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ON THE INTERPRETATION OF TELLURIC FIELD ANOMALY OVER AN INCLINED NORMAL FAULT*

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Abstract

Basement faults in a sedimentary basin generally produce significant telluric field anomalies and interpretation of these anomalies is however beset with several problems. It is shown in the present study that the first and second gradients of the telluric field anomaly over a fault can provide valuable basis for the evaluation of relevant geometrical parameters, namely, the trace, angle of inclination and throw of the fault. Using the method of conformal mapping and numerical integration by Runga-Kutta method, theoretical telluric field response curves and their gradients over a fault have been obtained for a wide range of model parameters. Based on these computations, a nomogram has been presented and a methodology has been suggested to evaluate the parameters of the fault.

Introduction

Basement faults and other structural features occurring in sedimentary basin are known to produce significant telluric field anomalies. Interpretation of these anomalies particularly in the case of faults poses several problems. It is known that the telluric field anomaly curve across a fault shows a gradual transition extending over a large distance and hence makes it difficult to determine the detailed configuration, particularly for larger throws (Berdechevisky, 1960, Li-Y-Shu, 1963). The angle of fault can be quantitatively determined for larger throws, while the estimates become only qualitative in the case of moderate and low throws (Naidu, 1965). An attempt is made in the present study to suggest a procedure for obtaining the parameters of a basement fault from the telluric field anomaly curve and its gradients.

Theory

A two dimensional fault is assumed in an infinitely resistive basement underlying a pile of conducting sediments. Using the method of schwartz-christofel transformation together with the Runga-kutta method of numerical integration, telluric field has been computed across the fault model (Fig. 1) and the computational approach adopted here is the same as that outlined in Naidu (1965). The telluric field (E) across a fault is given by

$$E = -\frac{dV}{dX} = -\frac{I}{\pi}\frac{I}{P}\left(\frac{U-L}{U}\right)^{\frac{\alpha}{\pi}} \qquad (1)$$

where

V = telluric potential

I = current strength

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h = depth to basement on up thrown side of the fault

H = depth to basement on down thrown side of the fault

α = angle of fault

$P = -h/H$

$$L = \left(1 - \frac{h}{H}\right)^{\pi/\alpha}$$

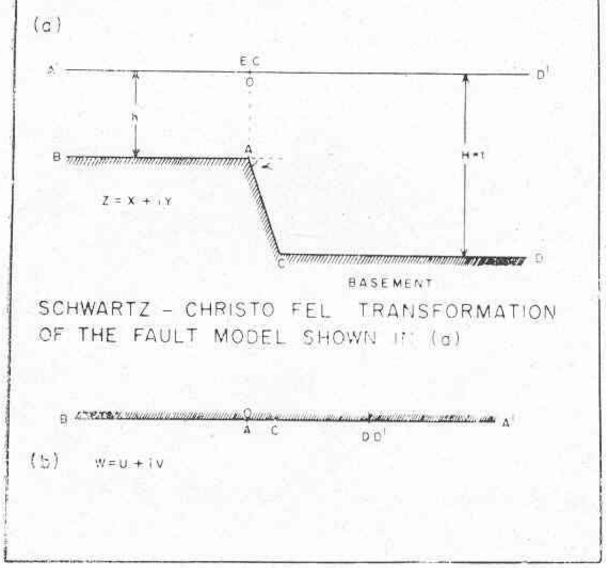


FIG - 1
GEOMETRY OF THE FAULT MODEL

SCHWARTZ - CHRISTO FEL TRANSFORMATION OF THE FAULT MODEL SHOWN IN (a)

Telluric field anomaly curves were obtained for several models for h/H values of 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9 and for various values of 'α' 18°, 36°, 54°, 72° and 90°. Fig.2 shows a set of telluric field curves for different values of h/H.

As we proceed from the down thrown side, the telluric field anomaly, starting from an asymptotic value ($E_{min.}$) well away from the origin of the fault shows a gradual increase and as we cross the fault it again assumes an asymptotic value ($E_{max.}$) on the upthrown side. The ratio of the asymptotic values of the telluric field is related to the ratio of the depths on either side of the fault as

$$\frac{E_{min.}}{E_{max.}} = \frac{h}{H} \qquad (2)$$

It is observed that the maximum and minimum values of the telluric field (i. e. the asymptotic values on either side of the fault) remain unaltered irrespective of the changes in the angle of the fault while they are dependent only on the ratio h/H and hence it is difficult to say anything about the angle of the fault from the telluric field anomaly curve. Similarly, since the transition in the telluric field across the fault is rather gradual it is generally difficult to find out the trace of the fault (i. e., origin of the fault) from the telluric field anomaly curve alone. However, the width of the anomaly i. e., the gradual change between the two asymptotic values increases as the angle of fault decreases, with the result the gradients of telluric field anomaly show enough sensitivity to changs in the angle of fault and hence can be considered as useful parameters for delineating the fault geometry. In view of this, computations have been carried out for the gradients and second gradients of telluric field also, for different fault models, and a set of curves is shown in Figure 3 (a) and (b).

The first $\left(\frac{dE}{dX}\right)$ and second horizontal $\left(\frac{d^2E}{dX^2}\right)$ gradients of telluric field are computed from

$$\frac{dE}{dX} = \frac{\alpha}{\pi} \quad \frac{dU}{dX} \quad \frac{dV}{dX} \quad \frac{L}{U(U-L)} \qquad (3)$$

$$\frac{d^2E}{dX^2} = \frac{\alpha}{\pi} \quad \frac{L}{U(U-L)} \left[\left(\frac{dU}{dX} \right)^2 \frac{dV}{dX} \; \frac{L-2U}{U(U-L)} + \frac{dU}{dX} \quad \frac{d^2V}{dX^2} + \frac{d^2U}{dX^2} \quad \frac{dV}{dX} \right] \tag{4}$$

FIG-2

TELLURIC FIELD ANOMALY CURVES ACROSS A FAULT FOR DIFFERENT VALUES OF $\frac{h}{H}$

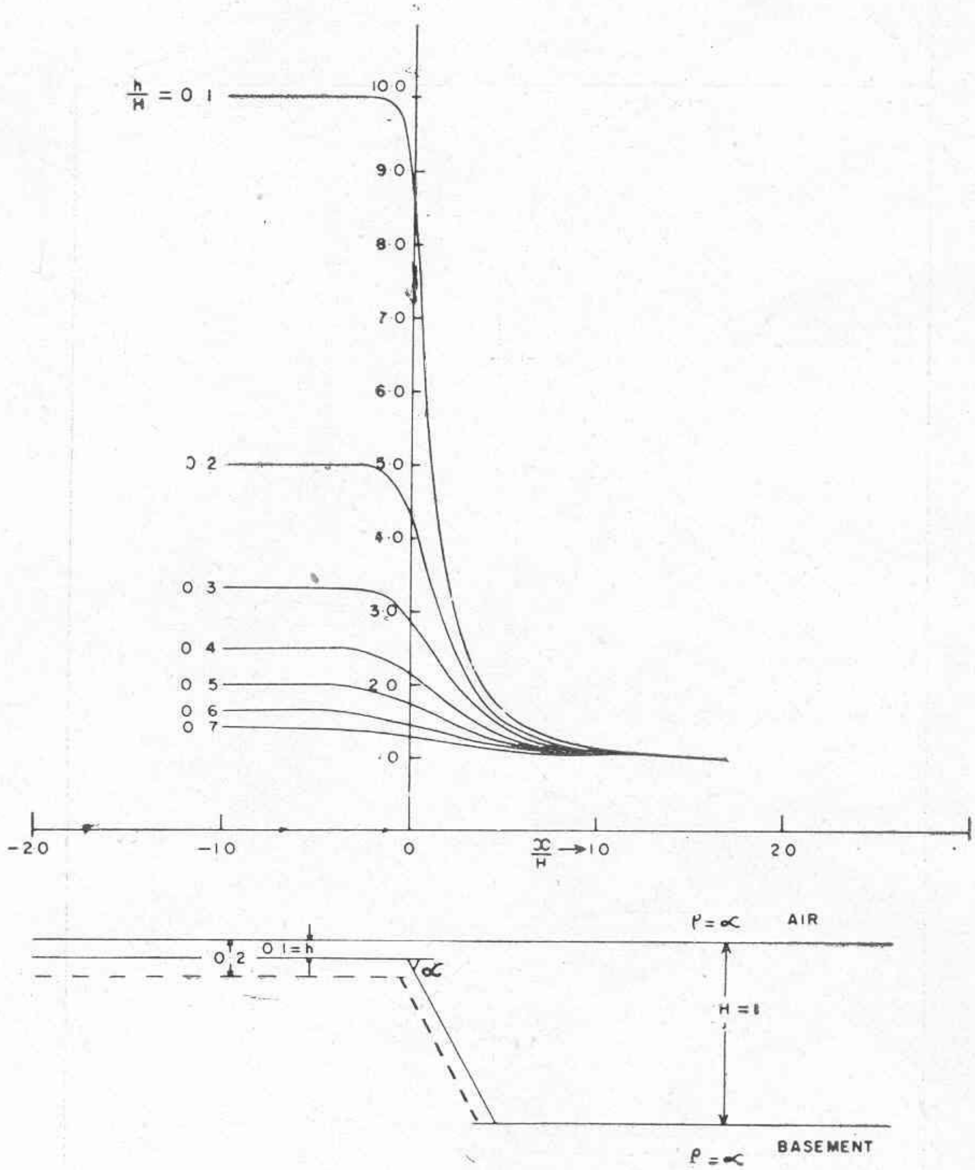


FIG-3a TELLURIC FIELD, ITS GRADIENT AND SECOND GRADIENT ACROSS A FAULT FOR $\frac{h}{H}$ = 0.6 AND FOR DIFFERENT VALUES OF 'α'

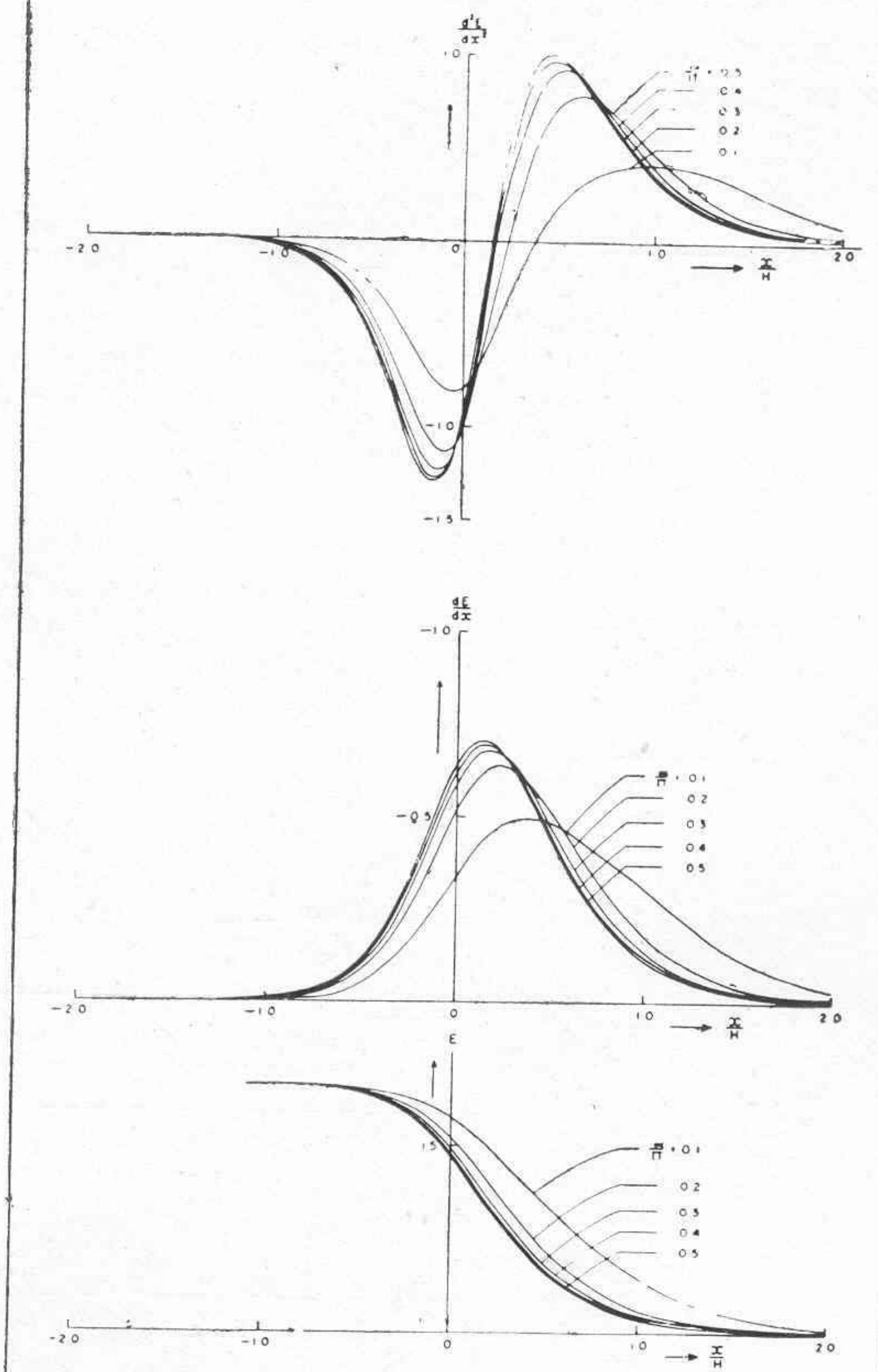
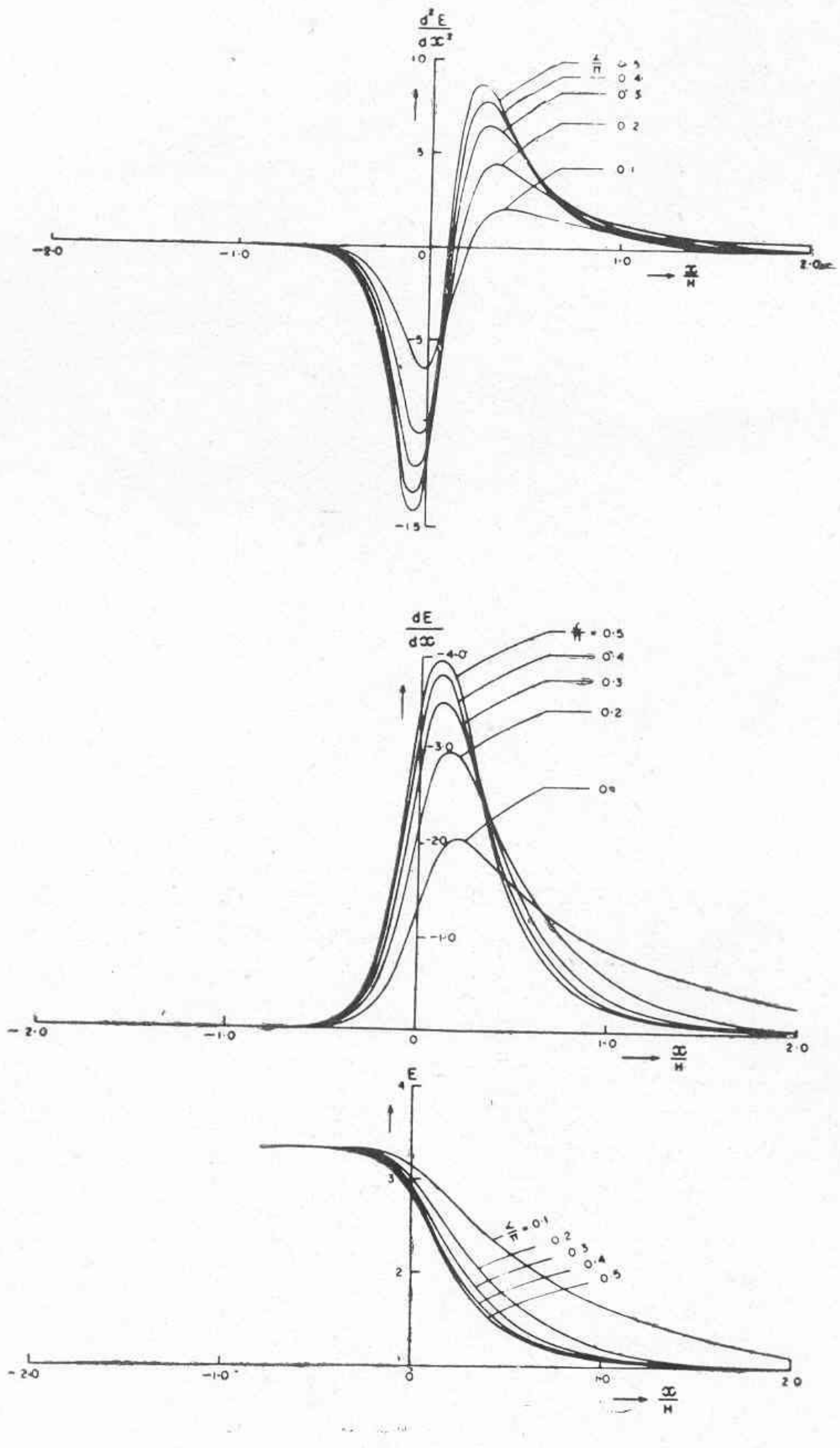


FIG-5b

TELLURIC FIELD, ITS GRADIENT AND SECOND GRADIENT ACROSS A FAULT FOR $\frac{h}{H}$ = 0.3 AND FOR DIFFERENT VALUES OF α



All the computations were carried out on a PDP 11/40 Computer using double precision arithmatic.

Discussion

The magnitudes of the gradients, as also the horizontal distance of maximum gradient from the origin of the fault are observed to be sensitive to variations in 'α'. Since it is not possible to reproduce all the plots we summerise the salient features.

1. The magnitudes of first horizontal gradient ($\frac{dE}{dX}$) decreases with increase of h/H (i. e. as the throw of the fault decreases) but this decrease tends to stop for values h/H beyond say 0.6, with the result, the gradient values assume more or less a stationary magnitude for higher values of h/H. The $\frac{dE}{dX}$ values also decrease with decrease of the angle of fault (α) considerably. But, for large h/H values, the effect of 'α' on the magnitude of gradient is almost negligible in the higher α range while it is just apparent for very low values of α.

ii) The location of gradient maximum X_{max} gradient (i. e. the point where $\frac{dE}{dX}$ assume its maximum value) also shows systematic variations depending on h/H and α values (Fig. 4). It increases with increase of h/H up to a value about 0.6, and then decreases with a further increase of h/H value. The changes are more pronounced for low α—values, while they are not as much for higher angle faults. In fact it can be noticed for higher angle faults (say for $\frac{\alpha}{\pi}$ greater than 0.3) the effect of α on $X_{max.}$ grad., is only marginal. Thus knowing the value of h/H, and knowing an approximate value of α it will be possible to estimate the location of origin of the fault fairly accurately, from Fig. 4.

iii) The Second horizontal gradient of telluric field over a fault is characterized by a minimum ($E_{xx\ min.}$) on the upthrown side and maximum ($E_{xx\ max.}$) on the down thrown side. In general, the minimum is well defined and its location on the X-axis shows less variations with changes in h/H.

The amplitude of these two peaks tend to become equal, as the h/H value approaches unity. Thus the $E_{xx\ max}/E_{xx\ min.}$ ratio which is about 0.6 for $h/H=0.1$, becomes nearly unity for h/H greater than 0.9.

The interpretation of telluric field anomaly over an inclined normal fault involves the estimation of

i) The depth ratio on both sides of the fault

ii) The angle of inclination of the fault

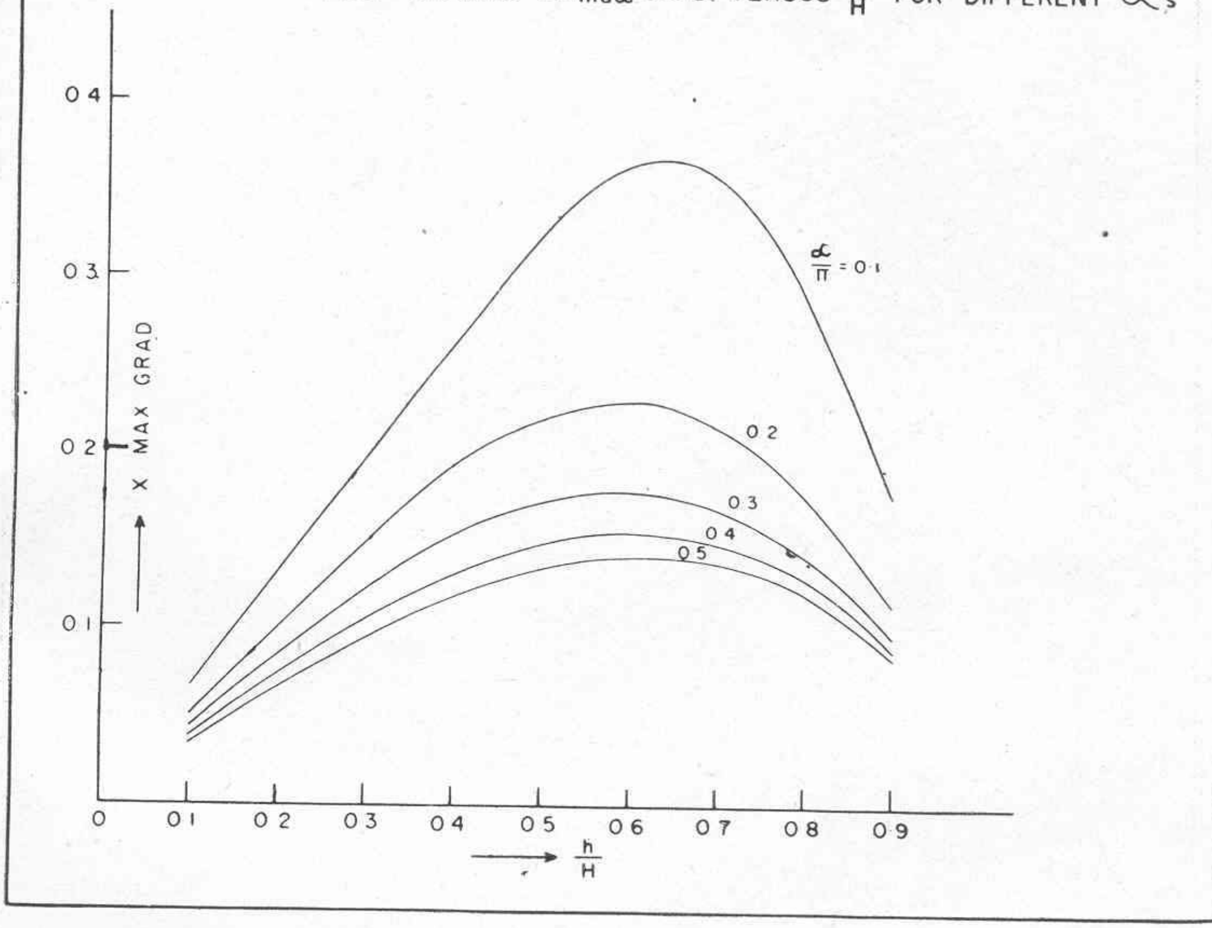
and

iii) The position of the fault

Since the asymptotic values of telluric field on either side of fault is directly related to the depth ratio, it can be readily estimated from the observed telluric field profile using equation 2. For finding the inclination and position of the fault, a nomogram is prepared using the three characteristic values $E_{xx\ max.}$ i.e., the maximum second gradient value, $E_{xx\ min.}$, the minimum second gradient value, E_{xx} (O), the second gradient value at the origin and is shown in Fig. 5. In this figure the ratio $E_{xx\ max.}/E_{xx\ min.}$ is plotted against $E_{xx}(O)/E_{xx\ min.}$ for various values of h/H and α. Further. in Fig. 4 are shown the variations of X maximum gradient with corresponding changes in h/H, for various values of α. Using these two diagrams, the angle of inclination as also the position of the fault can be estimated (excepting for very large h/H values say greater than 0.8) as detailed below.

FIG-4

PLOT SHOWING x_{max} GRAD. VERSUS $\frac{h}{H}$ FOR DIFFERENT α's



1. From the measured telluric field data, the first and second gradient values are obtained for the profile and the ratio $E_{xx\ max}/E_{xx\ min}$. is calculated.

2. (i) Knowing $E_{xx\ max}./E_{xx\ min}$. and h/H, the angle and the corresponding ratio $E_{xx}(O)/E_{xx\ min}$. are read from Fig. 5.

(ii) Multiplying $E_{xx}(0)/E_{xx\ min}$. with $E_{xx\ min}$. which is already known, the value of $E_{xx}(0)$ is obtained. And using this value the origin of the fault can be located from the plot of second derivative values along the profile.

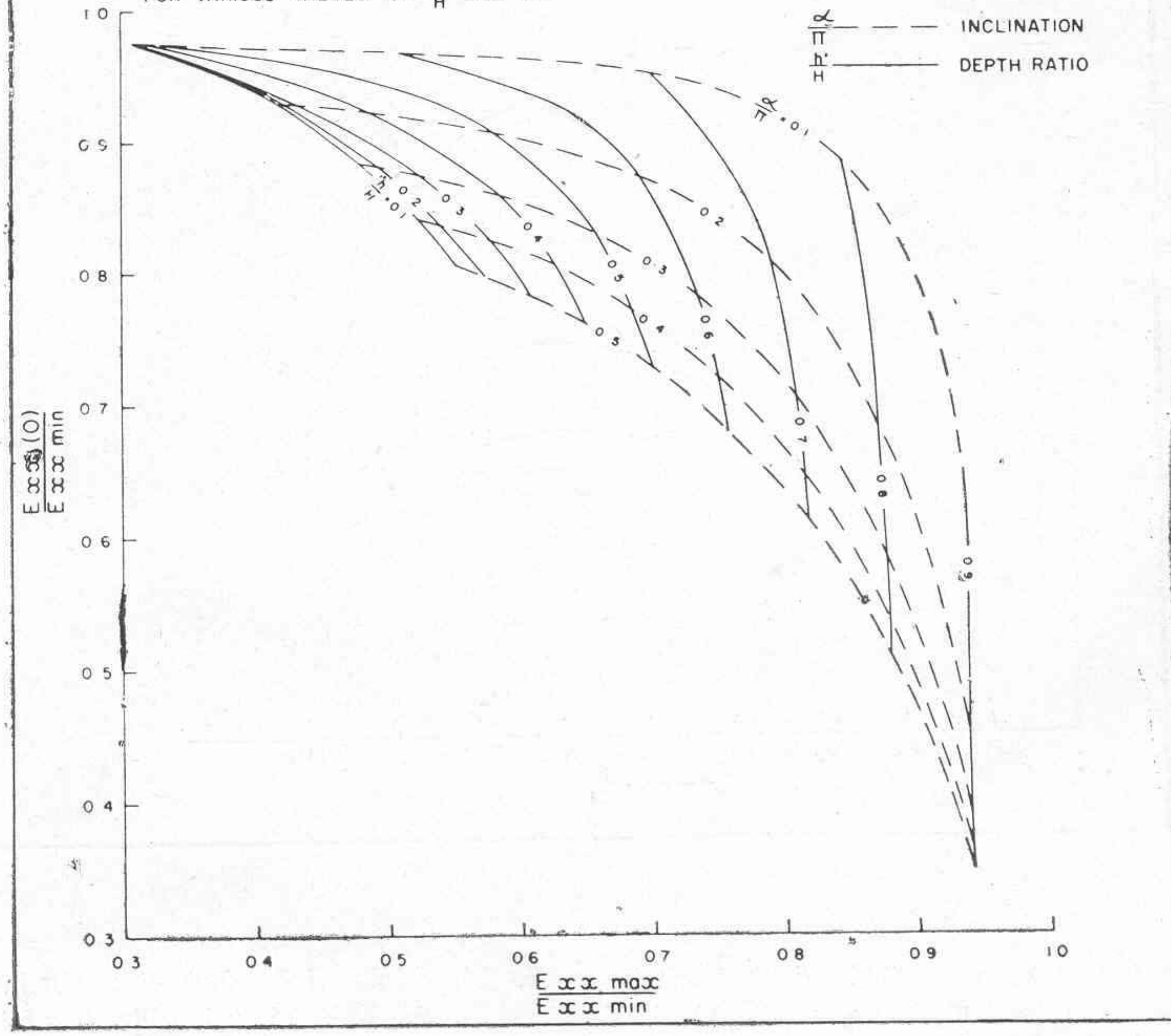
3. The origin of the fault thus obtained may be checked again using Fig. 4 as follows.

(i) Using the α and h/H values, the X_{max}. grad. is read.

(ii) Since the maximum gradient will be always towards the down thrown side of the fault, the origin will be located towards the up-thrown side from the maximum gradient, at a distance read in (i) and this can be picked up from the plot obtained for variations of $\frac{dE}{dX}$ along the profile..

The position thus obtained should be consistent with that estimated using the Fig. 5.

FIG-5 A NOMOGRAM SHOWING THE RELATIONSHIP BETWEEN E_{xx} max, E_{xx} min AND E_{xx} (o) FOR VARIOUS VALUES OF $\frac{h}{H}$ AND α



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