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INSTRUMENTS AND METHODS

THE MEASUREMENT OF VERTICAL STRAIN IN GLACIER BORE HOLES

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ABSTRACT. A method to measure the vertical strain in glacier bore holes is described that entails placement of passive markers at varying depths. The position of these markers with respect to a surface reference is measured by an electronic sensor lowered into the hole. These measurements can be combined with inclinometer measurements to yield the total velocity vector in the ice surrounding the hole. Although the method was designed for use in a 0.05 m diameter hole, it can easily be applied to holes of different diameters and to winter snow covers as well as glacier ice.

RÉSUMÉ. *La mesure de la deformation verticale dans un forage glaciaire.* On décrit une mesure de la déformation verticale dans un forage glaciaire qui implique la mise en place de témoins passifs à des profondeurs variées. La position de ces témoins est mesurée par un capteur électronique que l'on descend dans le forage. Ces mesures peuvent être combinées avec des mesures à l'inclinomètre afin d'obtenir tous les éléments du vecteur vitesse dans la glace entourant le trou. Bien que la méthode ait été conçue pour être employée dans un forage de 5 cm de diamètre, on peut facilement l'appliquer à des trous de différents diamètres et a des manteaux neigeux hivernaux, aussi bien qu'à de la glace de glacier.

ZUSAMMENFASSUNG. *Die Messung vertikaler Verformung in Gletscherbohrlöchern.* Es wird eine Methode zur Messung der vertikalen Verformung in Gletscherbohrlöchern beschrieben, bei der passive Markierungen in verschiedenen Tiefen anzubringen sind. Die Lage dieser Markierungsringe gegenüber einem Bezugspunkt an der Oberfläche wird mit einem in das Loch abgesenkten elektrischen Fühler gemessen. Um den gesamten Geschwindigkeitsvektor des Eises in der Umgebung des Loches zu erhalten, ist eine Kombination mit Klinometermessungen möglich. Obwohl die Methode für ein Bohrloch von 0,05 m Durchmesser entwickelt wurde, lässt sie sich leicht für Löcher mit anderen Durchmessern verwenden, und zwar sowohl in Winterschneedecken wie in Gletschereis.

THE vertical strain in a glacier bore hole can be measured with a high degree of accuracy by a simple electronic position locator. The apparatus consists of two main parts; a marker implanting device and a marker detection instrument. Figure 1a is a sketch of the detection instrument and three markers in a drill hole. The markers are electrically conducting rings which are placed concentric to the axis of the hole and in a plane perpendicular to the axis. These rings can be detected by passing a resonant electrical circuit consisting of an inductor and capacitor driven by an oscillator at the resonant frequency through the marker ring. When the inductor of the resonant circuit is coplanar with the marker ring, its inductance is changed and the frequency of the resonant circuit changes. The voltage across the inductor will drop in a measurable fashion as the resonant frequency of the inductor and capacitor circuit changes.

The marker implanter (a) and two markers (b) are shown in Figure 2. The markers are phosphor-bronze spring stock 0.46 m long, 50 mm wide and 0.75 mm thick. One marker is shown rolled into a coil roughly 50 mm in diameter and the other is pictured unrolled. It was found necessary to bend the ends of the phosphor bronze strips slightly to ensure that they would lie in a compact coil in the drill hole. This bend is apparent in the unrolled marker shown in the figure. The implanter is a brass cylinder 50 mm in diameter and 0.6 m long which contains a closely fitting spring-loaded piston in the bottom end. The implanter is cocked by pushing the piston into the cylinder and locking it in position with a latch that can be tripped by a solenoid located just above the piston. A coiled marker is inserted into the lower end of the cylinder after cocking. The marker is implanted in the drill hole by lowering the cylinder to the desired depth and energizing the solenoid. This allows the piston to push

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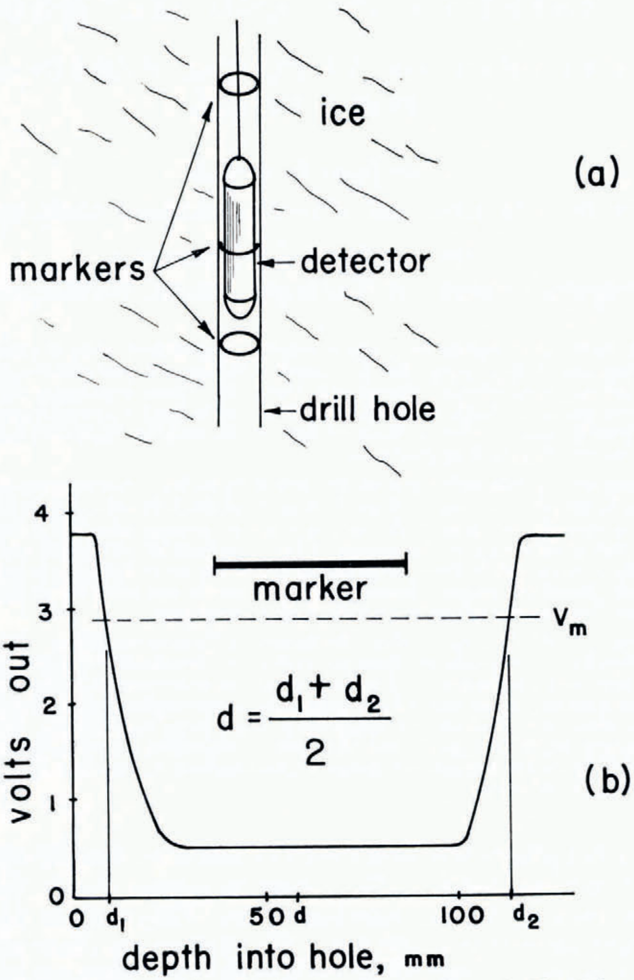

Fig. 1. (a) Sketch of detector instrument located in drill hole with markers in place. (b) Electrical output in vicinity of marker.

the coiled marker out the bottom of the cylinder. Upon exit from the cylinder the marker expands against the wall of the drill hole.

The marker detection instrument (c) shown in Figure 2 is housed in a polyvinylchloride pressure capsule 370 mm long and 50 mm in diameter. The capsule, which contains the simple circuitry required for detection, is suspended in the hole from a two-conductor cable marked in 0.1 m increments. This cable, together with a millimeter scale attached to the surface reference mark, provides the measurement scale for determining the marker positions.

A simplified diagram of the electronics contained in the capsule is shown in Figure 3. The three main parts of the detector are a pulse generator, a resonant circuit and a voltage measuring circuit. When the detector is passed through a marker, the value of the output voltage, V_{out}, is sharply reduced. Figure 1b is a plot of the output voltage as the detector is passed through a marker. Note that the curve is symmetric with respect to the marker location. Two depth measurements are made to locate the marker. Some voltage (V_m in the figure) is selected and the depths d_1 and d_2 are measured and averaged to give d, the location of the marker.

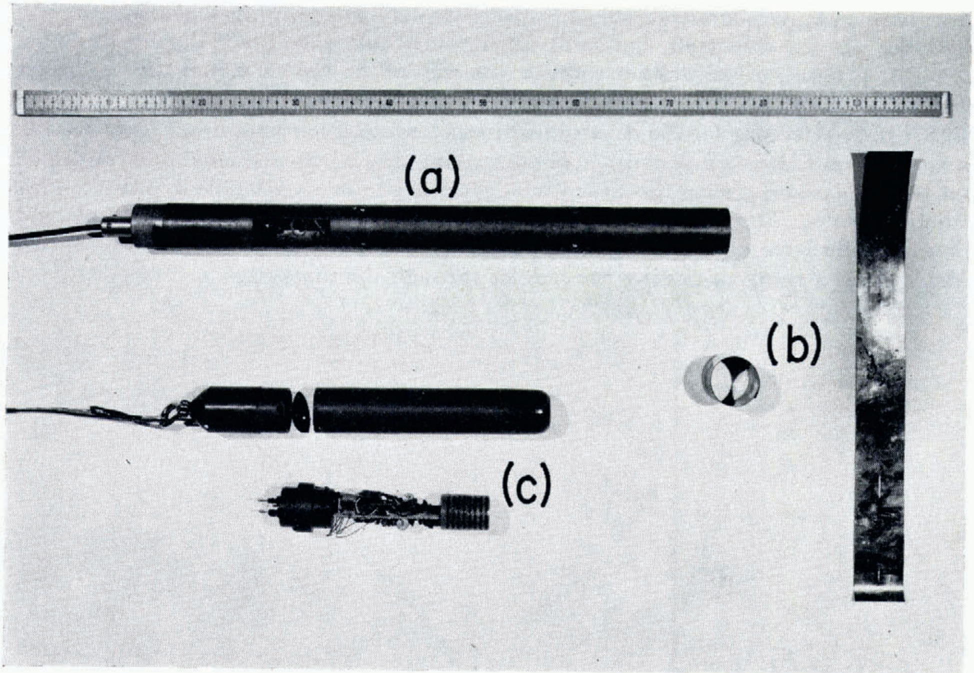

Fig. 2. (a) Marker implanter with (b) one coiled and one uncoiled marker. (c) Detector instrument with electronic contents. The scale is one meter long.

Initial test of this instrument was made in 1971 when three holes were bored below the west ice fall of the Blue Glacier on Mount Olympus, Washington State. They were approximately 90 m deep and were thermally reamed to a diameter of 62 mm. Markers were placed in each hole starting at the bottom and proceeding to the top. The markers were spaced at approximately 5 m intervals for the first 30 m from the bottom and at 10 m intervals thereafter. All of the markers were stamped with identifying numbers to allow identification at any future date should they be found on the surface down-glacier.

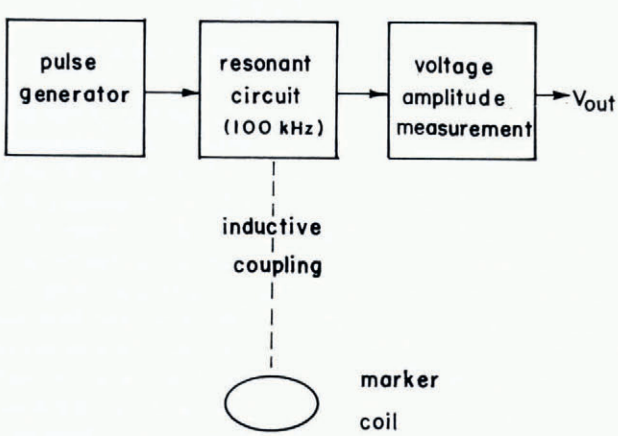

Fig. 3. Block diagram of detector electronics.

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Location measurements were begun approximately one day after placing the markers in the holes. It was expected that some regelation would take place during this time as a result of the pressure of the marker rings on the wall of the hole and that this would provide secure marker position.

The surface reference for the depth measurements was a horizontal bar supported by two vertical stakes each driven to a depth of about two meters. Measurements were continued for a period of ten days and during this time it was necessary to ream one hole in order to lower the detection capsule. The reamer used was the same one which reamed the hole initially. Marker locations were determined before and after reaming and no movement of the markers was detected as a result of passing the reamer through the markers.

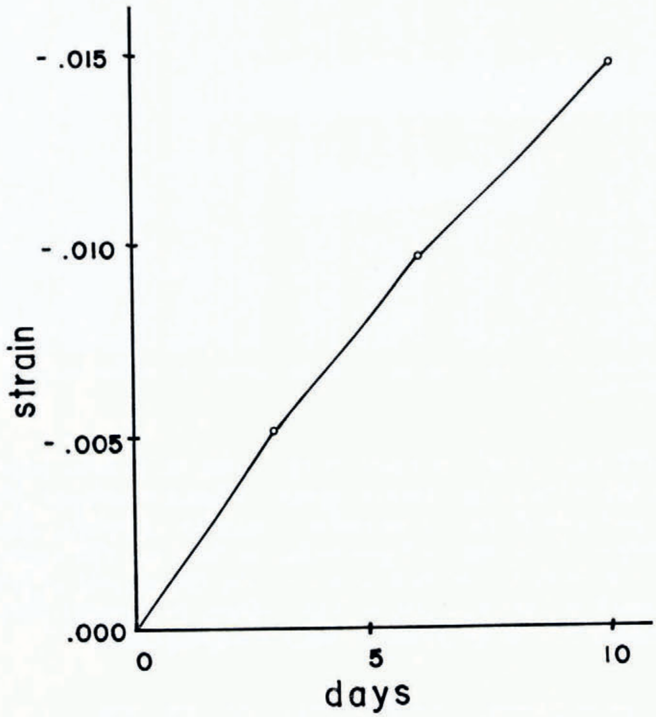

Fig. 4. Strain measured over interval from 80 to 85 m depth.

Because the region of measurement was an active portion of the glacier, results clearly demonstrating changes in the distance between markers were observed within a few days. A plot of strain measured over a five meter interval from 80 to 85 m below the surface is shown in Figure 4. It is estimated that the error in depth measurement is less than ± 2 mm which gives an error in strain over a five meter interval of ± 0.0008. It is seen that the error in measurement is a small portion of the total strain shown in the figure.

A total of forty markers were placed in the three holes and of these two were displaced while measuring marker location. Both were displaced on the first day of measurement. Marking tape on the support cable of the detection instrument was probably responsible for catching and displacing the markers. After removal of the tape, no further problems were encountered. One possible method to ensure secure marker placement is to heat the markers inductively after placement to supplement regelation and allow them to expand slightly into the walls of the drill hole.

One distinct advantage of this method is that, with proper ring placement, the drill hole is free of obstructions and any other instruments can be lowered through the markers.

A further use of this strain-measuring technique has been made for the purpose of observing creep in a winter snow cover (personal communication from D. M. McClung). In this case approximately 50 markers were placed in nine bore holes drilled in a snow cover 5–6 m deep and the initial positions determined electronically. The holes were then filled with sawdust and later exposed by digging pits to identify the creep profiles. Vertical strain in each case could be determined by measuring directly the changes in marker position.

The technique described above was used in glacier drill holes that contained water below about ten meters beneath the surface. Markers were placed successfully in water-filled and air-filled portions of the holes as well as air-filled holes in snow. This technique is applicable to holes drilled in any material and filled with any fluid provided that the electrical conductivity of the material and the fluid is much less than the conductivity of the phosphor-bronze marker rings.

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