# A GRID TECHNIQUE FOR MEASURING ICE TUNNEL DEFORMATION

By T. R. Butkovich and J. K. Landauer
(Snow, Ice and Permafrost Research Establishment, Corps of Engineers, U.S. Army, Wilmette, Ill., U.S.A.)

Abstract. A new method for measuring ice tunnel deformation and closure is described. It includes cutting slots into a smooth vertical wall, forcing wet dyed string into the slots and freezing it in. Results of one year's installation are given for each of 13 grids installed throughout a 366 m. ice tunnel. Two important visual observations are reported. The first is that no differential shearing was found; and the second, that heavy dirt bands that occurred throughout the tunnel appeared to have extruded into the tunnel opening. A possible explanation is that dirty ice is more plastic than clear ice.

Résumé. On décrit une méthode nouvelle pour mesurer la déformation et la contraction de tunnels dans la glace. Cette méthode consiste à tailler des rainures dans une paroi verticale et lisse, à enfoncer dans ces rainures des cordes teintes, à l'état mouillé, et à les y laisser geler. On donne les résultats d'un an d'installation pour chacun des 13 réseaux installés dans un tunnel de glace de 366 m. Deux observations visuelles importantes sont mentionnées, la première quant au fait qu'on n'a pas constaté de cisaillement différentiel et la seconde relative au fait que d'importantes bandes de terre qui se présentent sur toute la longueur du tunnel semblent s'épancher dans l'ouverture du tunnel. Une explication possible serait d'en déduire que la glace terreuse est plus plastique que la glace pure.

Zusammenfassung. Eine neue Methode zur Messung der Deformation von Eisstollenwänden wird beschrieben bestehend darin, dass in die ebenen vertikalen Wände ein quadratisches Netz von Schlitzen gefräst wird und in die Schlitze nasse gefärbte Schnüre eingelegt werden, die festfrieren. Für 13 in einem 366 m langen Stollen angebrachte Netze werden die Resultate für einjährige Deformation mitgeteilt. Folgende Beobachtungen konnten unmittelbar an Ort und Stelle gemacht werden:

Erstens wurde ausschliesslich differentielle Scherung festgestellt, und zweitens wurde beobachtet, dass die Stollenwände dort lokal in die Tunnelöffnung ausgebogen wurden, wo Bänder von stark schmutzigem Eis vorlagen. Eine mögliche Erklärung wird darin gesehen, dass schmutziges Eis platischer ist als klares.

A new method for measuring deformation and closure of an ice tunnel has been devised. This technique requires the installation of grid lines on a smooth section of the tunnel wall. Although this method necessitates the work of smoothing the wall, it has the significant advantage over other ones of making the movement readily visible.

The technique was used on sections of tunnel wall that had been left relatively smooth by the excavation process. The larger irregularities were removed with an ice axe, and a smooth face was obtained by some slight melting with a blow torch. One to two centimeters deep vertical and horizontal slots were cut with a portable rotary electric saw. The cuts were made at 20 cm. intervals to form a one meter square grid. Pieces of dyed, wet string were forced into the slots and frozen into place by spraying with cold water.

The tunnel where the grids were installed has been described elsewhere.[1, 2, 3] It extended 366 m. into a cold ice cap, with its long axis in the direction of the glacier flow, and had several large rooms branching off. The ice temperatures varied between $-5°$ and $-10°$ C. Several grids were installed in 1956 and 13 more in the summer of 1957. The 1957 grids were remeasured and photographed after 10 months, in June 1958. Line separations were measured to the nearest millimeter. Angle measurements were taken on the upper and lower horizontal and left and right vertical lines. Table I gives the pertinent information. The height of the ice above the grids and the surface slope were determined from a level survey. The hydrostatic stress values are assumed equal to the weight of the overlying ice, and the shear stress is taken to be equal to the hydrostatic stress multiplied by the sine of the surface angle.

Figs. 1 a-c (opposite) show photographs of some of the grids. The vertical compression of the grids is obvious. The average reduction varied up to 16 per cent, generally increasing with increasing hydrostatic stress. The horizontal reductions are small, but indicate a tendency towards "extending flow".



https://doi.org/10.3189/S0022143000017251 Published online by Cambridge University Press

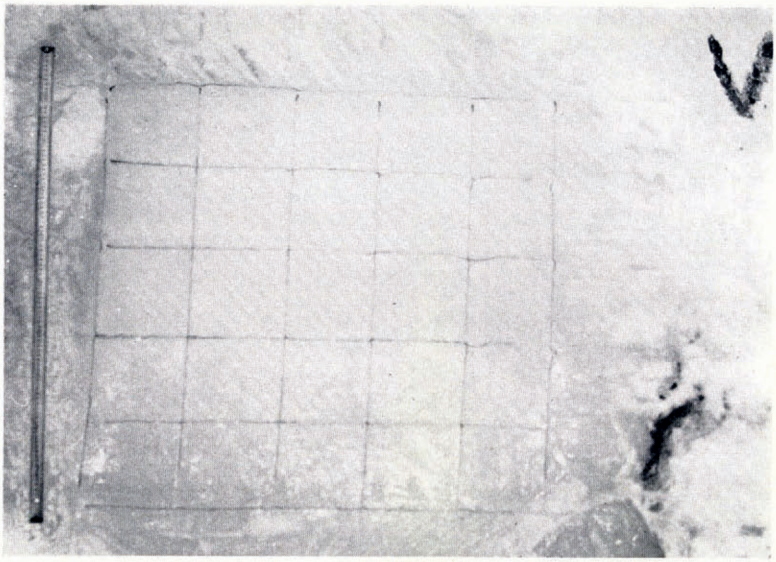

*Fig. 1 (a)*
*Grid No. 7*

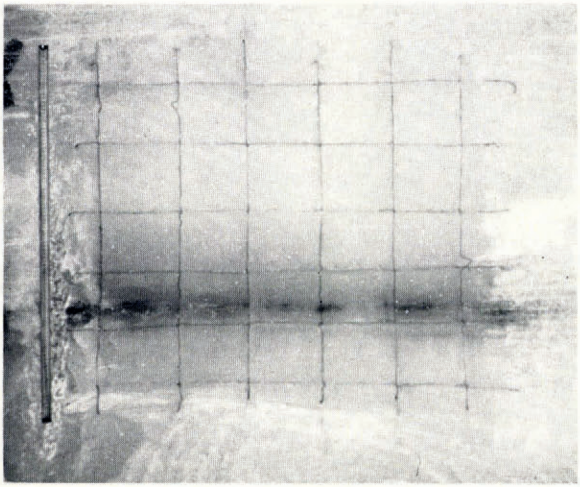

*Fig. 1 (b)*
*Grid No. 10*

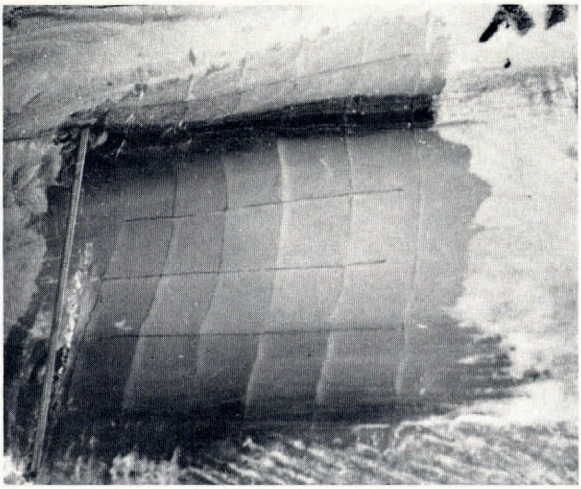

*Fig. 1 (c)*
*Grid No. 11*

*Photographs of some grids showing change from originally square sections*

https://doi.org/10.3189/S0022143000017251 Published online by Cambridge University Press

The vertical compression can be explained by tunnel closure. The results (Table I) indicate some dependence of the amount of reduction on stress, but there is a great deal of scatter. The stress situation is evidently complicated.

Shear, as measured with a Brunton compass, was generally 1 to 3 degrees from the vertical in the direction of flow towards the portal. Tilting of the horizontal lines of the grids was less than 1 degree in most cases, but in one case as much as 4 degrees. However, the initial angular setting of the grids may have been in error by a few degrees. An attempt to relate shear stress to shear strain rate was quantitatively unsuccessful because of scatter in the data.

Two important visual observations were made. The first was that no shearing along the dirt bands was found. Apparently, then, strong shearing is not associated with dirt banding. A second observation was that heavy dirt bands that occurred throughout the tunnel had extruded as much as several centimeters into the tunnel opening. The amount of extrusion appeared to be greater with an increased concentration of dirt in the band. Fig. 1 c is an oblique view of grid 11, which contained a heavy dirt band and shows this effect. A probable explanation is that dirty ice is more plastic than clean ice. This unexpected result needs further study.

*MS. received 7 January 1959*

TABLE I. DEFORMATION OF 1957 GRIDS AFTER 10 MONTHS

| *Grid No.* | *Position* *Distance from Portal* | *Height of Ice Above Grid* | *Surface Angle* | *Hydro-static Stress* | *Shear Stress* | *Average Reduction* *Vertical* | *Horizontal* | *Shear Angles* *Horizontal* *Upper* | *Lower* | *Vertical* *Left* | *Right* | *Remarks* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m. | m. | degrees | kg./cm.² | kg./cm.² | % | % | degrees | degrees | degrees | degrees | |
| 1 | 28 | 18·3 | 36·5 | 1·67 | 0·99 | 1·5 | 0·0 | 0·5* | 1·0* | 0·5† | 1·5† | North Wall |
| 2 | 64 | 41·5 | 4·6 | 3·78 | 0·30 | 1·9 | −0·7 | 0·0 | 0·5* | 1·2† | 1·0† | North Wall |
| 3 | 84 | 43·0 | 4·6 | 3·92 | 0·31 | 9·5 | −0·5 | 0·5 | 1·5 | 3·0† | 3·2† | South Wall |
| 4 | 160 | 46·3 | 3·5 | 4·22 | 0·25 | 7·6 | 0·6 | 0·5 | 0·2 | 0·8† | 2·5† | South Wall |
| 5 | 200 | 49·4 | 6·9 | 4·50 | 0·54 | 6·5 | 0·2 | 0·1 | 1·0* | 0·5† | 0·1† | North Wall—9×30 m. Room |
| 6 | 200 | 49·4 | 6·9 | 4·50 | 0·54 | 10·1 | −0·1 | 0·0 | 0·0 | 0·3 | 0·0 | East Wall—9×30 m. Room |
| 7 | 210 | 50·3 | 4·6 | 4·58 | 0·37 | 7·7 | −0·6 | 1·5* | 0·3* | 3·3† | 2·7† | South Wall |
| 8 | 250 | 53·6 | 5·7 | 4·89 | 0·49 | 6·3 | −0·2 | 0·0 | 0·1* | 4·0† | 4·1† | South Wall |
| 9 | 255 | 54·6 | 5·7 | 4·97 | 0·50 | 7·2 | 0·7 | 8·5 | 0·0 | 3·1† | 2·7† | South Wall—6×30 m. Room |
| 10 | 255 | 54·6 | 5·7 | 4·97 | 0·50 | 16·4 | −0·3 | 1·0 | 1·7 | 1·0 | 0·5 | West Wall—6×30 m. Room |
| 11 | 285 | 57·0 | 4·6 | 5·19 | 0·42 | 8·0 | −1·2 | 1·0* | 1·7* | 3·5† | 2·7† | North Wall |
| 12 | 305 | 58·5 | 4·6 | 5·33 | 0·43 | 12·3 | −3·5 | 2·0* | 3·3* | 2·0† | 1·0† | North Wall |
| 13 | 355 | 62·2 | 5·7 | 5·67 | 0·57 | 5·2 | −1·3 | 1·3* | 4·2* | 1·2† | 2·7† | North Wall |

* Dips toward portal. †—Inclined toward portal.

## REFERENCES

1. Butkovich, T. R. Some physical properties of ice from the TUTO tunnel and ramp, Thule, Greenland. *U.S. Snow, Ice and Permafrost Research Establishment, Research Report* 47. [In press.]
2. Landauer, J. K. Some preliminary observations on the plasticity of Greenland glaciers. *U.S. Snow, Ice and Permafrost Research Establishment, Research Report* 33, 1957, 6 p.
3. Rausch, D. *Studies of ice excavation*. Colorado School of Mines, D.Sc. thesis, 1958.