts as control section in the reach of Ganges river in Bangladesh.

CHAPTER VI

CONCLUSIONS

The following conclusions can be drawn from this study:

i. The Ganges is a predominantly irregular and flat meandering river.

ii. The Ganges is showing a tendency to reduce her sinuosity. The sinuosity varied from 1.41 to 1.14 in 1968, 1.36 to 1.04 in 1969, and 1.17 to 1.02 in 1976. Hence sinuosity of the thalweg in general is getting flatter.

iii. The Ganges river in Bangladesh is developing braiding in some of its meandering reaches.

iv. In the low-water stage, prior to the passage of the flood, the river is sub-divided into numerous small channels, with one of these generally serving as the main channel and carrying a larger portion of the flow. The thalweg shifts continuously from one position to another within the bank lines with the passage of floods. The shifting of thalweg is due to the movement of sand bars and mid-channel islands and also due to aggradation.

v. The shifting of bank lines is erratic and gradual. It can be said that in the year 1976 erosion was slightly higher on the left bank than on the right bank with reference to the bank line of 1956 in the reach of

Ganges river under study. The erratic movement of bank lines is due to the frequent shifting of the thalweg in respective years.

vi. The rivers with low sinuosity have wide and shallow cross-section and steeper bed slopes.

vii. The meandering length (wave length) rapidly increases with a small increase of the average width of the river.

viii. The average width of the river increases rapidly with the minor increases in average depth of the river.

Some additional data would greatly facilitated similar research studies on river morphology. Presently only one discharge measuring station is maintained at Harding bridge. Some additional discharge measuring stations are essentially required both upstream and downstream of the Hardinge bridge. Besides discharge, sediment samples should also be collected.

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APPENDIX - A

FIGURES

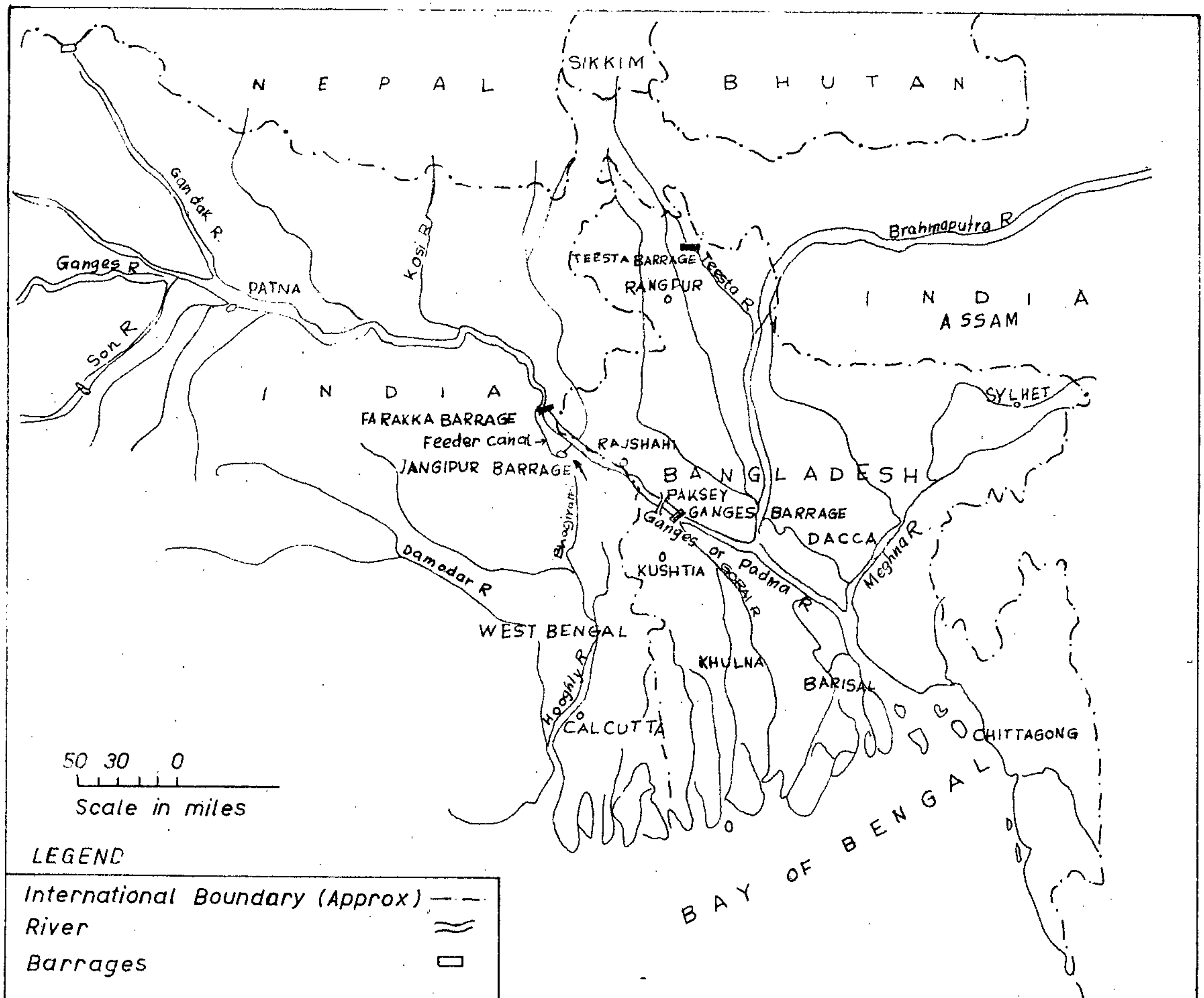


Fig. 1. Index map showing Ganges Basin in India and Bangladesh.

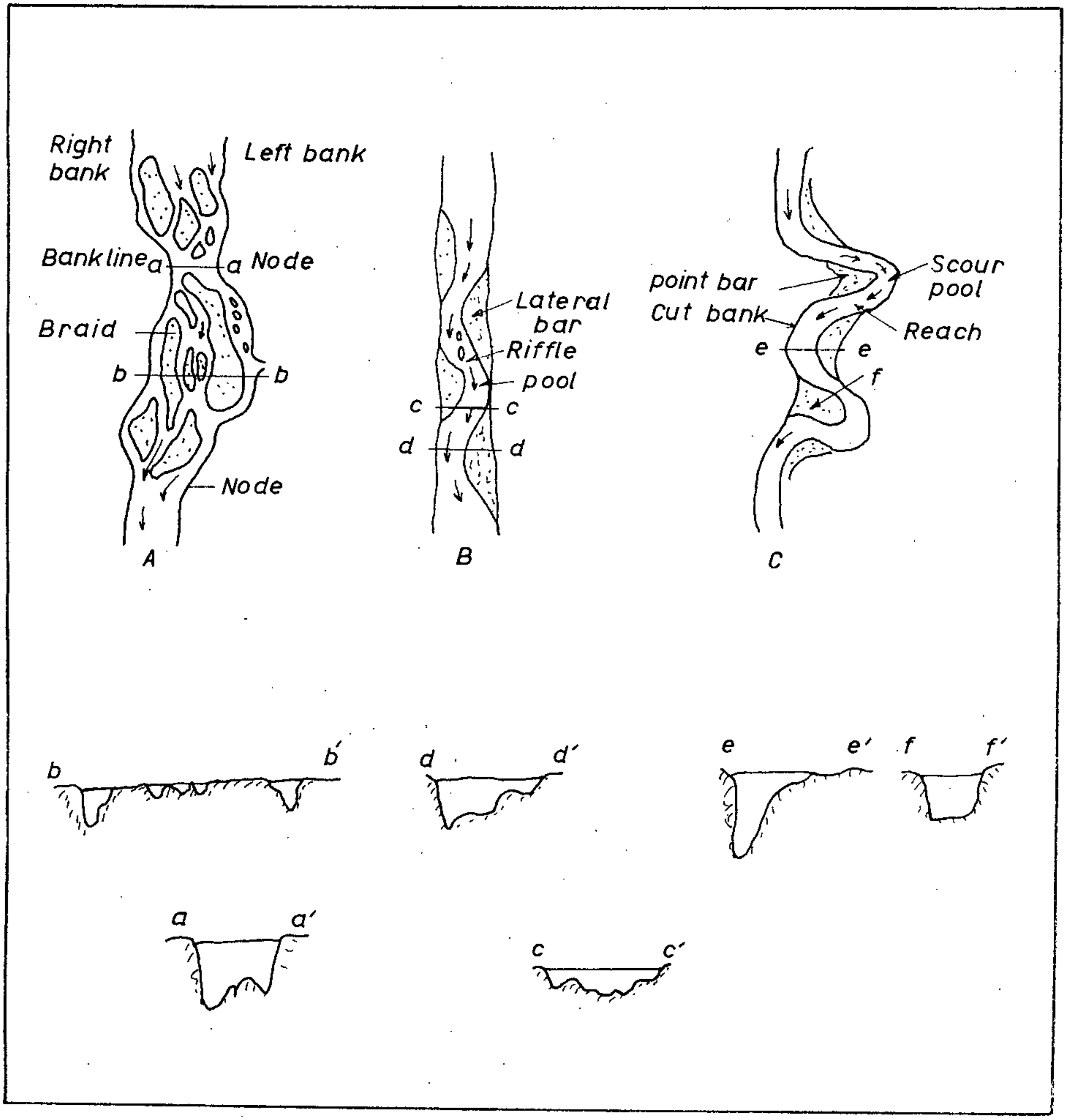


FIG. NO. 2. RIVER CHANNEL PATTERNS AND TYPICAL CROSS-SECTION A. BRAIDED, B. STRAIGHT, C. MEANDERING (After leopold, 1964).

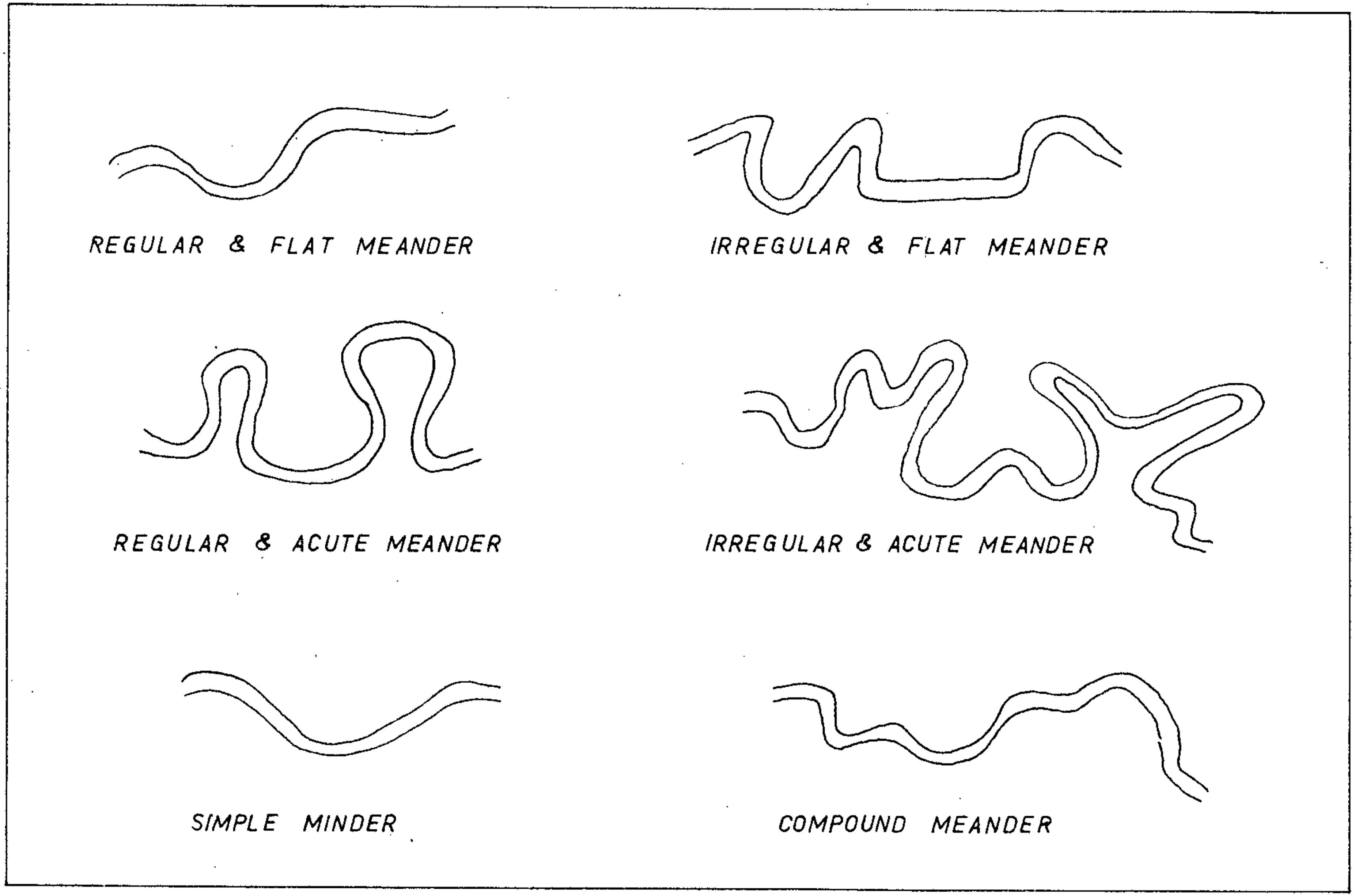


FIG. 3 TYPES OF MEANDER (AFTER CHITALE 1970).

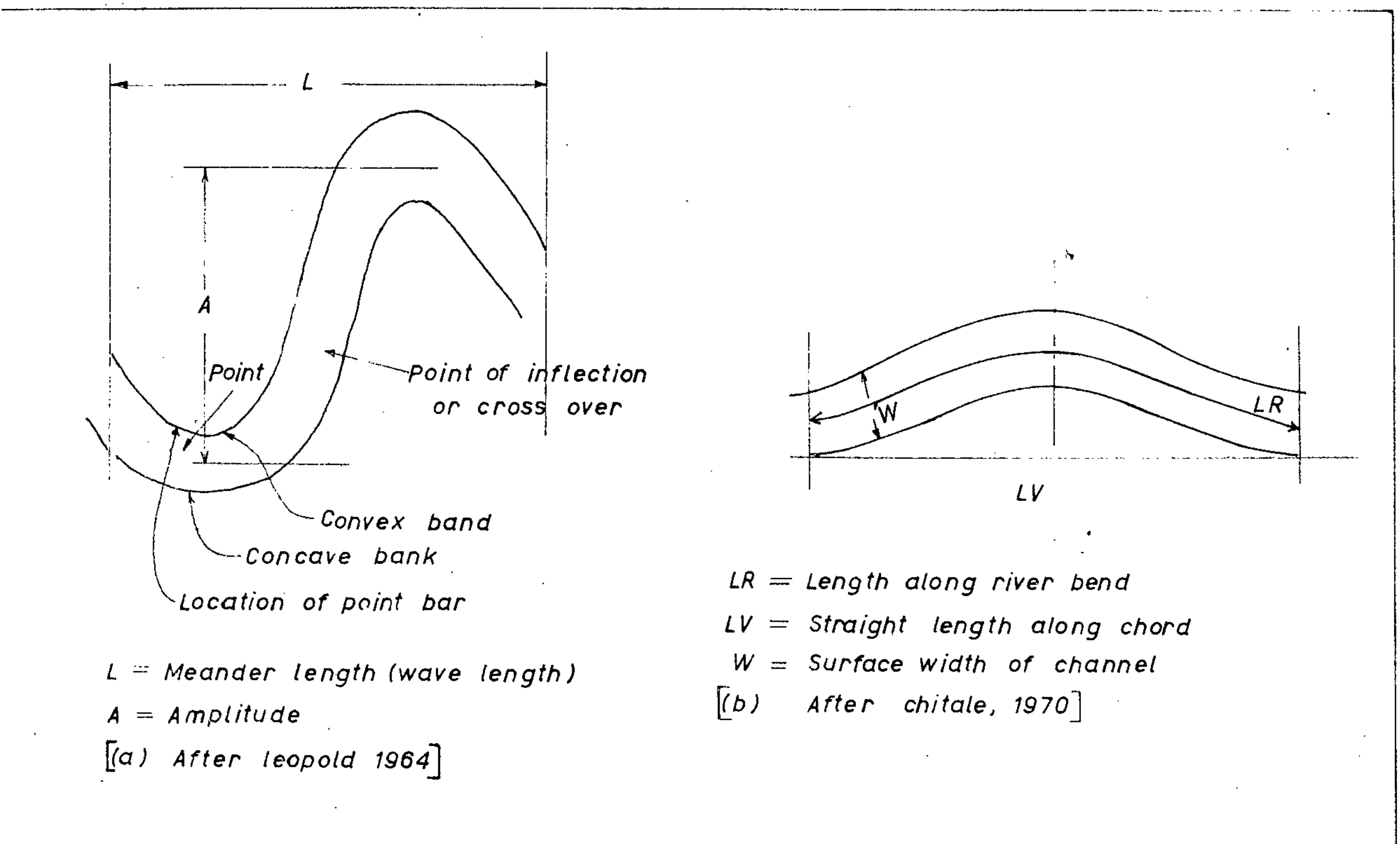
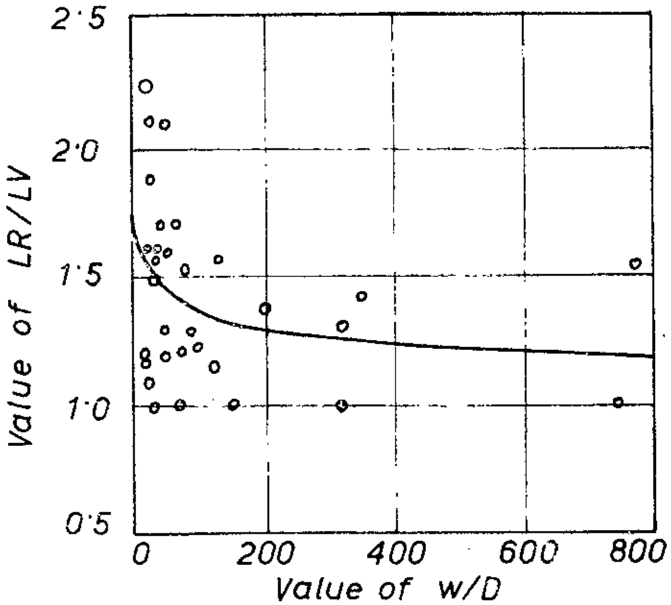
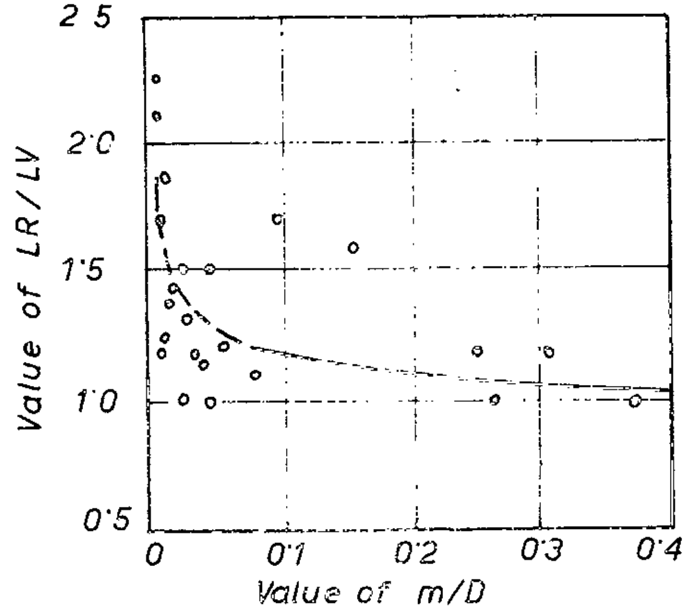


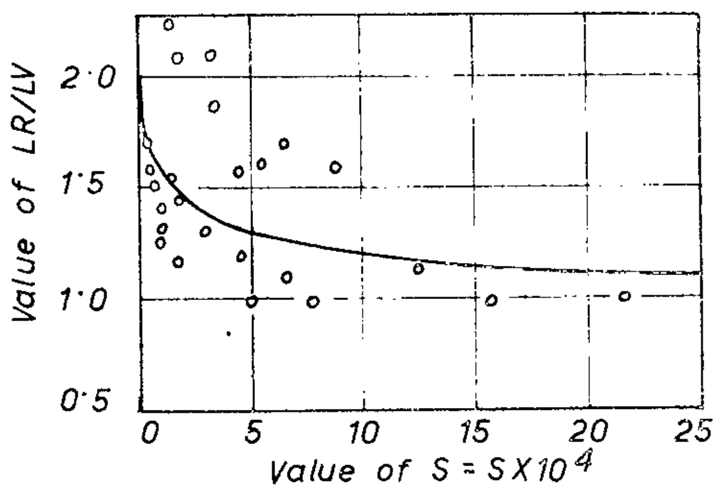
FIG. 4 DEFINITION SKETCH FOR MEANDERS.



A. Relationship between sinuosity ratio, LR/LV and channel shape w/D.



C. Relationship between sinuosity ratio, LR/LV and Relative size of Bed material m/D.



B. Relationship between sinuosity ratio, LR/LV and slopes.

FIG. 5. A, B and C (After chitale, 1970)

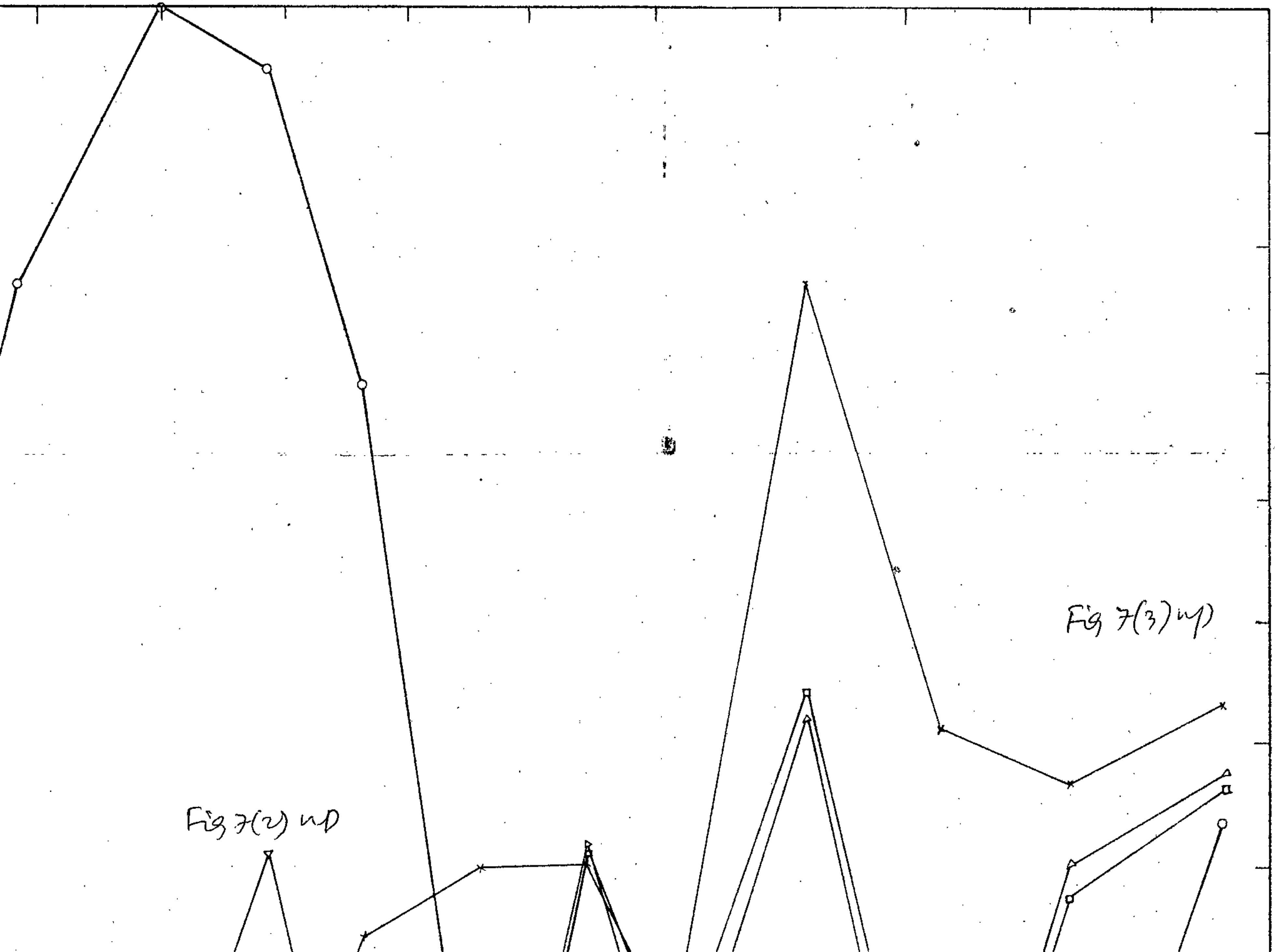


Fig 7(2) nD
Fig 7(3) nD

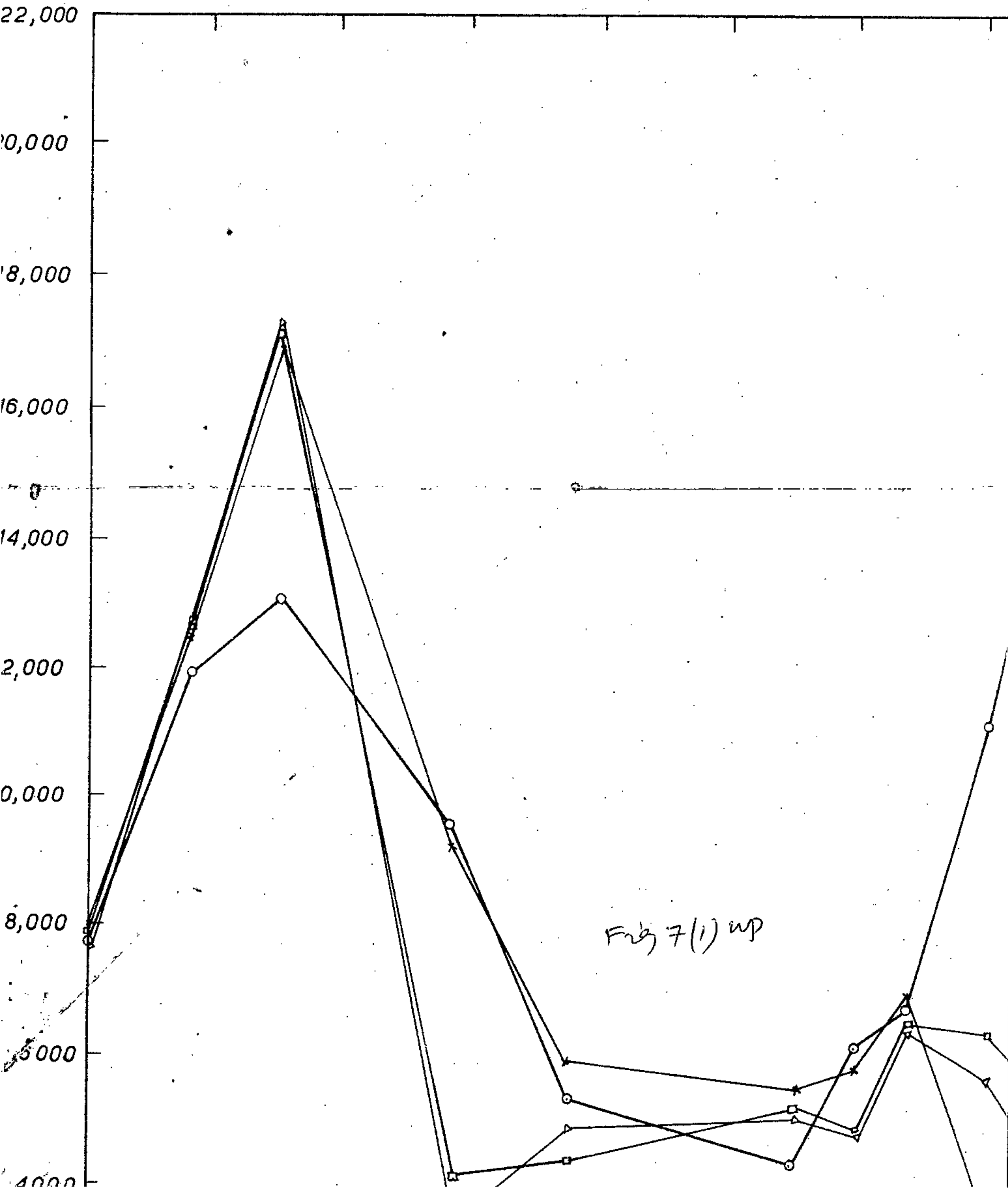

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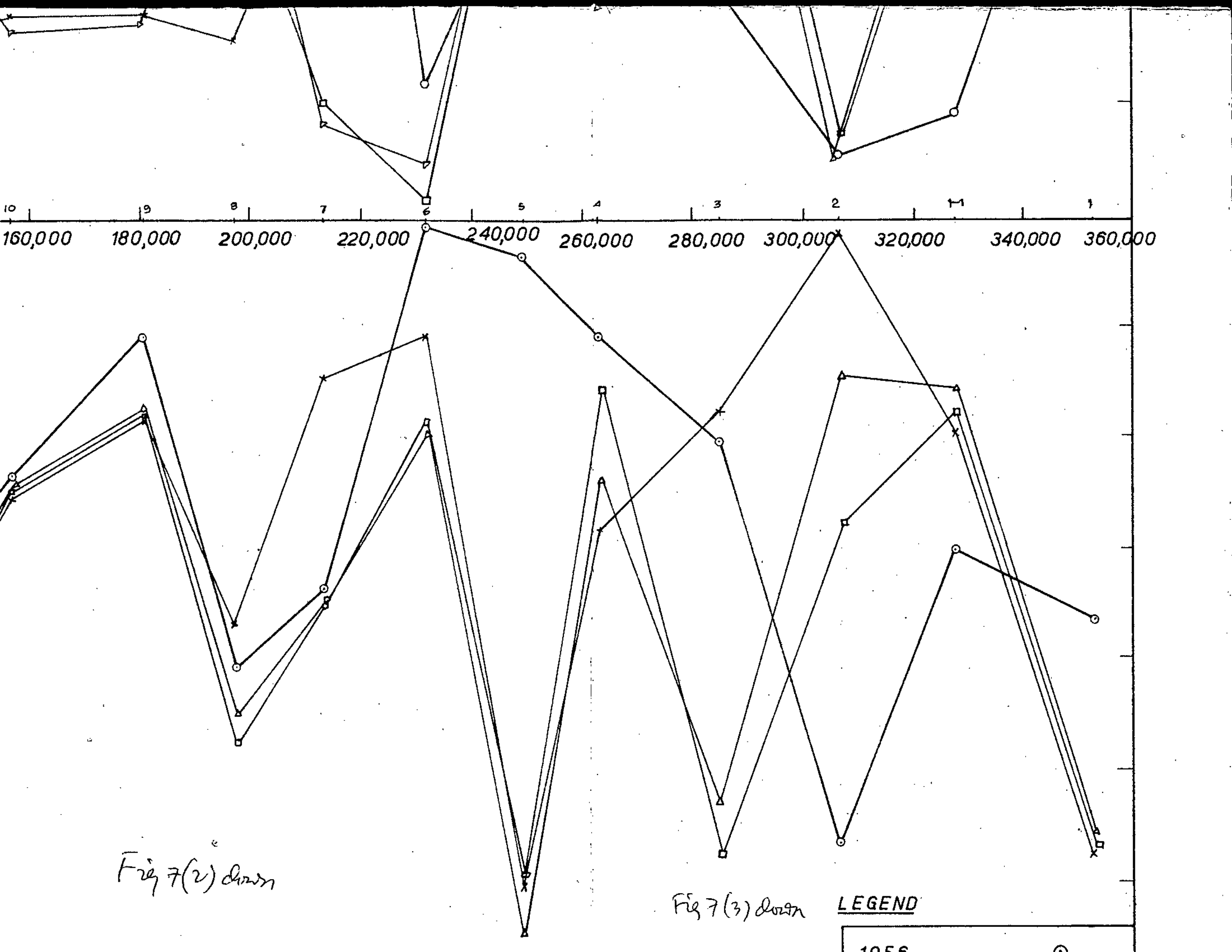
Fig 7(1) up



10
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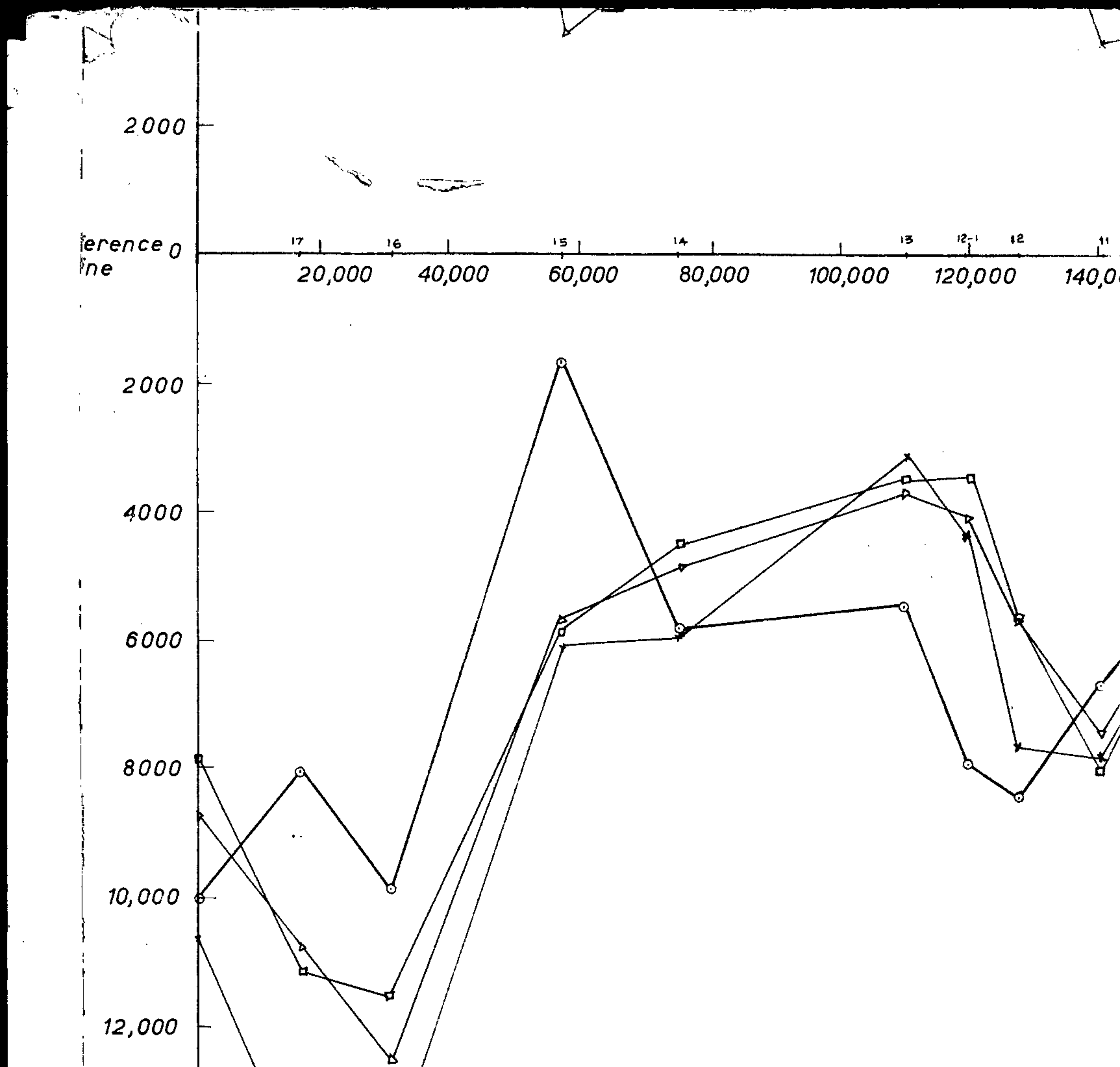
Fig 7(2) drawn
Fig 7(3) drawn
LEGEND



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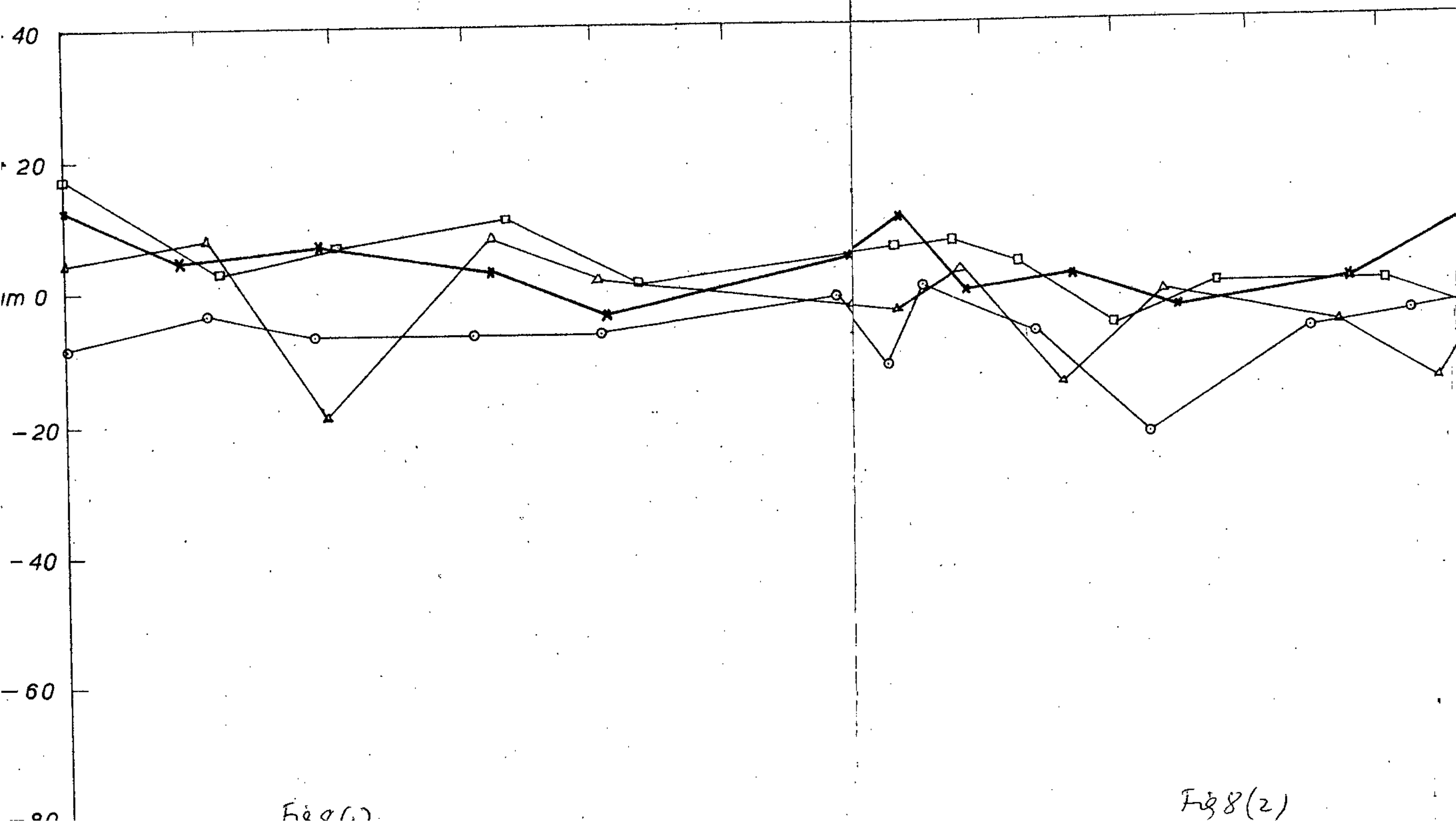
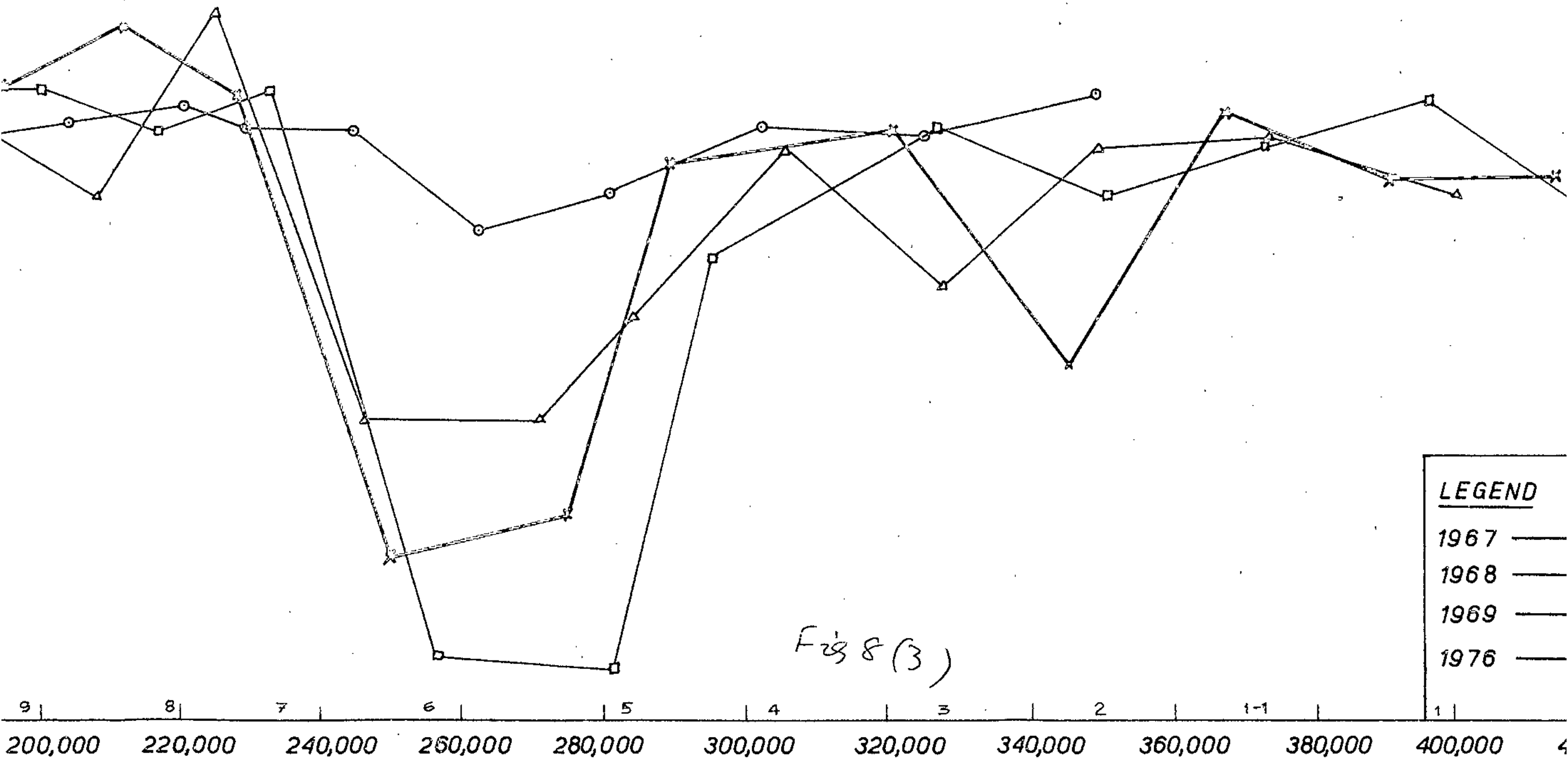
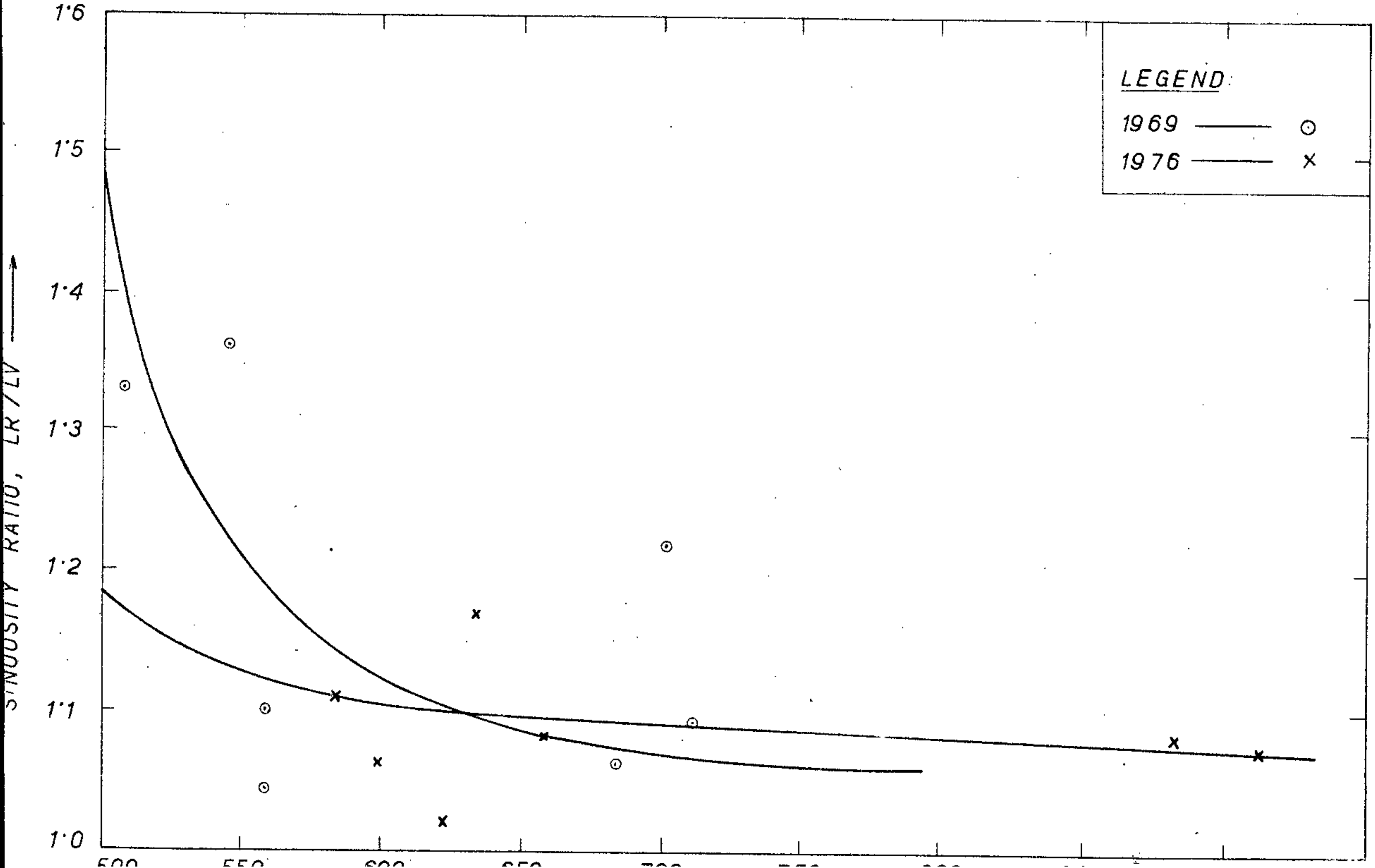


Fig 8(1)

Fig 8(2)



IFEERENT YEARS.



LEGEND:
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1976 ×
SINUOSITY RATIO, LR/LV
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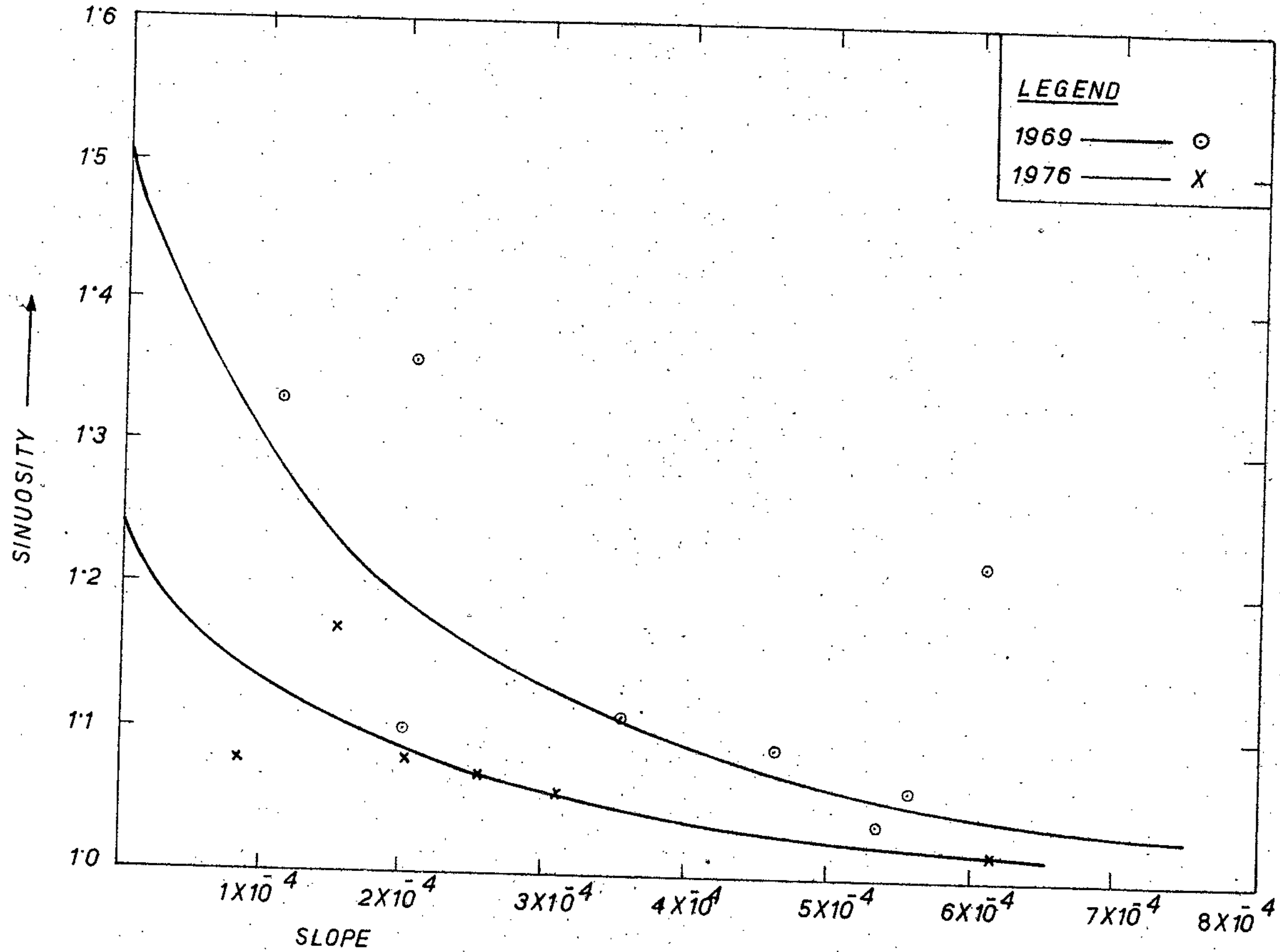


FIG. 10 RELATIONSHIP BETWEEN SINUOSITY AND SLOPE FOR THE YEAR 1969 AND 1976.

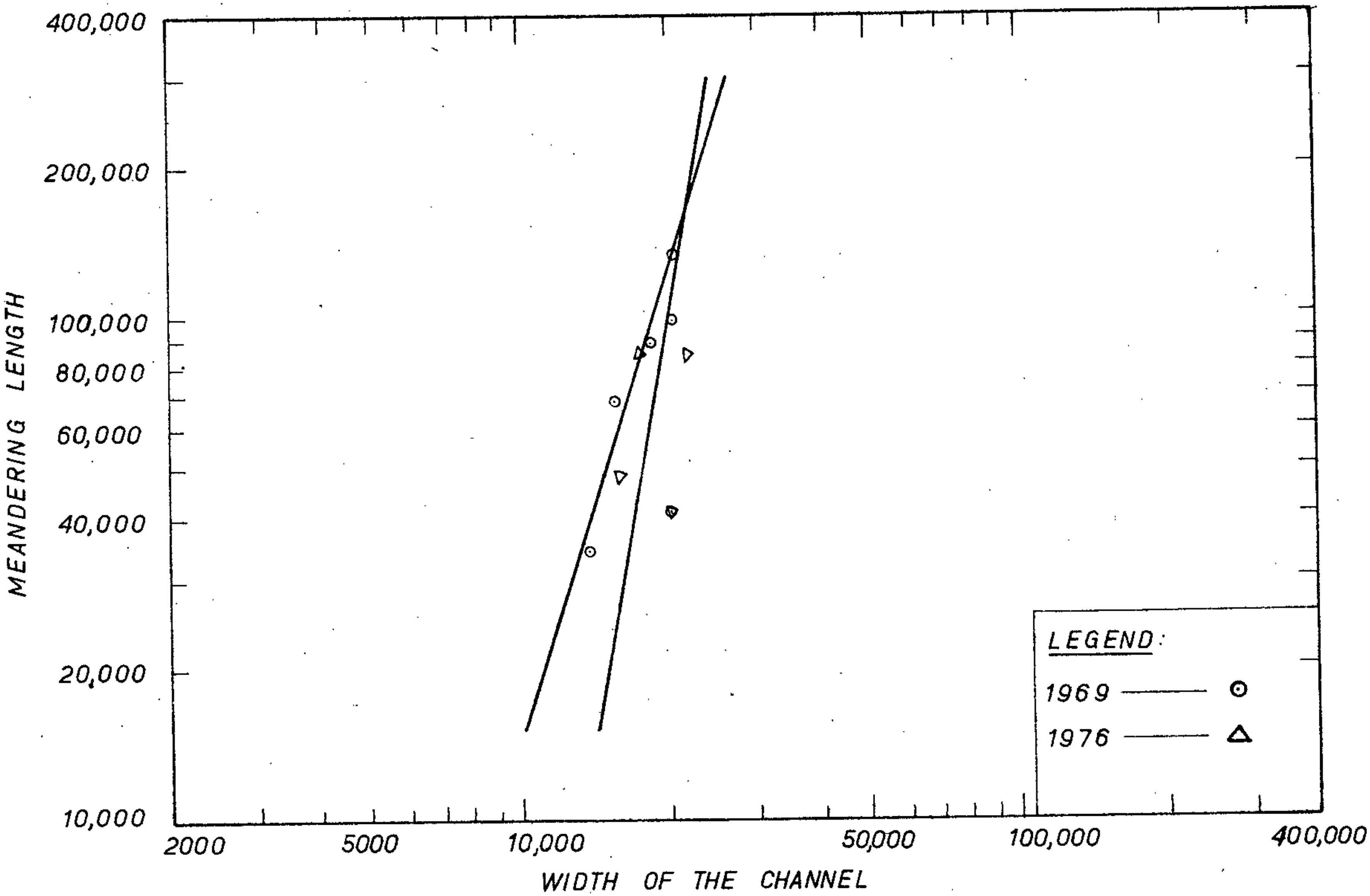


FIG. 11. Relationship between meandering length (wave length) and width of the channel for the year 1969 and 1976.

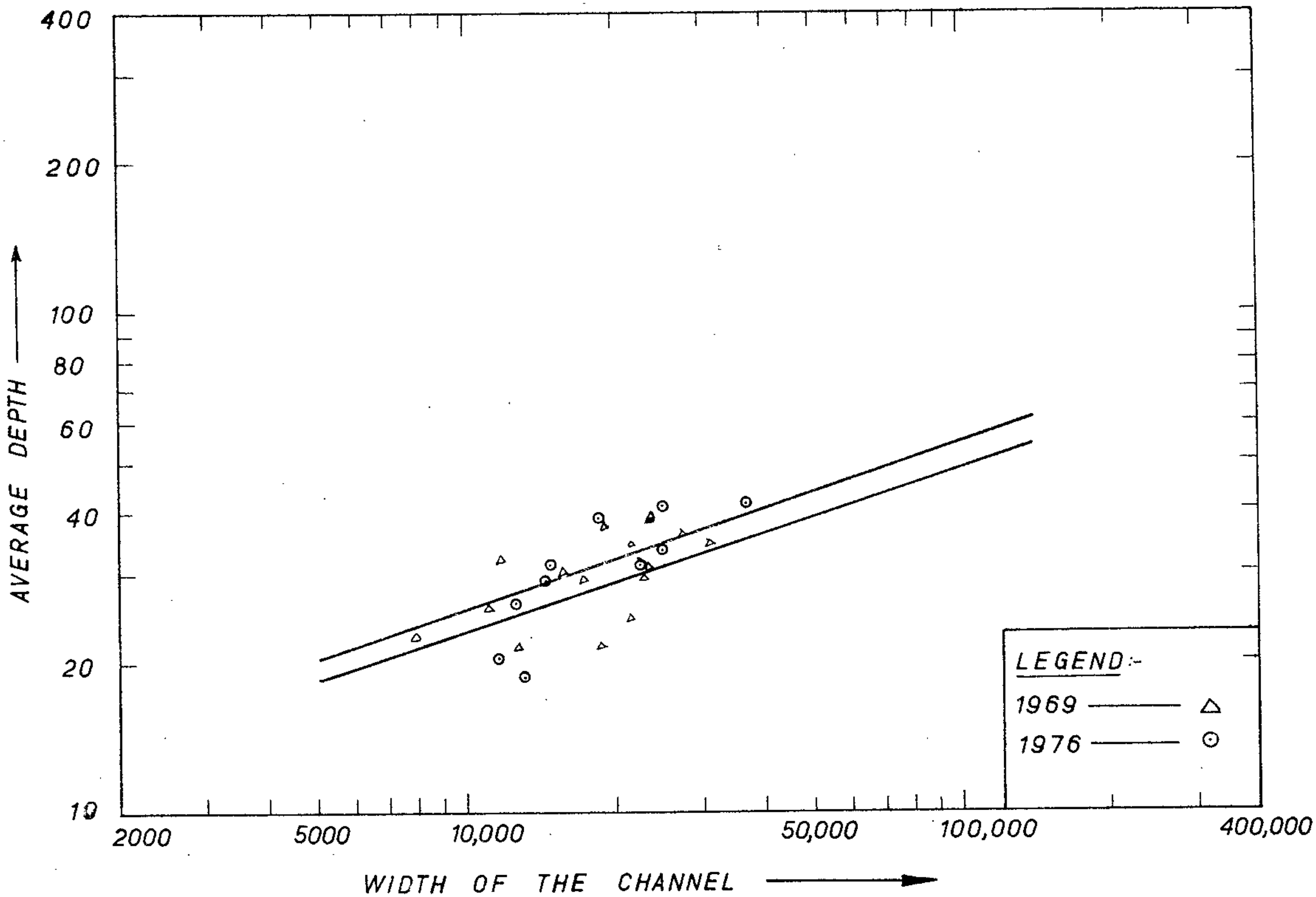


FIG. 12 RELATIONSHIP BETWEEN AVERAGE DEPTH AND WIDTH OF THE CHANNEL FOR DIFFERENT YEARS.

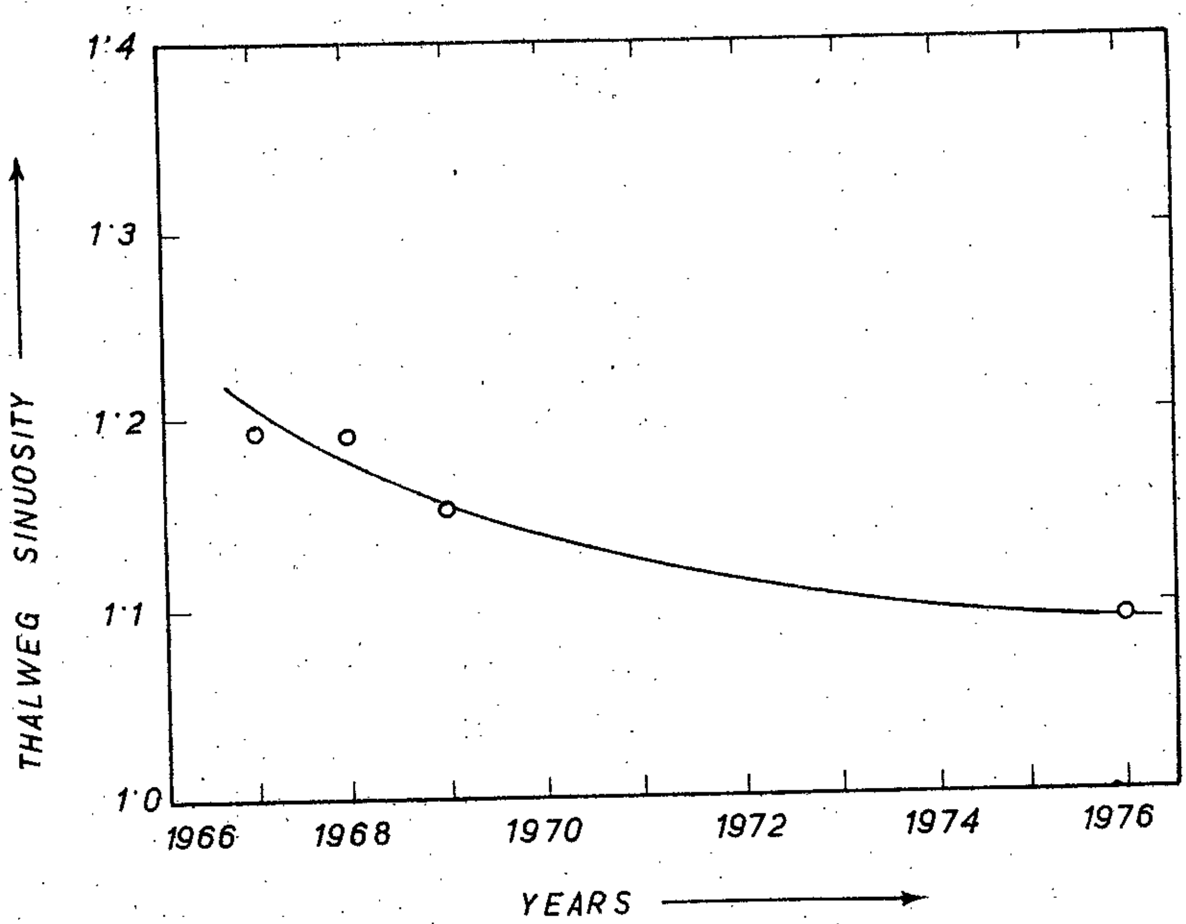


FIG. 13. VARIATION OF THALWEG SINUOSITY BETWEEN 1967 AND 1976.

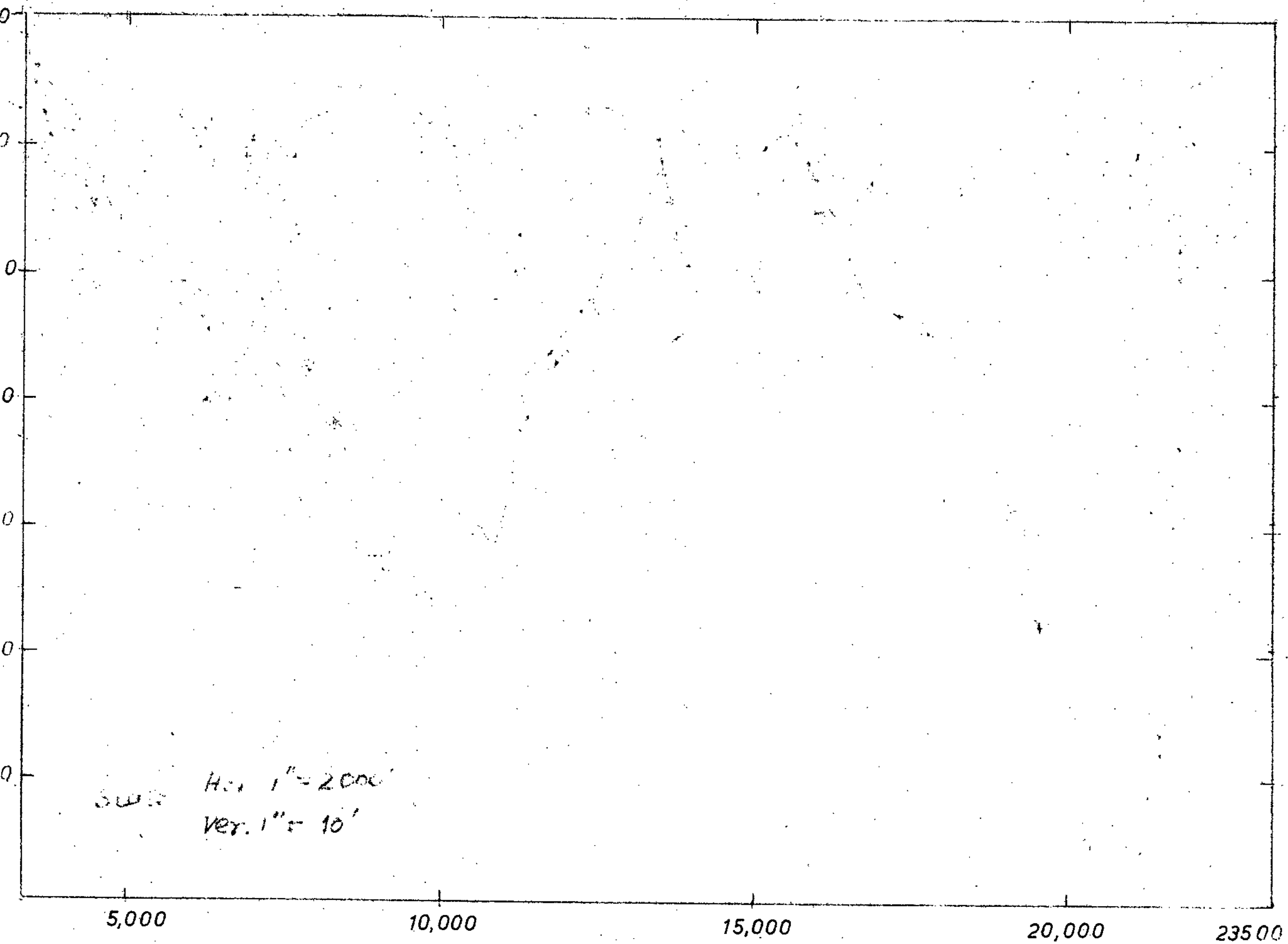


FIG. 14 CROSS SECTION G # 18 IN GANGES RIVER FOR 1967 1968 1969 & 1976.

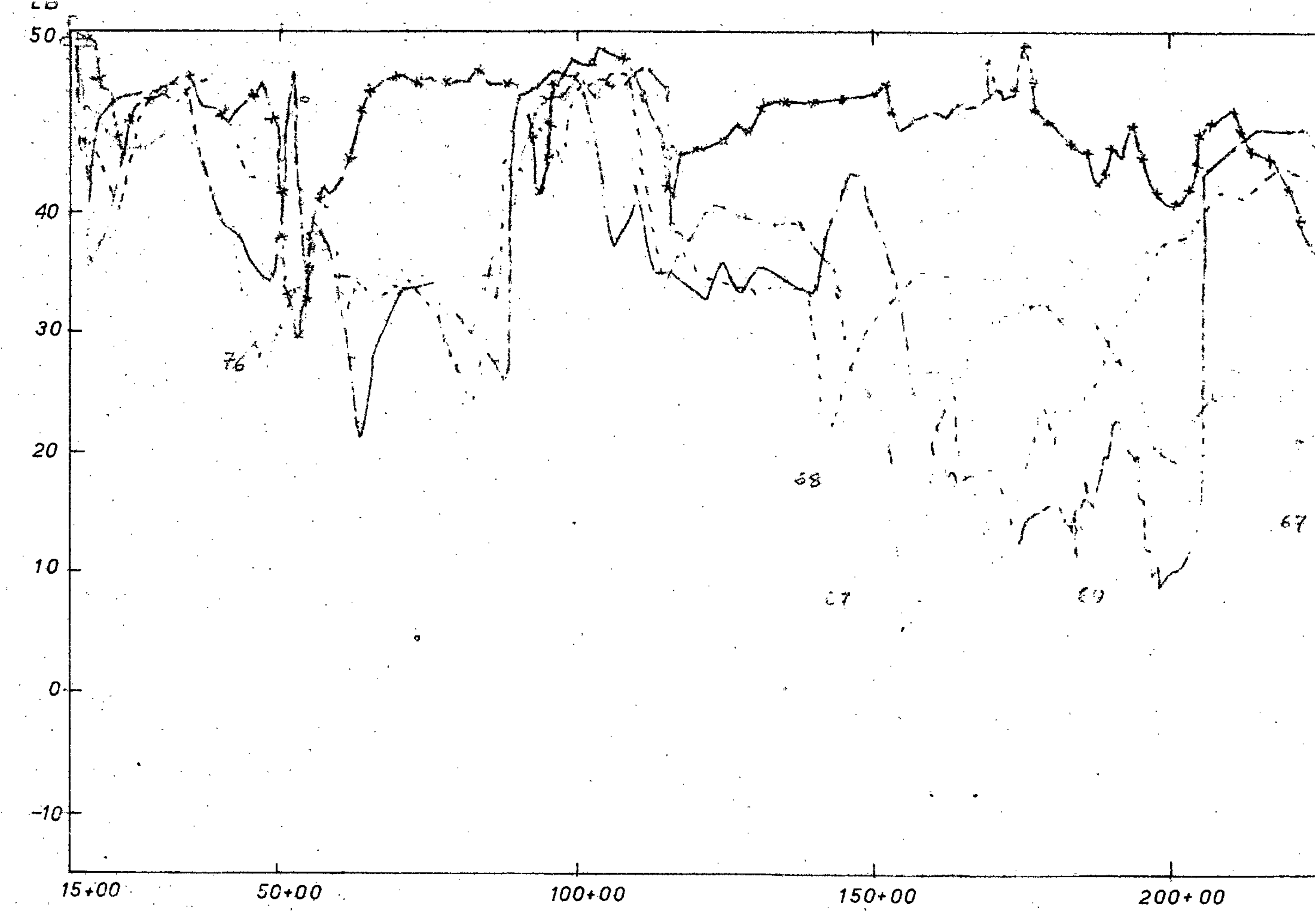


FIG NO. 15 CROSS SECTION G # 17 IN GANGES RIVER FOR 1967, 1968, 1969 & 1976.

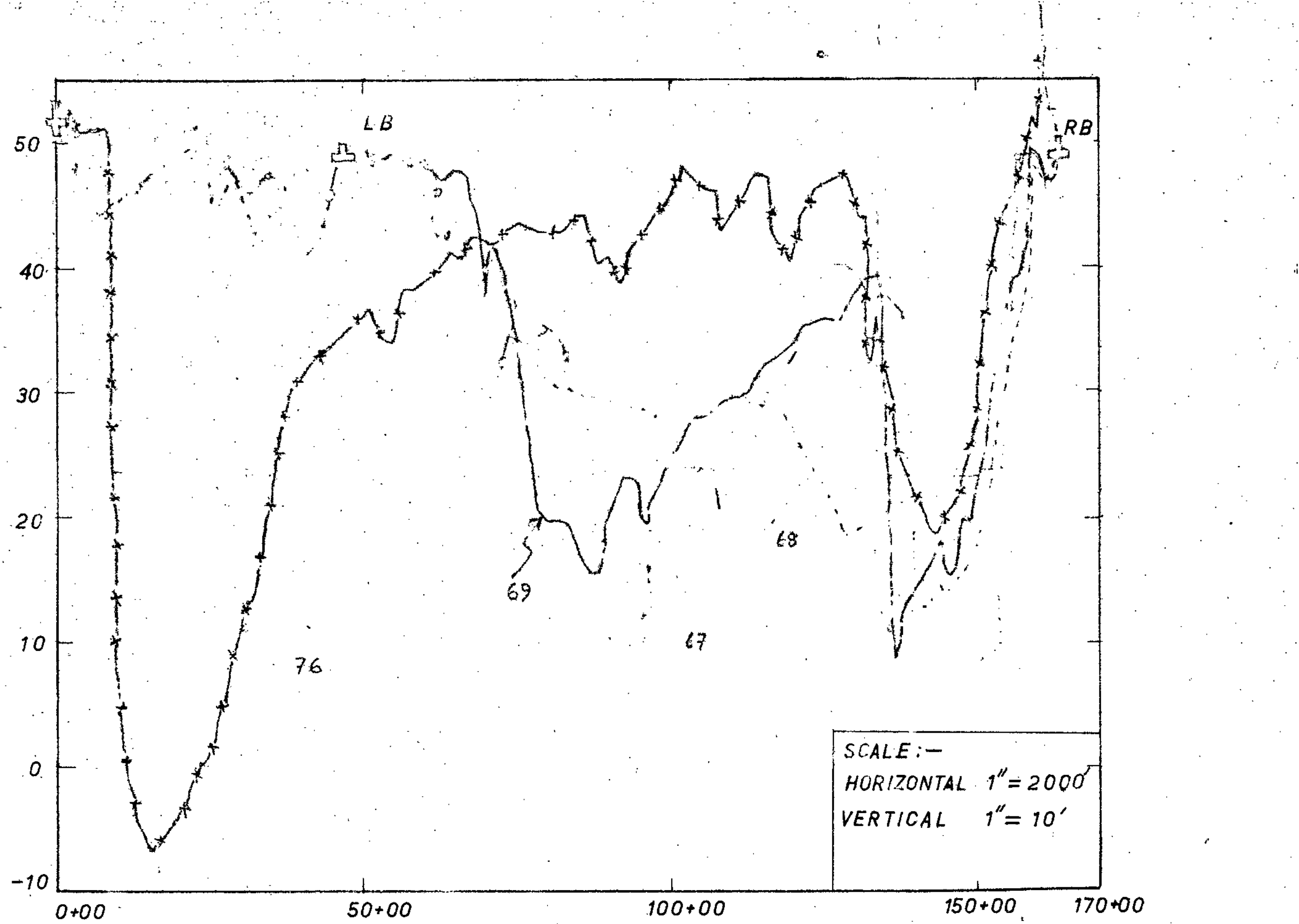
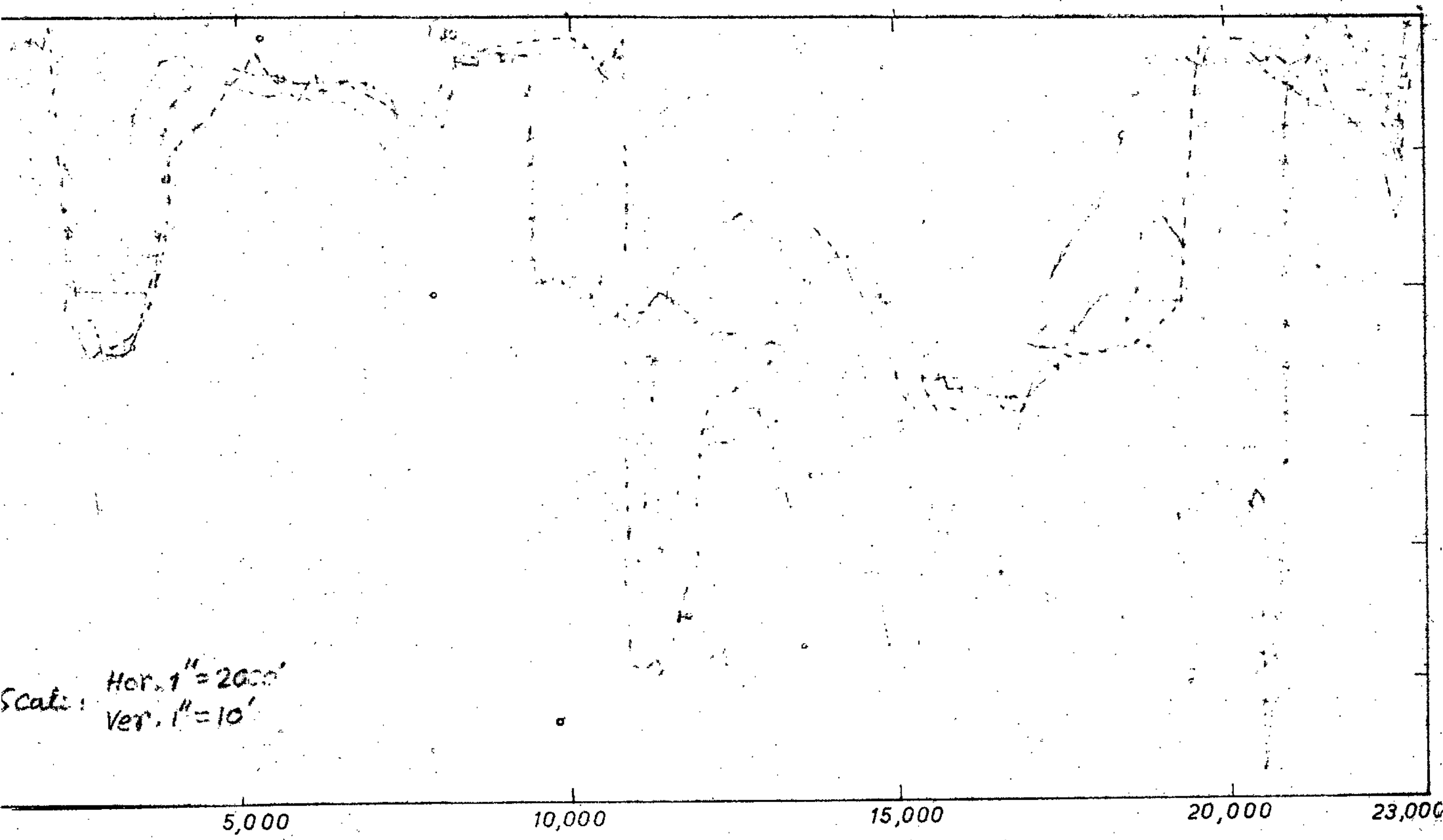


FIG. NO. 17 CROSS SECTION G # 15 IN GANGES RIVER FOR 1967, 1968, 1969 & 1976



8 CROSS SECTION G# 14 IN GANGES RIVER FOR 1967, 1968, 1969, & 1976.

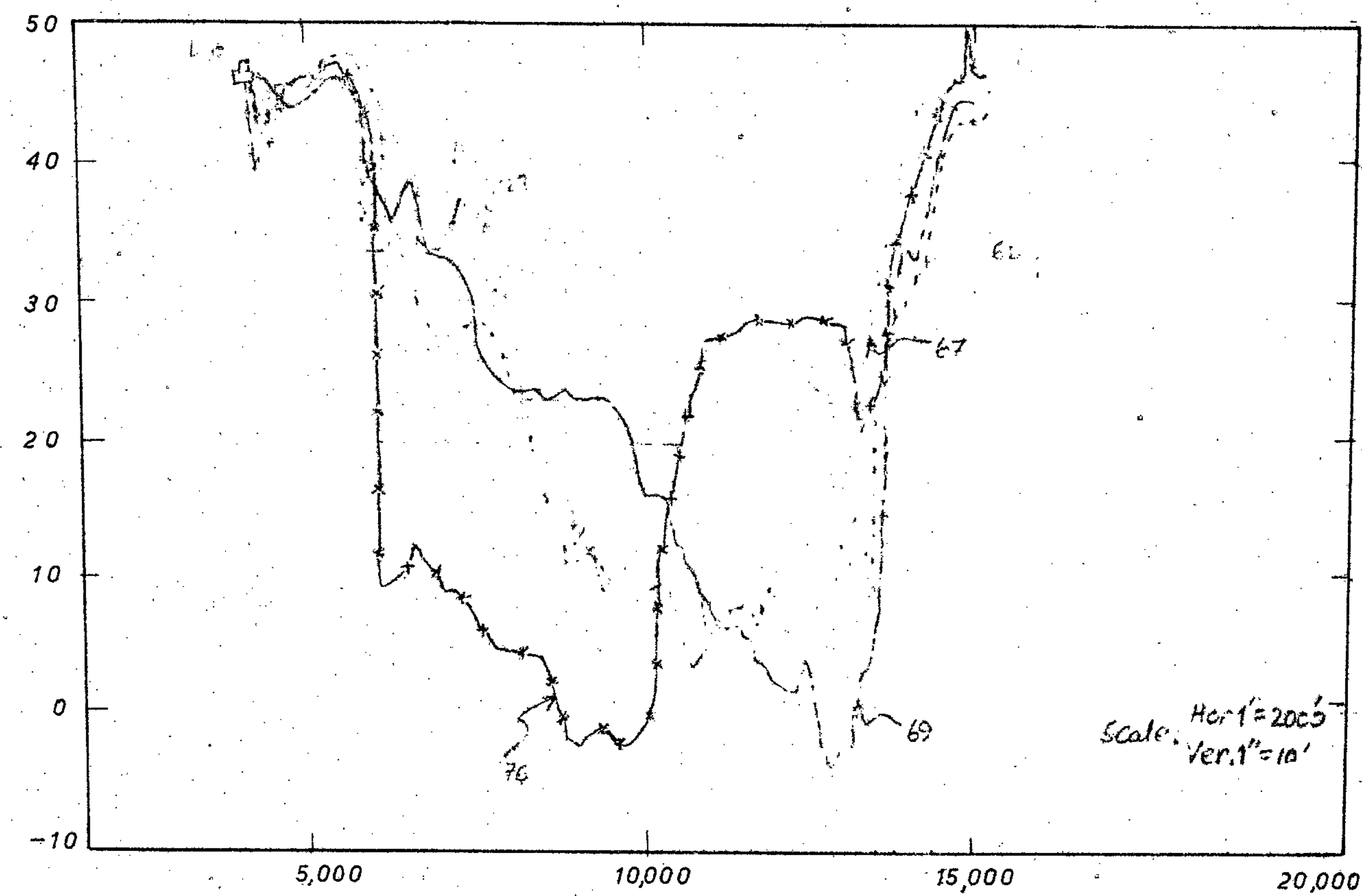
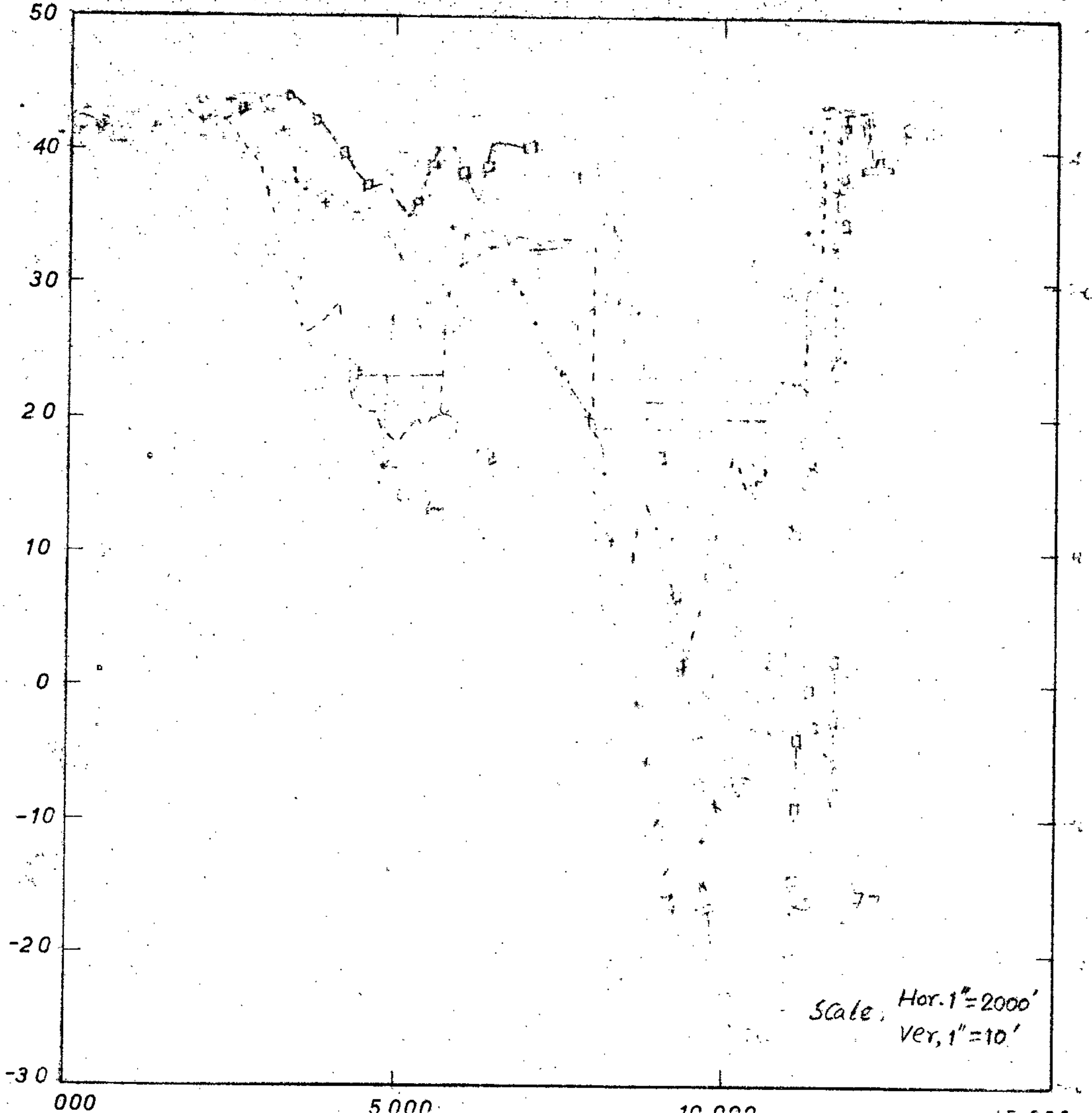


FIG. 19 CROSS SECTION G # 13 IN GANGES RIVER FOR 1967, 1968, 1969, & 1976.



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Scale: Hor. 1" = 2000'
Ver. 1" = 10'

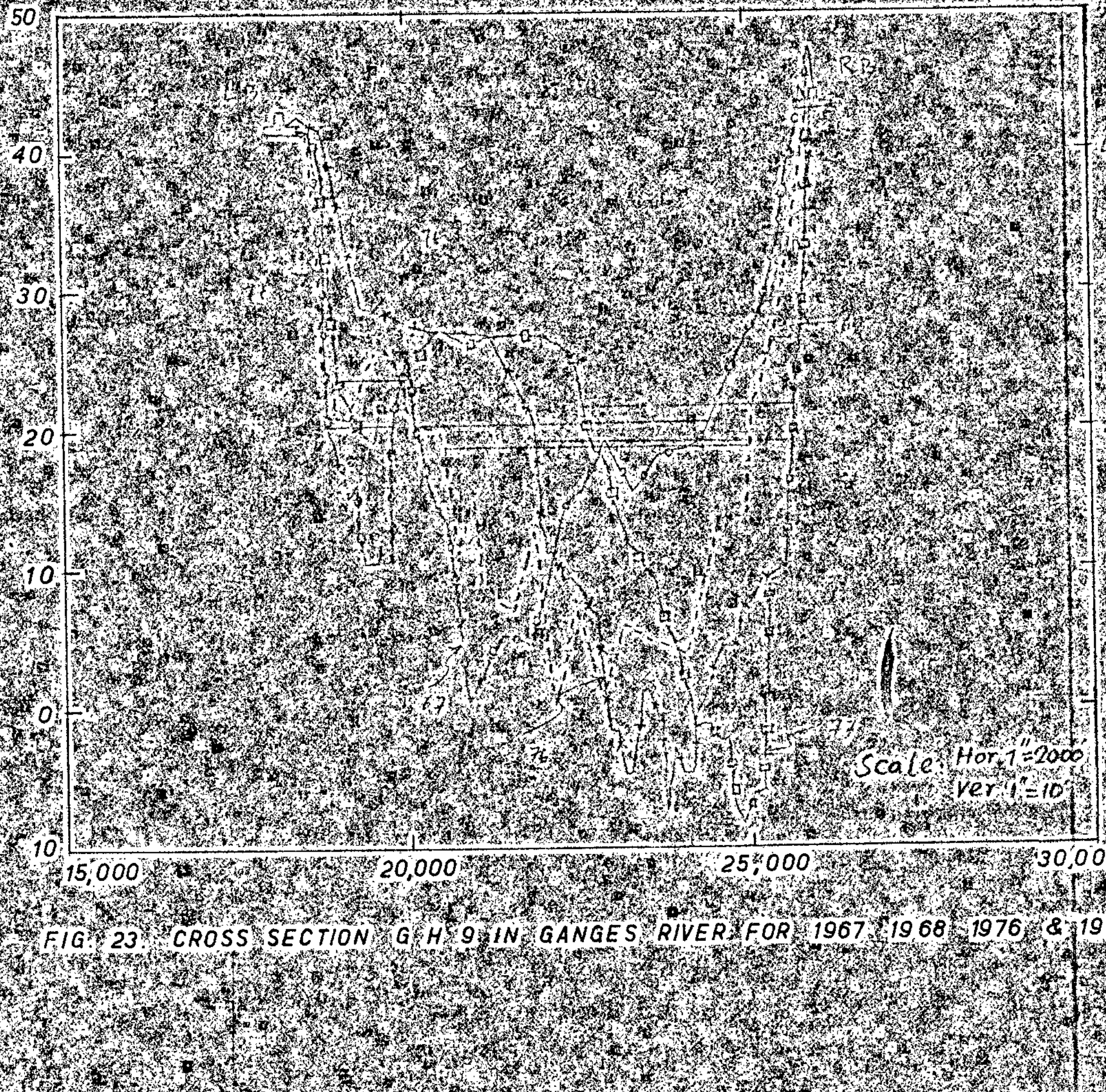


FIG. 23. CROSS SECTION G H 9 IN GANGES RIVER FOR 1967, 1968, 1976 & 1977.

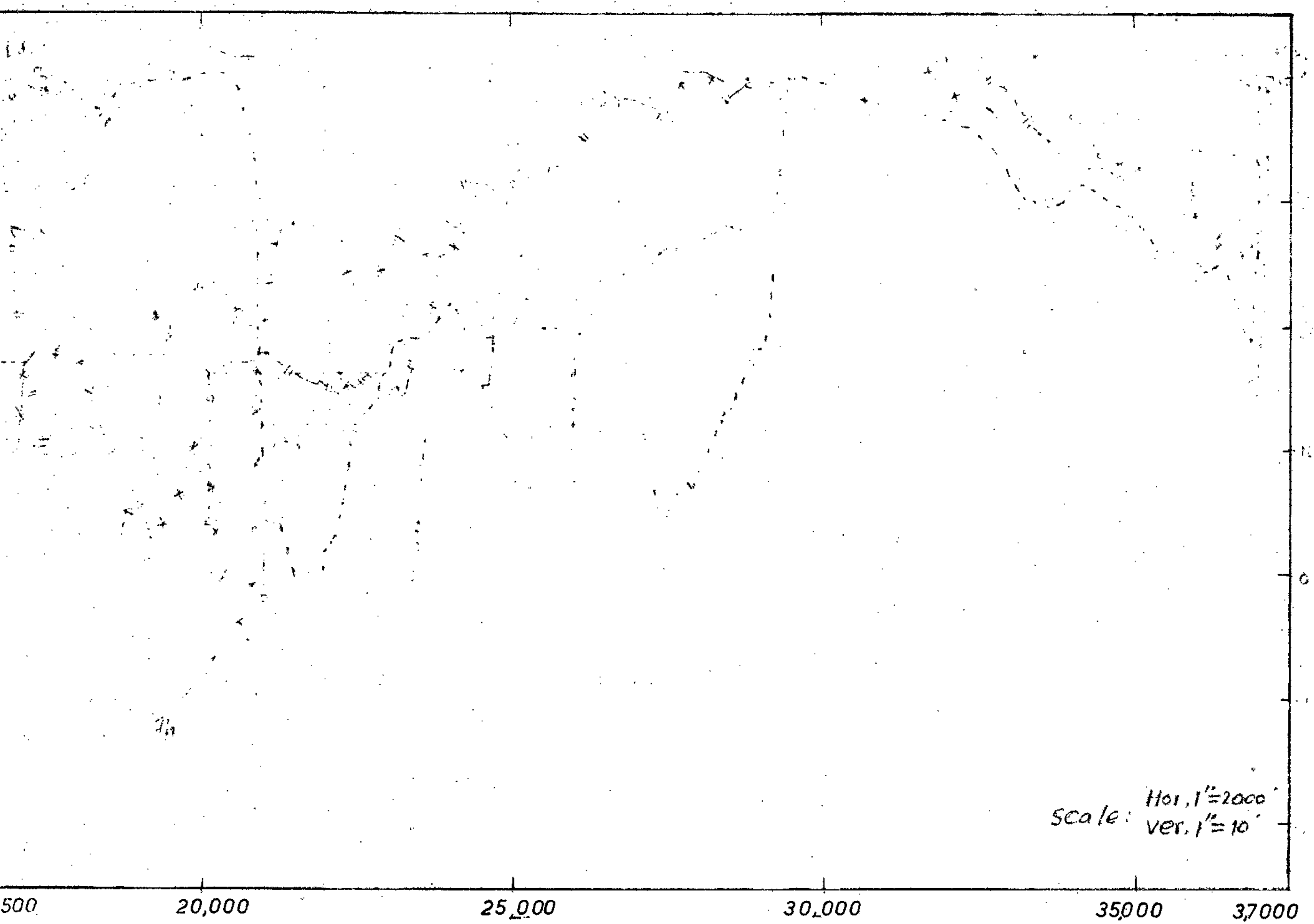


FIG. 25 CROSS SECTION G # 7 IN GANGES RIVER FOR 1974 & 1975.

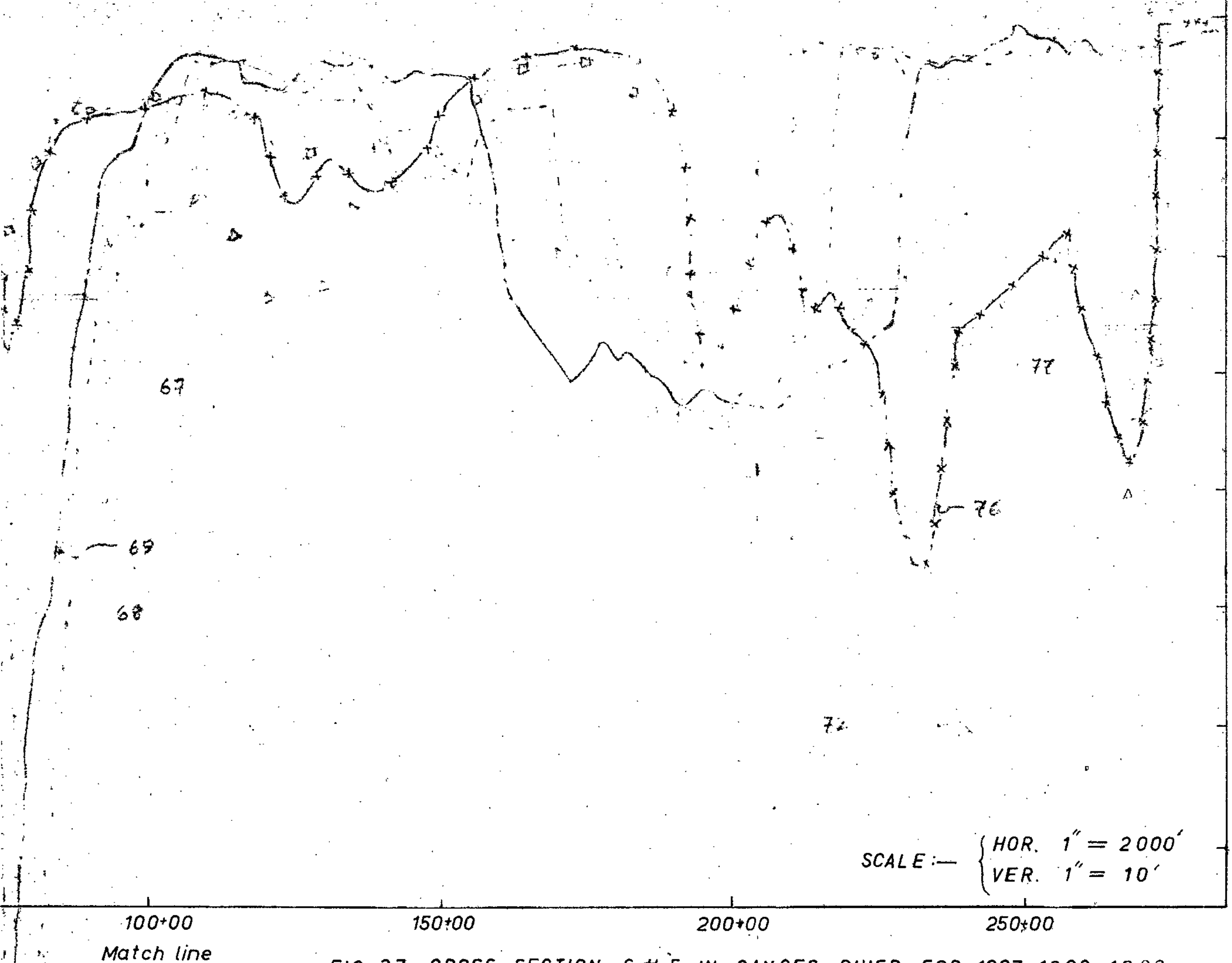


FIG. 27 CROSS SECTION G # 5 IN GANGES RIVER FOR 1967, 1968, 1969, 1976 & 1977

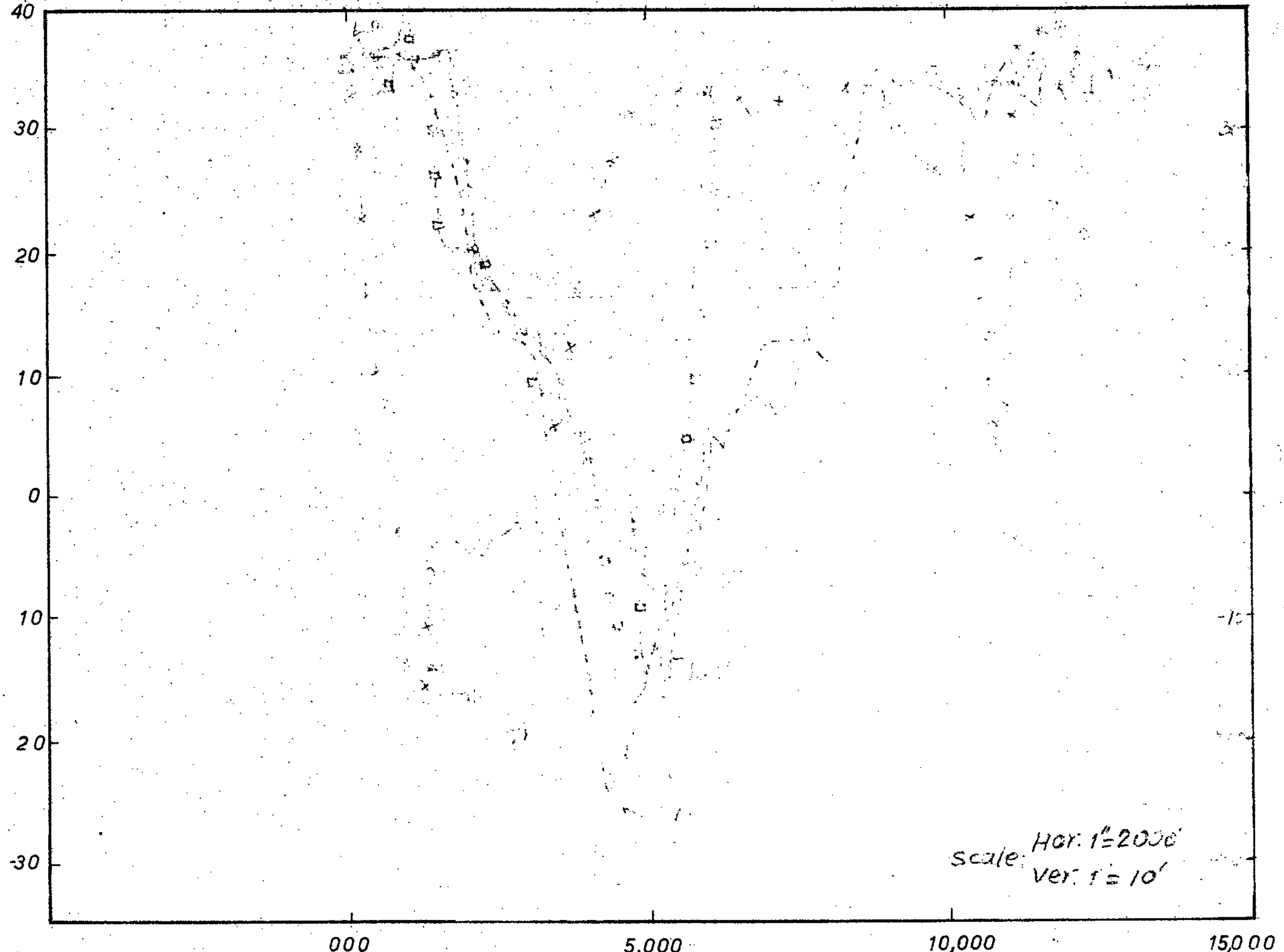
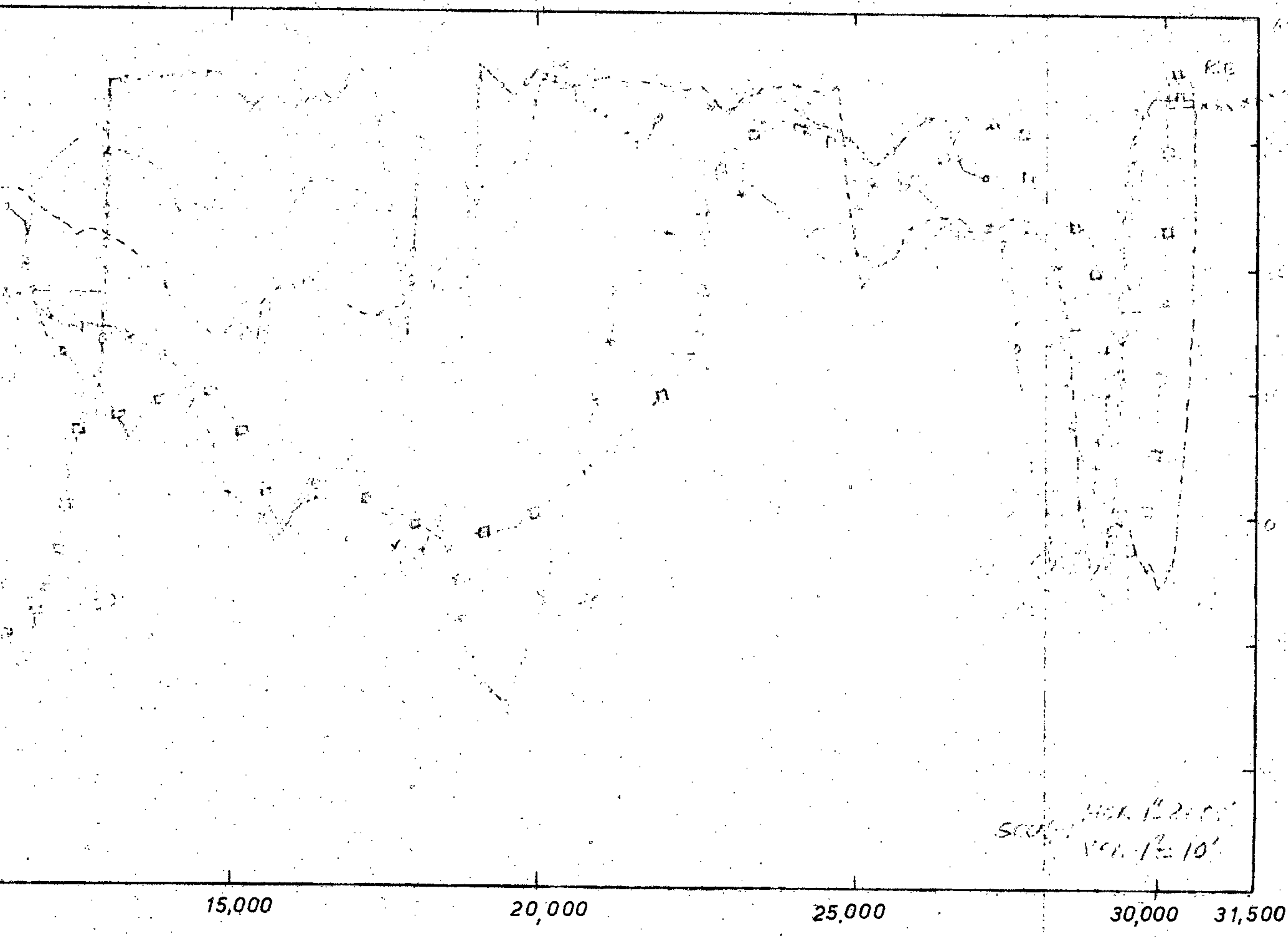


FIG. 28 CROSS SECTION G # 4 IN GANGES RIVER FOR 1967, 1968, 1969, 1976 & 1977.



SS SECTION G # 3 IN GANGES RIVER FOR 1967 1968 1969 1976 & 1977,

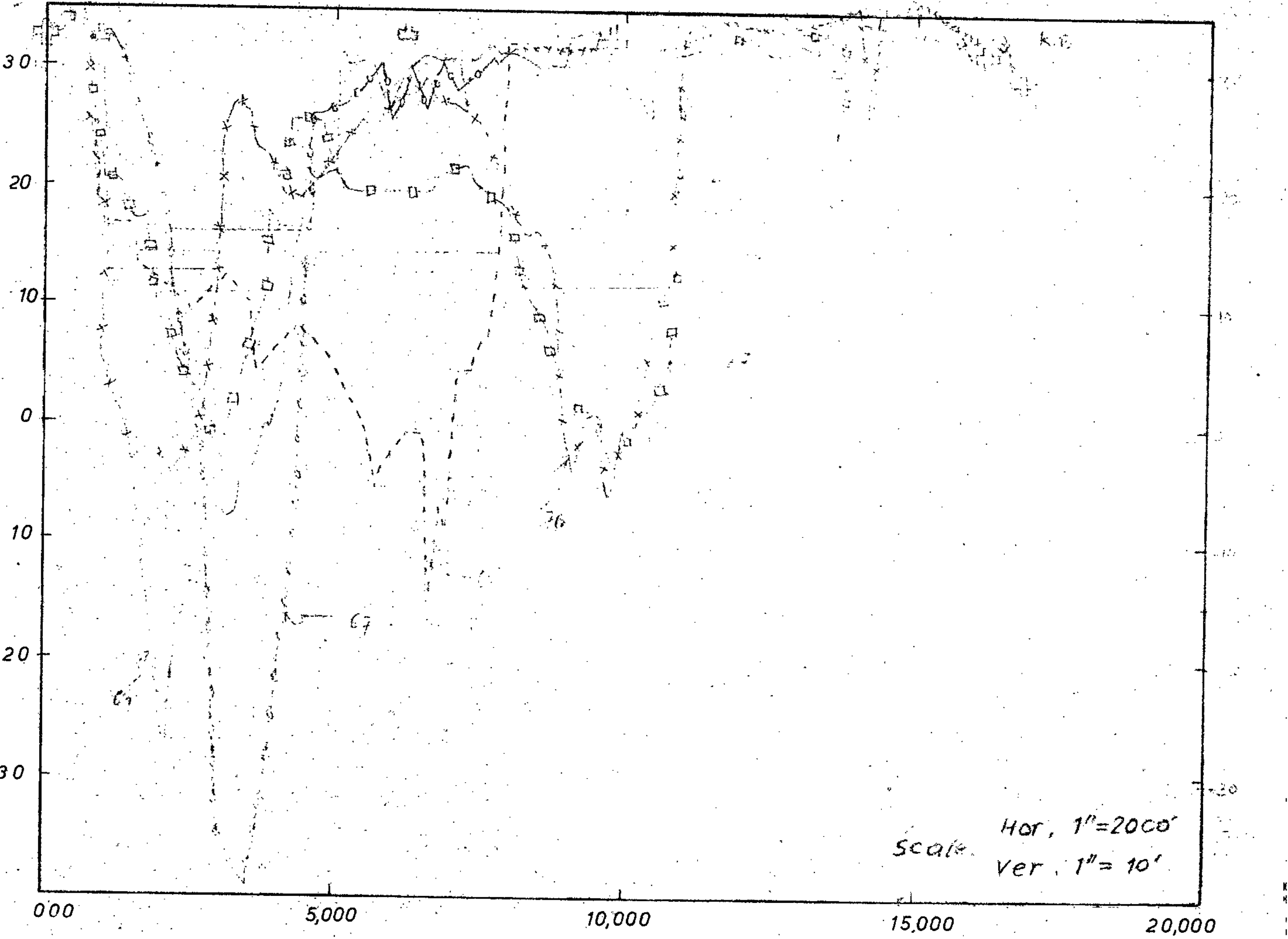


FIG. 30. CROSS SECTION G # 2 IN GANGES RIVER FOR 1967, 1968, 1969, 1976 & 1977

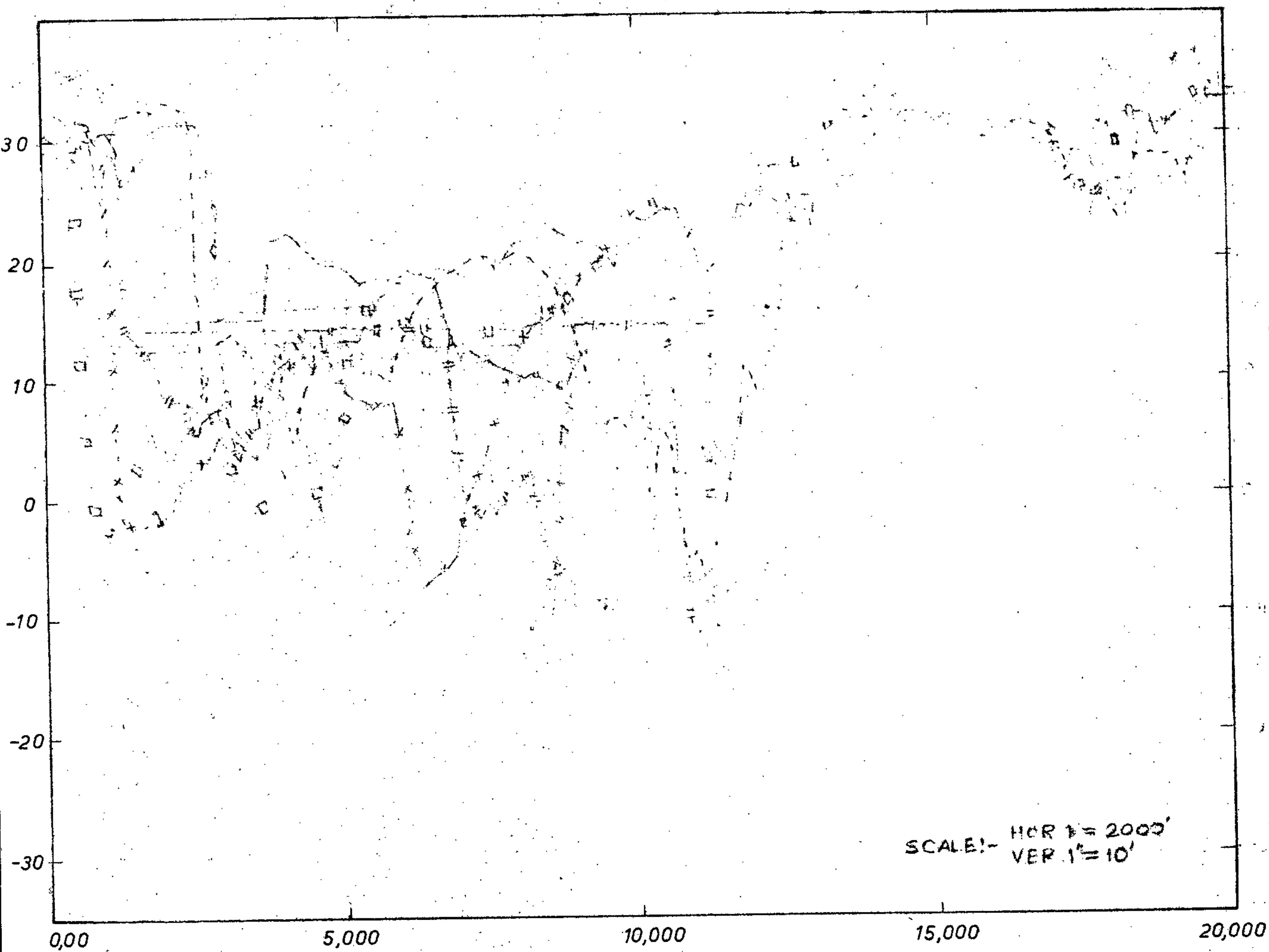
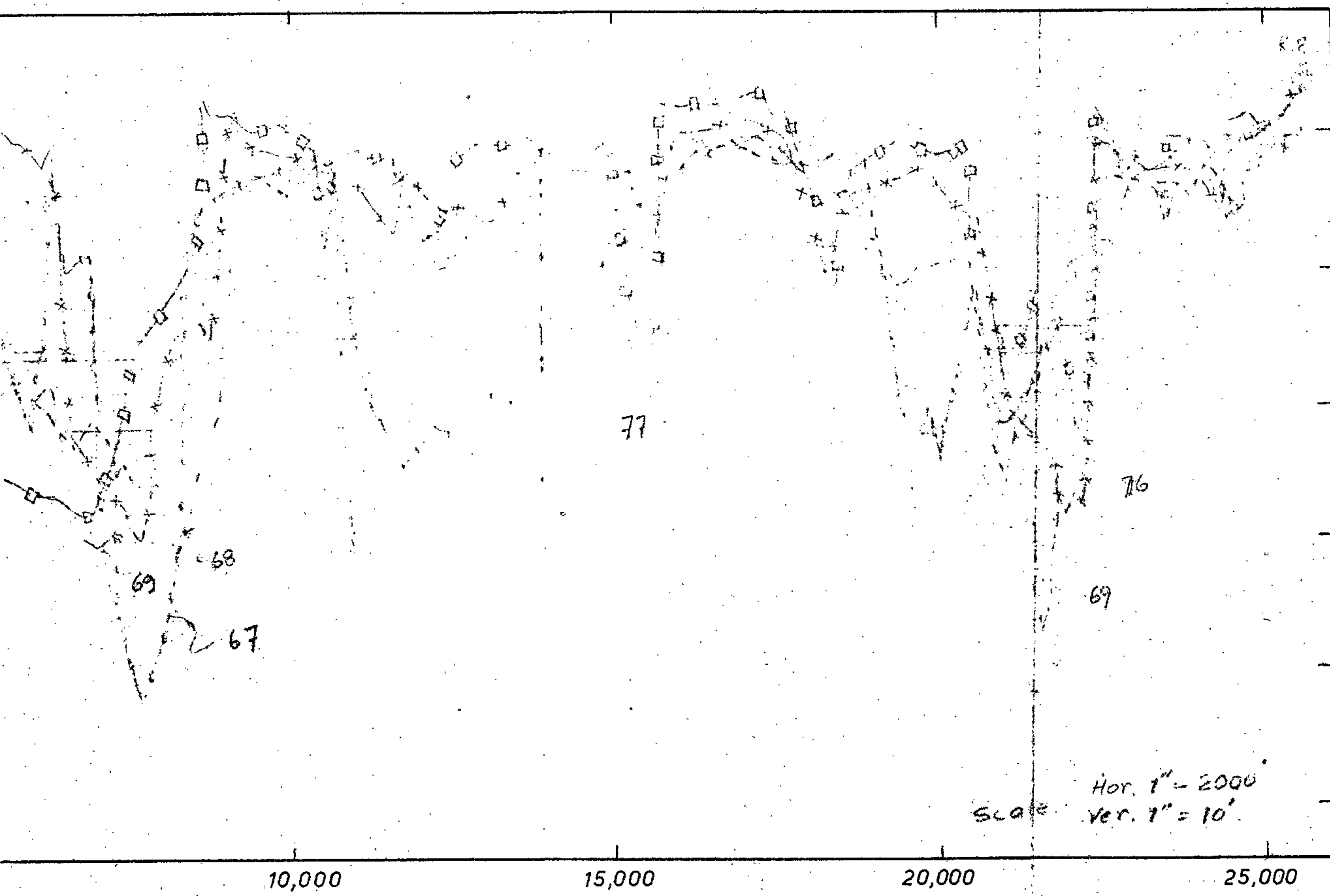


FIG. 31 CROSS SECTION G #1-1 IN GANGES RIVER FOR 1967, 1968, 1969, 1973, 1976,



SECTION G #-1 IN GANGES RIVER FOR 1967, 1968, 1969, 1976 & 1977.

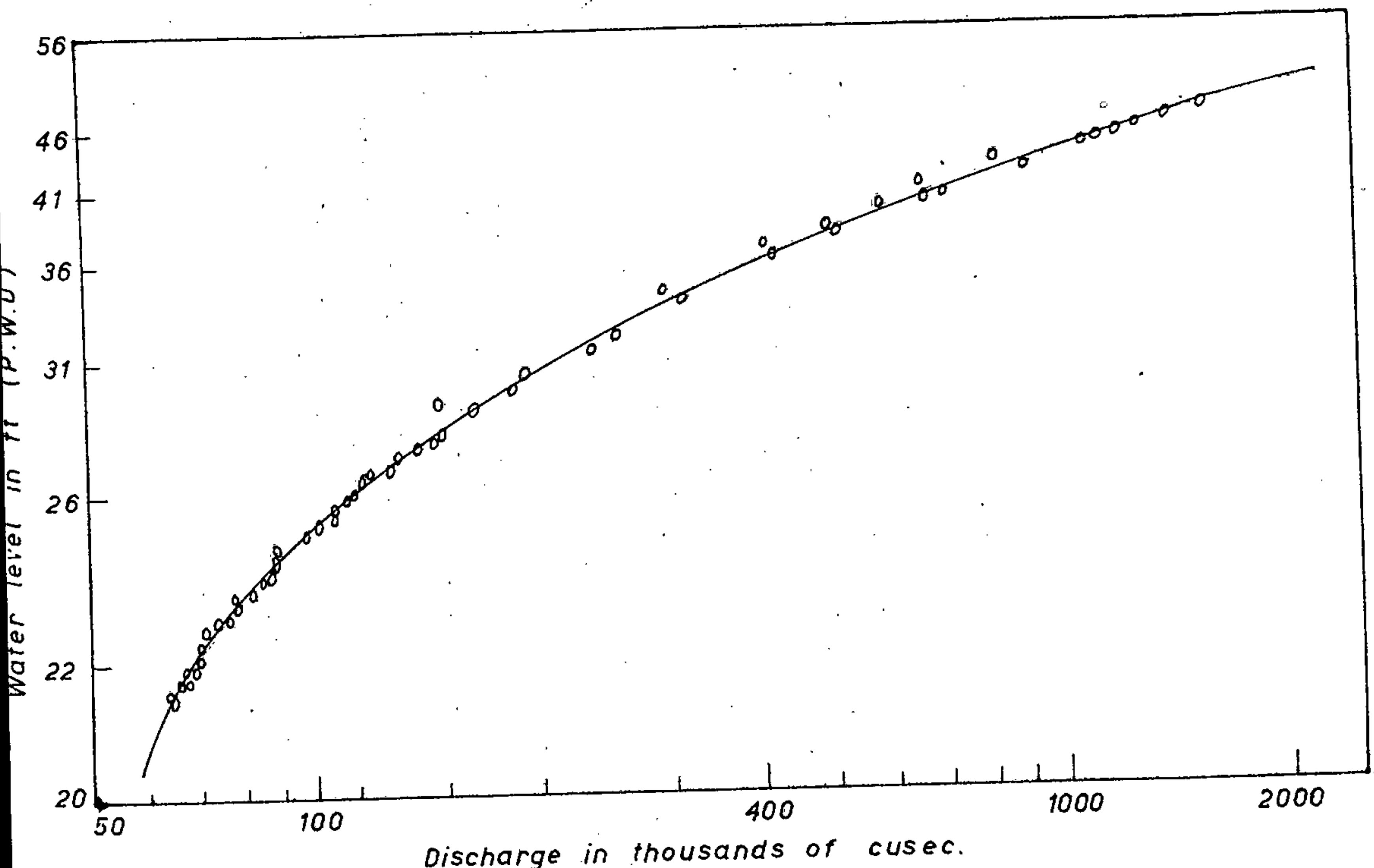
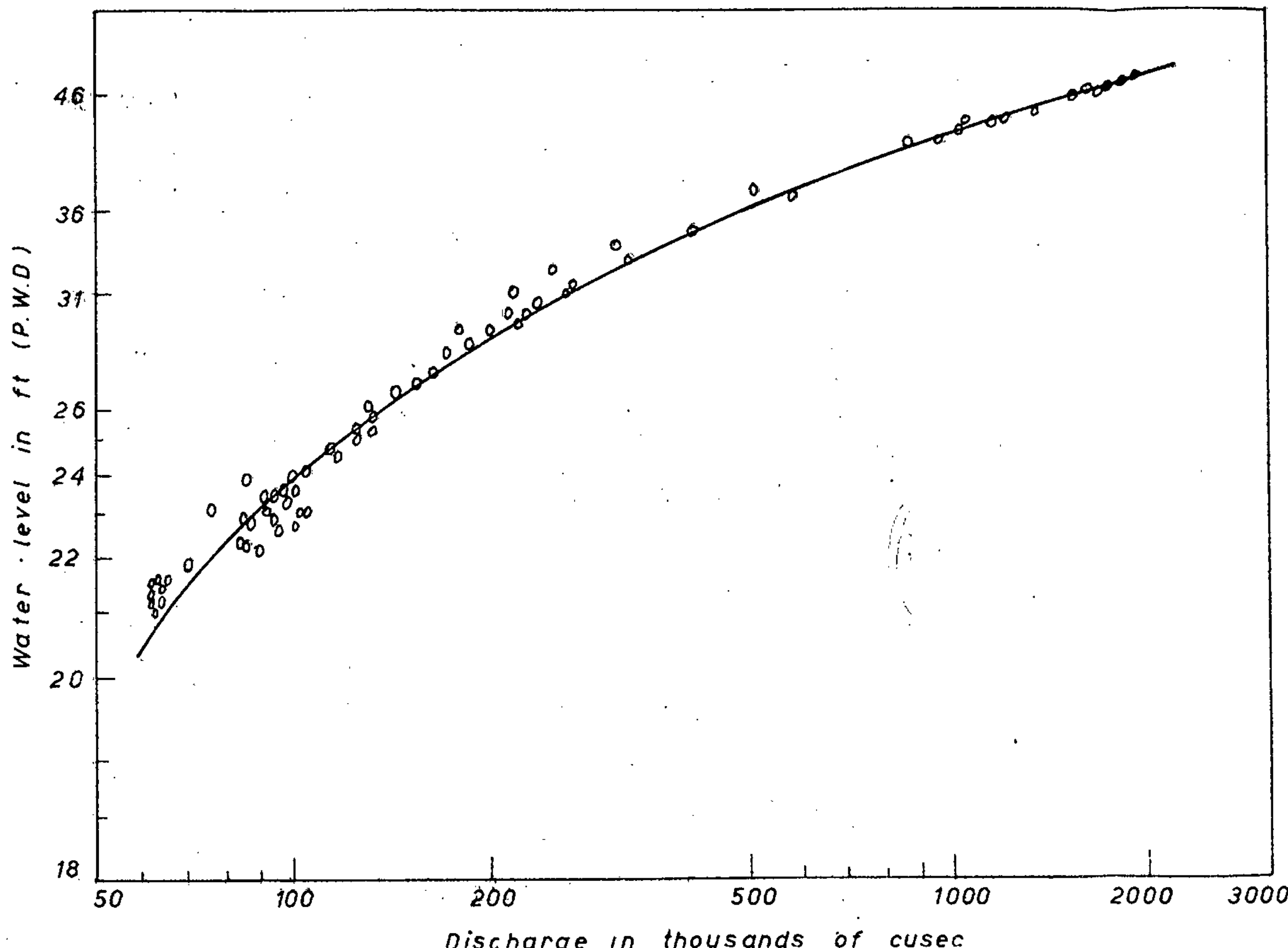


Fig. 33. Rating curve at Hardinge bridge for the year 1968–69.


Water · level in ft (P.W.D)
46
36
31
26
24
22
20
18
50
100
200
500
1000
2000
3000
Discharge in thousands of cusec

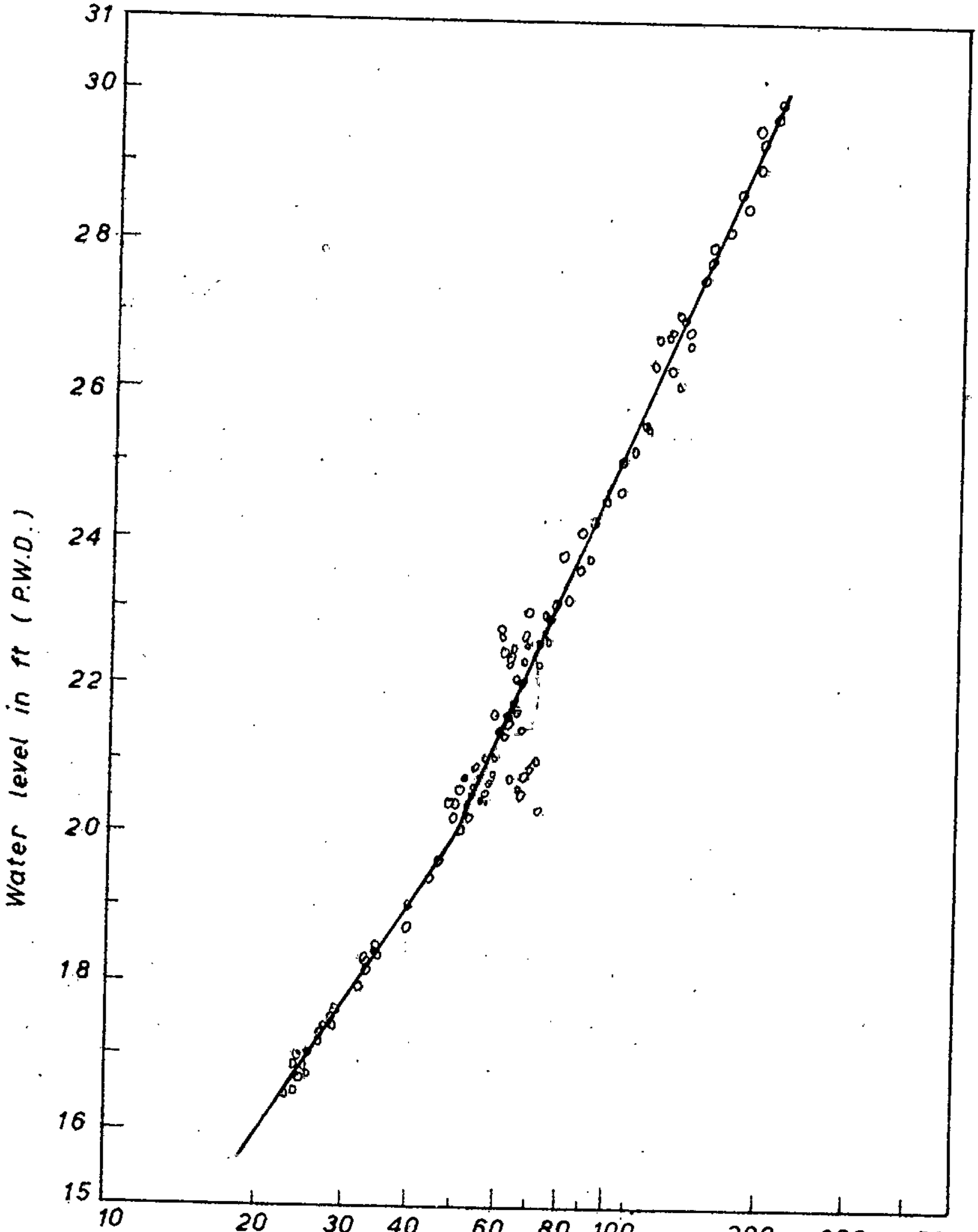


Fig. 35. Rating curve at Hardinge bridge for the year 1975-7

APPENDIX - B

DATA

TABLE - I

Data for locating the thalweg and for plotting the longitudinal profile along thalweg for different years.

X-sections	Years	Co-ordinate of Left bank	Co-ordinate of Right bank	Min. elev. in ft.	Distance of min. elev. from left bank	Length of thalweg line from G#18 towards G#0-1 in ft.
G=#= 18	1967	Latitude N	Latitude N	12.5	10,000	00
	'68	24°11'23.5"	24°08'05.0"	-17.5	8,000	00
	'69	Longitude E	Longitude E	5.0	12,700	00
	'76	88°47'.5.0"	88°45'26.6"	- 9.0	21,200	00
G #= 17	1967	N	N	5.0	15,400	17210.13
	'68	24°04'6.6"	24°11'03.5"	3.5	23,800	23325.55
	'69	E 88°48'51.9"	E 88°49'7.8"	7.5	24,000	21554.42
	'76			3.5	28,300	21387.33
G #= 16	1967	N	N	6.5	29,100	38664.29
	'68	24°04'28.8"	24°10'57.3"	6.0	29,300	40869.84
	'69	E 88°52'18.6"	E 88°51'0.5"	-19.0	29,200	39098.71
	'76			6.5	23,650	37762.00
G=#= 15	1967	N	N	3.0	9,400	64796.93
	'68	24°06'34.6"	24°09'5.1"	10.5	13,500	66935.65
	'69	E 89°56'39.7"	E 89°55'33.7"	8.0	13,650	64095.15
	'76			- 7.0	1,500	61488.57
G #= 14	1967	N	N	- 4.0	15,800	82207.55
	'68	24°06'23.2"	24°09'39.8"	0.5	11,200	87253.61
	'69	E 88°58'13.9"	E 89°01'12.6"	2.5	15,000	80636.91
	'76			- 7.0	20,600	81706.28
G #= 13	1967	N	N	5.0	10,600	118699.68
	'68	24°02'53.4"	24°02'13.1"	7.5	12,800	126419.15
	'69	E 89°04'31.5"	E 89°00'34.1"	- 2.5	12,700	118398.91
	'76			- 0.5	9,500	116861.70
G #= 12	1967	N	N	0.0	10,000	137979.57
	'68	23°58'07.7"	24°01'40.9"	5.0	15,700	144765.98
	'69	E 89°02'9.8"	E 89°03'4.9"	5.0	13,300	136444.47
	'76			0.0	8,000	131732.58

TABLE-I (Continued)

X-sections	Years	Co-ordinate of Left bank	Co-ordinate of Right bank	Min. elev. in ft.	Distance of min. elev. from left bank	Length of thalweg line from G#18 towards G#0-1 in ft.
G #= 11	1967	Latitude N	Latitude N	2.0	23,700	153821.68
	'68	23°56'38.0"	24°01'24.6"	- 7.0	23,500	159469.26
	'69	Longitude E	Longitude E	-11.0	23,600	151148.26
	'76	89°02'22.4"	89°07'19.2"	- 5.0	22,500	147773.08
G #= 10	1967			- 4.0	29,700	169962.43
	'68	N 23°56'18.4"	N 24°00'49.8"	- 1.0	28,200	175910.77
	'69	E 89°07'42.1"	E 89°10'44.3"	- 1.0	28,300	167355.84
	'76			-22.5	28,000	164147.75
G #= 9	1967			0.0	20,800	195359.88
	'68	N 23°59'45.9"	N 23°54'28.7"	0.0	22,200	200639.87
	'69	E 89°12'51.5"	E 89°12'18.2"	- 8.5	25,300	193254.56
	'76			- 7.5	23,800	188542.67
G #= 8	1967			8.5	22,800	212068.73
	'68	N 23°59'27.3"	N 23°54'25.0"	- 7.5	23,700	217014.54
	'69	E 89°16'41.9"	E 89°15'1.9"	-13.5	22,300	208793.79
	'76			5.0	24,500	204081.90
G #= 7	1967			- 1.5	23,500	228109.23
	'68	N 23°51'32.1"	N 23°58'31.4"	- 1.0	21,500	233222.12
	'69	E 89°17'11.6"	E 89°19'25.9"	1.0	21,100	224500.11
	'76			- 6.0	20,750	220122.86
G ## 6	1967			-66.7	12,600	250265.17
	'68	N 23°52'46.4"	N 23°57'51.3"	-81.2	12,500	256012.99
	'69	E 89°21'52.0"	E 89°19'39.1"	-47.5	12,800	246889.97
	'76			- 6.0	4,300	229646.9[illegible]
G=#= 5	1967			-61.7	7,800	275996.80
	'68	N 23°55'38.7"	N 23°52'46.2"	-82.5	7,700	281744.62
	'69	E 89°26'30.2"	E 89°21'52.1"	-47.1	7,500	271786.16
	'76			- 6.0	23,300	245019.04

TABLE - I (Continued)

X-sections	Year	Co-ordinate of Left bank	Co-ordinate of Right bank	Min elev. in ft.	Distance of min. elev. from left bank	Length of thalweg line from G#=18 towards G#=0-1 in ft.
G # 4	1967	Latitude N	Latitude N	-11.0	4,800	289698.06
	'68	23°52'24.4"	23°50'50.3"	-24.0	4,300	295512.71
	'69	Longitude E	Longitude E	-32.0	4,000	284651.97
	'76	89°27'0.8"	89°23'45.3"	-20.0	1,000	263064.60
G # 3	1967	23°52'15.1" N	23°47'16.5" N	- 6.0	29,100	321511.71
	'68			- 5.0	30,000	327593.70
	'69	89°29'23.3" E	89°29'0.5" E	- 9.5	17,900	306540.86
	'76			-15.0	12,600	281778.51
G # 2	1967	23°46'50.6" N	23°50'58.6" N	-39.0	12,000	345171.44
	'68			-15.5	15,100	350484.82
	'69	89°32'44.5" E	89°33'7.3" E	-28.0	10,600	328095.29
	'76			- 6.0	9,700	303834.19
G # 1-1	1967	23°50'43.9" N	23°47'55.8" N	- 3.5	10,600	366959.78
	'68			- 8.0	11,300	372440.25
	'69	89°36'41.9" E	89°36'39.4" E	- 8.5	12,700	349482.62
	'76			- 7.5	6,300	325054.43
G # 1	1967	23°45'29.7" N	23°49'44.4" N	-12.5	7,700	391354.70
	'68			- 2.0	6,300	396634.66
	'69	89°40'30.6" E	89°41'10.1" E	-15.0	8,250	373042.10
	'76			0.0	7,700	349783.53
G=# 01	1967	23°49'32.1" N	23°43'46.3" N	-12.0	5,600	414078.74
	'68			-21.0	22,200	429250.34
	'69	89°45'54.3" E	89°45'41.2" E	-15.0	7,500	400778.69
	'76					

TABLE - II

Data for drawing the bank lines for differert years on the course map and also for finding out the relationship between average depth and average width of the river for different years.

X-sections	Years	Length of Ref.line from G#18 towards G#1 in ft.	From Ref. point Distance of left bank in ft.	From Ref. pt.Dist.of Right bank in ft.	Average depth in ft.	Average width in ft.
G # 18	1956	00	7752.91	10092.15	40.43	18400
	1968	00	7880.58	7953.41	39.30	18400
	1969	00	7752.90	8788.86	39.85	18400
	1976	00	7953.41	10626.83	39.45	18400
G # 17	1956	16642.01	11863.28	8020.25	36.44	28650
	'68	,,	12631.89	11194.93	38.14	30250
	'69	,,	12698.73	10793.92	36.09	27050
	'76	,,	12464.80	14669.61	40.36	24900
G # 16	1956	31746,81	13032.90	9858.22	41.47	37380
	'68	,,	17159.99	11529.12	43.61	36120
	'69	,,	17210.12	12531.64	39.43	23350
	'76	,,	16842.52	13968.60	41.80	36650
G # 15	1956	57598.69	9423.79	1604.05	35.60	16150
	'68	,,	4010.12	5848.10	34.23	13900
	'69	,,	3475.44	5681.00	32.34	11700
	'76	,,	9189.87	6082.02	33.04	15000
G # 14	1956	74889.06	5280.00	5814.68	35.09	21000
	'68	,,	4344.30	4511.39	34.71	21100
	'69	,,	4812.15	4878.98	34.72	21400
	'76	,,	5814.68	5948.35	29.56	14600
G # 13	1956	110044.48	4210.63	5413.67	30.16	12600
	'68	,,	5012.66	3475.44	28.06	12500
	'69	,,	4945.82	3675.95	26.15	11000
	'76	,,	5413.67	3174.68	26.52	12400

TABLE -II (Continued)

X-sections	Years	Length of Ref. line from G#18 towards G#1 in ft.	From Ref. point Distance of left bank in ft.	From Ref. pt. Dist. of Right bank in ft.	Average depth in ft.	Average width in ft.
G # 12	1956	127354.85	6683.54	8521.51	29.85	20400
	'68	,,	6449.62	5747.84	33.49	21800
	'69	,,	6349.36	5781.26	28.12	17200
	'76	,,	6917.46	7686.07	28.98	22100
G # 11	1956	140053.58	11027.84	6750.37	34.57	23400
	'68	,,	6282.53	8020.25	33.00	23600
	'69	,,	5580.75	7452.15	30.50	15500
	'76	,,	3274.93	7886.58	29.27	16300
G # 10	1956	156628.76	17544.29	4611.64	22.19	12200
	'68	,,	4611.64	4845.56		
	'69	,,	3375.19	4245.31	34.08	30450
	'76	,,	3675.95	5012.65	26.62	12200
G # 9	1956	180522.42	22055.68	2172.15		
	'68	,,	3909.87	3542.28	30.80	25600
	'69	,,	3508.86	3408.61	22.45	7800
	'76	,,	3675.95	3675.95	33.29	25100
G # 8	1956	197231.27	19048.09	8153.92		
	'68	,,	7552.40	9475.21	28.46	28300
	'69	,,	8287.59	8955.94	29.84	22900
	'76	,,	3241.52	7351.89	30.21	22900
G # 7	1956	213438.85	15806.57	6683.54		
	'68	,,	2025.06	6934.17	31.16	35600
	'69	,,	1670.89	6850.63	31.01	23000
	'76	,,	7017.72	2840.50	29.45	23400
G # 6	1956	231484.41	2472.91	200 .51		
	'68	,,	267.34	3776.20	27.65	15400
	'69	,,	935.70	3876.45	30.35	15800
	'75	,,	8020.25	2071.90	28.00	23100

TABLE - II (Continued)

X-sections	Year	Length of Ref.line from G#18 towards G #1 in ft.	From Ref. point Distance of left bank in ft.	From Ref. pt. Dist of Right bank in ft.	Average depth in ft.	Average width in ft.
G #= 5	1956	249930.98	6182.27	668.35		
	'68	,,	8287.59	11863.28	22.86	21000
	'69	,,	8421.26	11999.49	24.06	21100
	'76	,,	8103.79	12063.80	24.17	20400
G #= 4	1956	262729.98	3943.29	2172.15		
	'68	,,	4611.64	3107.85	14.06	10200
	'69	,,	3809.62	4745.31	14.51	94500
	'76	,,	5346.83	5614.17	20.24	11500
G #= 3	1956	284952.75	4110.37	4043.56		
	'68	,,	10961.00	11428.85	20.72	19600
	'69	,,	10426.32	10593.41	21.37	18700
	'76	,,	17444.04	3575.76	13.81	21100
G #= 2	1956	306607.42	1069.37	11295.18		
	'68	,,	1403.54	5513.92	17.87	12450
	'69	,,	1069.37	2840.50	21.48	12650
	'76	,,	10292.63	300.76	18.55	13000
G #= 1-1	1956	327894.49	1804.56	6015,19		
	'68	,,	7585.82	3542.28		
	'69	,,	8087.08	3176.68		
	'76	,,	9356.96	3876.45	21.22	19500
G ## 1	1956	352356.25	8688.60	7351.89		
	'68	,,	9256.70	11368.02		
	'69	,,	9524.40	11161.51		
	'76	,,	10626.83	11529.11	24.23	25400

TABLE - III

Data for finding out the relationship between sinuosity ratio and shape of the river for different years.

Year	Ganges river range	Length along river bend in ft. LR	St. length along chord in ft. LB	Sinuosity $\frac{LR}{LB}$	Average width of channel in ft.	Average Depth of channel in ft.	$\frac{W}{d}$
1968	G#18-G#15	66,835.4	58,748.32	1.14	24,667.5	38.82	635.43
	G#15-G#13	58,414.14	42,106.30	1.39	15,833.33	32.33	489.74
	G#16-G#21	94,438.42	67,169.58	1.41	20,905	35.15	594.74
	G# 7-G# 5	48,025.32	39,630.52	1.21	24,000	27.22	881.70
1969	G#18-G#14	80,703.75	73,686.03	1.10	20,380	36.49	558.51
	G#16-G#21	89,726.52	67,604.00	1.33	16,862	33.16	508.50
	G#12-G#11	24,227.83	23,191.88	1.04	16,350	29.31	557.83
	G#12-G#10	31,579.73	29,741.75	1.06	21,050	30.9	681.23
	G# 7-G# 5	48,455.67	39,633.39	1.22	19,966.67	28.47	701.32
	G# 6-G# 3	60,318.95	44,278.45	1.36	12,312.5	22.57	545.53
	G# 4-G# 2	44,111.37	40,435.42	1.09	13,600	19.12	711.29
1976	G#18-G#16	38,263.27	35,589.85	1.08	26,650	40.53	657.54
	G#16-G#14	45,247.57	38,697.70	1.17	22,083.33	34.8	634.59
	G#13-G#11	33,584.79	31,679.97	1.06	16,933.33	28.27	598.99
	G#12-G#10	32,381.75	29,273.91	1.11	16,866.67	28.29	582.01
	G#10-G# 9	24,896.19	24,328.10	1.02	18,650	29.96	622.50
	G# 5-G# 3	36,993.39	34,487.07	1.07	17,700	19.41	911.90
	G# 4-G# 1	62,491.10	58,013.13	1.08	16,300	18.46	882.99

TABLE - IV

Data for finding out the relationship between sinuosity ratio and bed slope of the river for different yrs.

Year	Ganges river range	Length along river bend in ft. LR	St.length along chord in ft. LB	Sinuosity $\frac{LR}{LB}$	Difference in bed elevation in ft.	Bed slope
1968	G#=18-G#=15	66,835.4	58,748.32	1.14	7.37	1.10×10^{-4}
	G#=15-G#=13	58,414.14	42,106.30	1.39	8.20	1.40×10^{-4}
	G#=16-G#=12	94,438.42	67,169.58	1.41	5.28	0.56×10^{-4}
	G#= 7-G#= 5	48,025.32	39,630.52	1.21	40.75	8.48×10^{-4}
1969	G#=18-G#=14	80,703.35	73,686.03	1.10	16.13	2.0×10^{-4}
	G#=16-G#=12	89,726.52	67,604.00	1.33	10.00	1.11×10^{-4}
	G#=12-G#=11	24,227.83	23,191.88	1.04	13.00	5.37×10^{-4}
	G#=12-G#=10	31,579.73	29,741.75	1.06	17.63	5.58×10^{-4}
	G#= 7-G#= 5	48,455.67	39,633.39	1.22	29.48	6.08×10^{-4}
	G#= 6-G#= 3	60,318.95	44,278.45	1.36	12 .67	2.10×10^{-4}
	G#= 4-G#= 2	44,111.37	40,435.42	1.09	20.50	4.65×10^{-4}
1976	G#=18-G#=16	38,263.27	35,589.85	1.08	7.95	2.08×10^{-4}
	G#=16-G#=14	45,247.57	38,697.70	1.17	6.95	1.54×10^{-4}
	G#=13-G#=11	33,584.79	31,679.97	1.06	10.42	3.10×10^{-4}
	G#=12-G#=10	32,381.75	29,273.91	1.11	11.50	3.55×10^{-4}
	G#=10-G#= 9	24,896.19	24,328.10	1.02	15.25	6.13×10^{-4}
	G#= 5-G#= 3	36,993.39	34,487.07	1.07	9.50	2.75×10^{-4}
	G#= 4-G#= 1	62,491.10	58,013.13	1.08	5.17	0.83×10^{-4}

TABLE - V

Data for finding out the relationship between meandering length and average width of the river for different yrs.

Name of years.	Ganges river range	Meandering length (wave length in ft.)	Width of the river in ft.
	G # 18 - G # 21	131,434.18	20,790
	G # 13 - G # 11	34,207.09	13,885
1969	G # 10 - G # 8	40,785.38	20,383.33
	G # 7 - G # 3	85,517.74	17,610
	G # 3 - G # 1	68,414.19	15,902.00
	G # 18 - G # 14	85,517.74	21,910
	G # 13 - G # 10	48,679.33	15,750
1976	G # 10 - G # 8	40,785.38	20,066.67
	G # 7 - G # 5	29,602.29	22,300
	G # 4 - G # 1	89,464.71	18,120

TABLE - VI

Data for finding the variation of thalweg sinuosity Between 1967 and 1976.

Years	Ganges river range	Total length along river bend in ft.	Straight length of river in ft.	Thalweg sinuosity
1967	G # 18 - G #1	390750.27	328914.37	1.188
1968	G # 18 - G #1	392065.92	328914.37	1.19
1969	G # 18 - G #1	378909.35	328914.37	1.15
1976	G # 18 - G #1	359174.49	328914.37	1.09