DIRECT MEASUREMENT OF THE VELOCITY DISTRIBUTION IN A VERTICAL PROFILE THROUGH A GLACIER

By M. F. PERUTZ

IN 1948 a steel tube was sunk into the Jungfraufirn with a view to measuring the velocity distribution in the interior of the glacier.* In October 1949 M. André Roch and the writer carried out another set of inclinometer readings of the tube, using an improved type of inclinometer designed by Mr. Charles Jason.

The first results of the experiment are now available and are summarized in Fig. 1 below. Curves I and II show the position of the tube in August 1948 and October 1949, respectively. During that period the glacier surface advanced by 38 m. The curves demonstrate that the surface

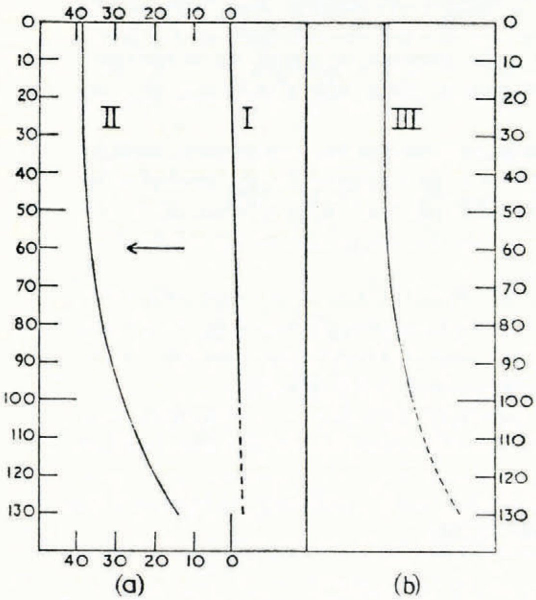

Fig. 1 (a). The ordinates show depth, the abscissae the displacement, in metres. The arrow shows the direction of flow. Curve I gives the position of the steel tube on 15.8.48, curve II that on 10.10.49

Fig. 1 (b). Curve III is a plot of the differences between curves I and II

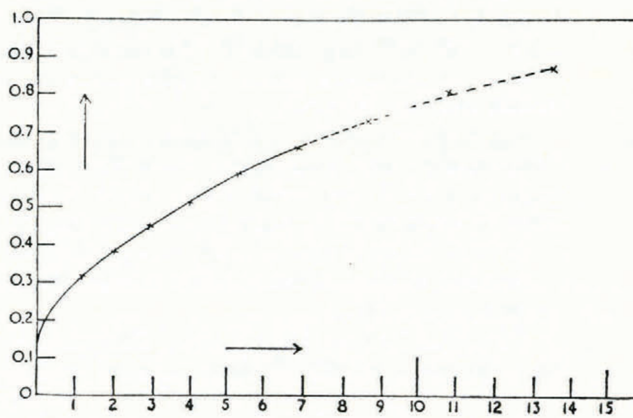

Fig. 2. Ordinates—Shear stress $\tau = Kg./cm.^2$

Abscissae—Creep rate $\frac{\partial \gamma}{\partial t} = 10^{-4}$ *cm. per cm. per day*

of the glacier travels fastest, and that the rate of flow decreases gradually towards the glacier bed. There is no evidence of extrusion flow. Figure 1b (curve III) which is a plot of the difference between curve II and I, shows the degree of bending of the tube. It is rigid to a depth of 50 m.; below this depth the curve is elliptical, with the greatest curvature near the glacier bed. The bottom 30 m. of curves I and III are drawn as dashed lines, because the first type of inclinometer, used in 1948, could not be lowered below 114 m. nor could its twist be controlled below 100 m. The original inclination of the tube below that depth is therefore uncertain.

The above results were used to calculate a tentative creep curve of ice (Fig. 2 above) with the

* See *Journal of Glaciology*, Vol. 1, No. 5, 1949, p. 249.

rate of shear $\frac{\partial \gamma}{\partial t}$ plotted as a function of the shear stress τ. This curve shows the yield stress of ice at 0° C. to be certainly no more than 0·1 kg./cm.[2] which is a tenth of the expected value. More accurate measurements carried out over a longer period may well prove that there is no detectable yield stress at all. On the other hand, the curve shows that creep only becomes really rapid at stresses approaching 1 kg./cm.[2], so that perhaps, as a first approximation at any rate, ice may be regarded as an ideally plastic material with a yield stress of that order.[1]

It should be mentioned that the experiment was carried out at an altitude of 3350 m., where the boundary between firn and ice lies at about 19 m. depth,[2] and where the entire glacier is at the pressure melting point, with the exception of a superficial crust of about 15 m. thickness which is penetrated by the winter cold wave.[3] A detailed account of this work will be published in due course.

REFERENCES

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3. Hughes, T. P., *and* Seligman, G. *Monthly Notices of the Royal Astronomical Society, Geophysical Supplement*, Vol. 4, No. 8, 1939, p. 261.

SOME COMMENTS ON GLACIER FLOW

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ABSTRACT. Drs. Orowan and Perutz have shown that glacier ice does not behave as a viscous fluid but is plastic like all crystalline materials. The present author discusses two observed types of ice flow:—(1) the normal, regular streaming flow in slow-moving glaciers; (2) *Block-Schollen* * movement in swiftly flowing ice. Mention is made of the shear plane or laminar flow theory of Philipp. It appears that Orowan's thesis is also applicable to *Block-Schollen* flow. The author agrees with Orowan on the fundamental point that when ice is subjected to shear stress a critical value of the shear stress exists beyond which the ice alters its consistency. But the author disagrees with Orowan in that he believes that below this critical value ice behaves as a viscous material, and he supports this view by reference to many phenomena, measurements and calculations.

ZUSAMMENFASSUNG. Ausgehend von der Feststellung von Dr. Orowan und Dr. Perutz, dass das Gletschereis sich nicht wie eine zähe Flüssigkeit bewegt, sondern ein plastisches Material wie alle kristallinen Körper ist, werden von den bisher bekannten Bewegungsarten des Eises: (1) die regelmässige in langsam fliessenden, (2) die Block-Schollen Bewegung in schnell bewegten Gletschern gekennzeichnet und die Philippsche Scherflächentheorie kurz gestreift. Dabei ergibt sich, dass die These von Dr. Orowan auf die Block-Schollen Bewegung anwendbar ist. Der Verfasser ist mit Dr. Orowan in einem entscheidenden Punkt einer Meinung, dass bei Überbeanspruchung des Eises durch Scherspannung ein kritischer Wert existiert, jenseits dessen das Eis seine Konsistenz ändert. Im Gegensatz zu Dr. Orowan ist der Verfasser aber der Meinung, dass sich unterhalb dieses kritischen Werts das Eis wie eine zähe Flüssigkeit bewegt, was durch eine Reihe von Erscheinungen, Messungen und Berechnungen sehr wahrscheinlich gemacht wird.

MY attention has been drawn to the discussion on "The flow of ice and of other solids" held at the Institute of Metals, London,† in April 1948, at which Dr. E. Orowan and Dr. M. F. Perutz made some important suggestions explanatory of glacier movement. They showed that ice does not behave as a liquid of constant viscosity but that it is a plastic material like all crystalline solids. May I be allowed to express my opinion on the very difficult and manifold problems and theories of glacier movement? I do so in the light of experience gained from the results of photogrammetric measurements on several glaciers of the Alps, Central Asia and Spitsbergen.[1]

The most important result of these researches was that there are two types of glacier flow which are fundamentally different:

* The term "*Block-Schollen*," as applied to glacier flow by Professor Finsterwalder in his original manuscript is left untranslated in this article since some English writers have used the term "Block Flow" in a somewhat different sense.—Ed.

† *Journal of Glaciology*, Vol. 1, No. 5, 1949, p. 231–40.