SURFACE VELOCITY AND STRAIN-RATE MEASUREMENTS ON SEVERAL ALASKAN GLACIERS, 1964

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

Theodore William Havas, Jr.

1965

2-125

SURFACE VELOCITY AND STRAIN-RATE MEASUREMENTS ON SEVERAL ALASKAN GLACIERS, 1964

By

Theodore William Havas, Jr.

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Civil and Sanitary Engineering

1965

ABSTRACT

SURFACE VELOCITY AND STRAIN-RATE MEASUREMENTS ON SEVERAL ALASKAN GLACIERS, 1964

by Theodore William Havas, Jr.

Stresses are calculated from measured strain-rates of several Alaskan glaciers. Also, measured surface velocities are compared with velocities obtained by Nye's plasticity solution. They are in reasonable agreement although important local deviations are noted.

The calculations were performed by means of several computer programs.

ACKNOWLEDGMENTS

The author wishes to express his gratitude to Dr. M. M. Miller, Professor of Geology and director of the Juneau Icefield Research Program, for his leadership in mountaineering and his informative lectures on glaciology.

Sincerely appreciated are the patient efforts of Dr. T. H. Wu, Professor of Civil Engineering and participant in J.I.R.P., for his assistance in conducting the surveys, guidance in writing the thesis, and keen interest in the subject of glacier mechanics.

Valuable assistance in computer programming was provided by Mr. P. Britner, Computer Specialist.

The staff of J.I.R.P. is thanked for their cooperation in collecting the data and the logistic and communication services.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Cont.)

LIST OF SYMBOLS

$a_1, a_2, b_1, b_2, c_1, c_2, d_1, d_2$	lengths of sides and diagonals of strain diamond.
c	yield stress.
g	constant of gravitation.
h	total depth of a glacier perpendicular to the bed.
l_0	unit of length.
n_0	surface longitudinal strain-rate.
A, B, n, w	emperical constants
U, V	x'', y'' components of displacement.
X, Y	dimensionless distances.
α	angle of inclination of glacier surface.
γ	shear strain.
$\dot{e}$	rate of strain.
θ	angle from y''-axis (positive clockwise).
τ	effective shear stress.
τ_0	shear stress corresponding to n_0.
$\sigma_x, \sigma_y, \tau_{xy}$	components of stress acting on an element.
ρ	density.
μ, ν	x,y components of velocity (m/yr.).
μ_m	maximum measured velocity in x' direction (M/yr.).
μ_0	maximum velocity (m/yr.).
$\mathcal{T}$	dimensionless shear stress.
$\mathcal{U}, \mathcal{V}$	dimensionless velocities.

LIST OF SYMBOLS (Cont.)

For computer programming (Appendices B and C) the following notations are used (see Table I for correlation between these symbols and text symbols).

g	group index of angles $_{g,j}$.
j	stake number.
m,N	movements.
n	values of Θ (same as Θ in text).
t	time.
B	distance from base line to a movement stake.
C	horizontal velocity vector.
CT	velocity vector.
D	velocity component along x'-axis.
E	velocity component along y'-axis.
F	strain.
G	maximum value of g.
L	length.
M	total movement.
R	residual value of a function.
S	Skip value.
T	maximum value of t.
V	location of movement stake (in x',y',z').
W	interval of time.
AO	value of B at t = 2.
BO	value of B at t = 1.
RO	x' coordinate at t = 1.
TO	x' coordinate at t = 2.

LIST OF SYMBOLS (Cont.)

y_m distance from base line to stake with maximum measured velocity.

y_0 distance from base line to location of maximum velocity.

y_τ distance from base line to location of zero shear stress.

$\dot{e}$ strain-rate.

ψ angle from base line to a movement stake.

Table I. Correlation of symbols.

Subroutine	Symbols and Words on Computer Output	Symbols in Text
JIRP	D	μ
	E	ν
	V	CT
NORRIS	E	$\dot{e}$
	E(0),E(45),E(90),E(135)	$\dot{e}_0, \dot{e}_{45}, \dot{e}_{90}, \dot{e}_{135}$
	E(1),E(2),E(3)	$\dot{e}_1, \dot{e}_2, \dot{e}_3$
	EX,EZ,EXZ	$\dot{e}_{x''}, \dot{e}_{y''}, \dot{e}_{x''y''}$
	SIGMA1,SIGMA3,SIGMAX	$\sigma_1, \sigma_3, \sigma_{x''}$
	T	$\dot{t}$
	TAU	τ
	THETA	Θ
	TXZ	$\tau_{x''y''}$
PROFILE	BETA	β
	DISTANCE	y'
	TXY	$(\tau_{x'y'})_{y'=0}$

CHAPTER I

INTRODUCTION

Glaciers are large masses of ice, snow, and firn[1] which flow. Observations of glacier movements have led to studies of the stress conditions in glaciers.

This study presents the results of surface strain-rate and velocity measurements made on several glaciers in the Juneau Icefield of Alaska. The icefield covers an area of approximately 1500 square miles and consists of a complex of glaciers.

One of the major valley glaciers of the Juneau Icefield is the Taku Glacier (Figure 1). This glacier is about 40 miles in length and extends from the present high plateau center of the icefield down to the tide water level of the Taku Inlet.

In this district there is a general pattern of retreat of the glaciers with the exception of the main trunk of the Taku (Miller, 1963). Advance or retreat of a glacier is commonly determined by terrestrial or aerial photogrammetric surveys of its terminus. However, the mechanisms that govern the movements of a glacier may be better understood if surface velocities and strain-rates are known.

The object of the 1964 study is to obtain information on the velocity distribution and stress conditions in the Taku Glacier and

[1]Firn is an intermediate form of glacier ice that is composed of recrystallized snow that has been retained from the preceding year or years. It may also contain refrozen meltwater.

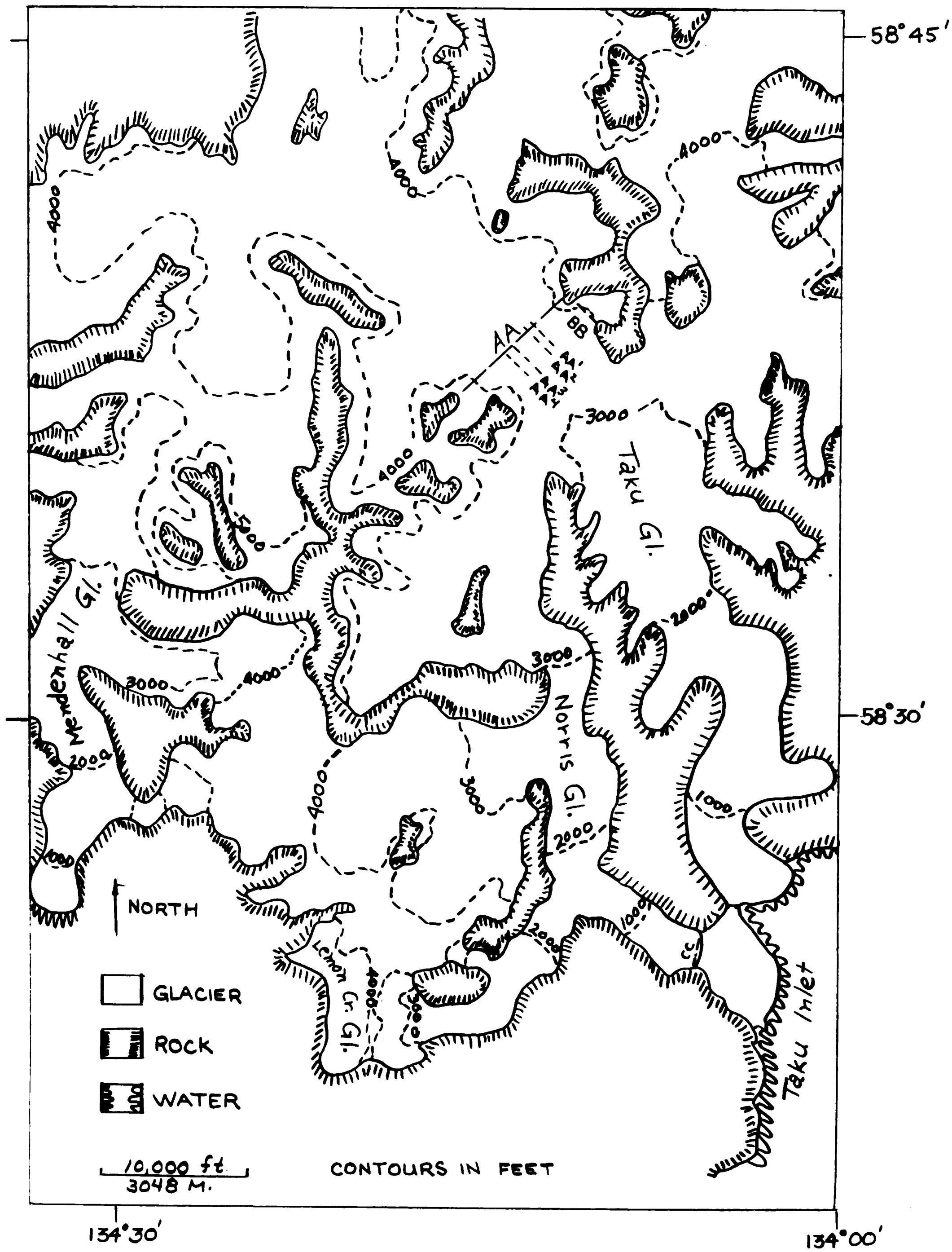

Figure 1. Map of part of Juneau Icefield.

several adjoining glaciers. Reference is made to the previous surveys of 1949-1953 (Miller, 1963) and 1963 (Wu and Christensen, 1964) at Camp 10 and other sites (Figures 2 and 3).

Surface velocity measurements were made across transverse profile AA at Camp 10 (Figure 4), transverse profile BB at Icy Basin (Figure 4), transverse profile CC on the Norris Glacier Terminus (Figure 5), and along longitudinal profiles AA^1, AA^2, AA^3, AA^4 at Camp 10 (Figure 1) and longitudinal profile DD on the Vaughan-Lewis Glacier (Figure 6).

Strain-rate measurements were made at locations designated as I, II near profile AA (Figures 1 and 4); III, IV, V at the Norris Glacier Terminus (Figure 5); and VI, VII on the Vaughan-Lewis Glacier (Figure 6).

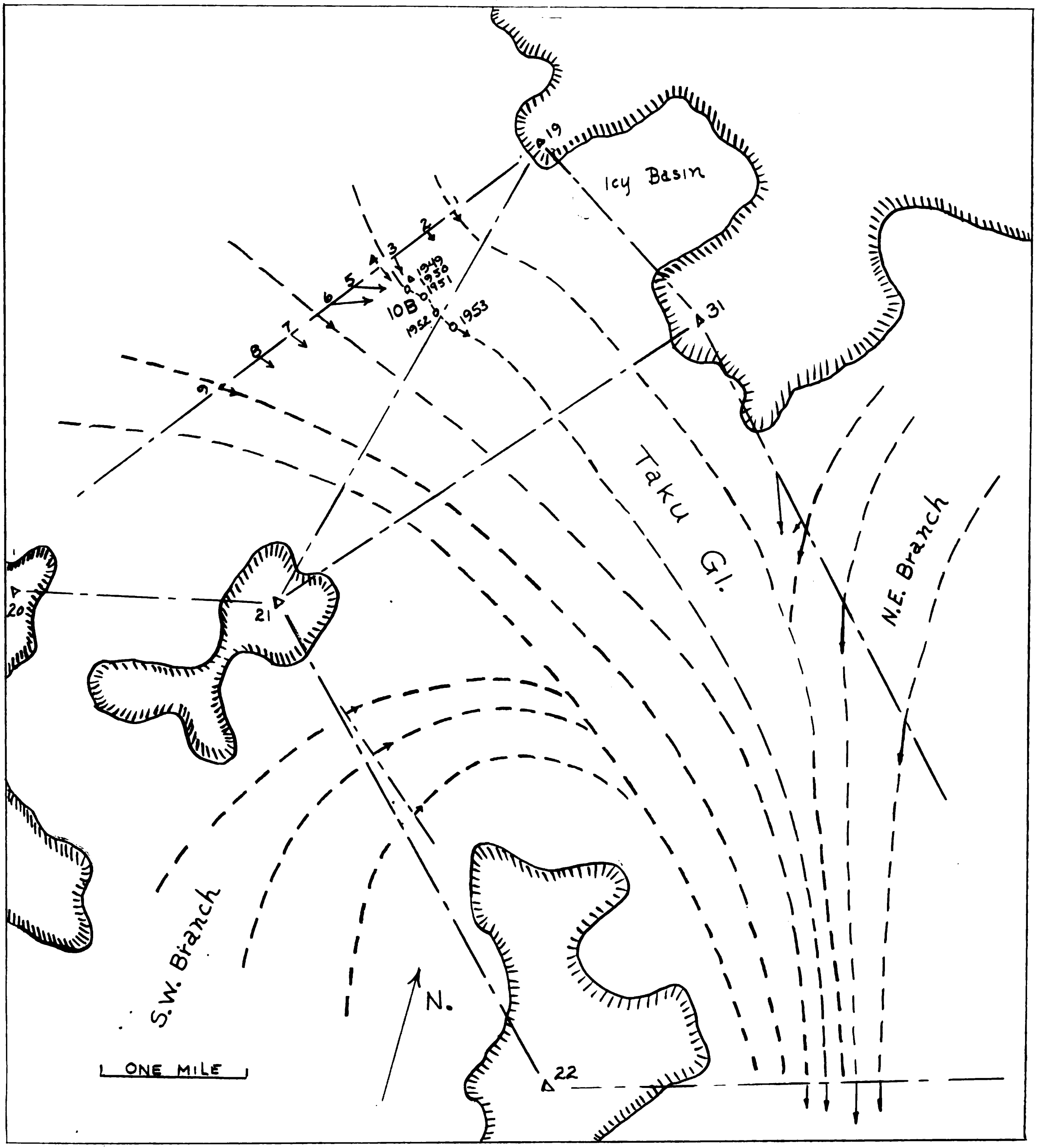

Figure 2. Results of 1949-1953 glacier movement surveys.

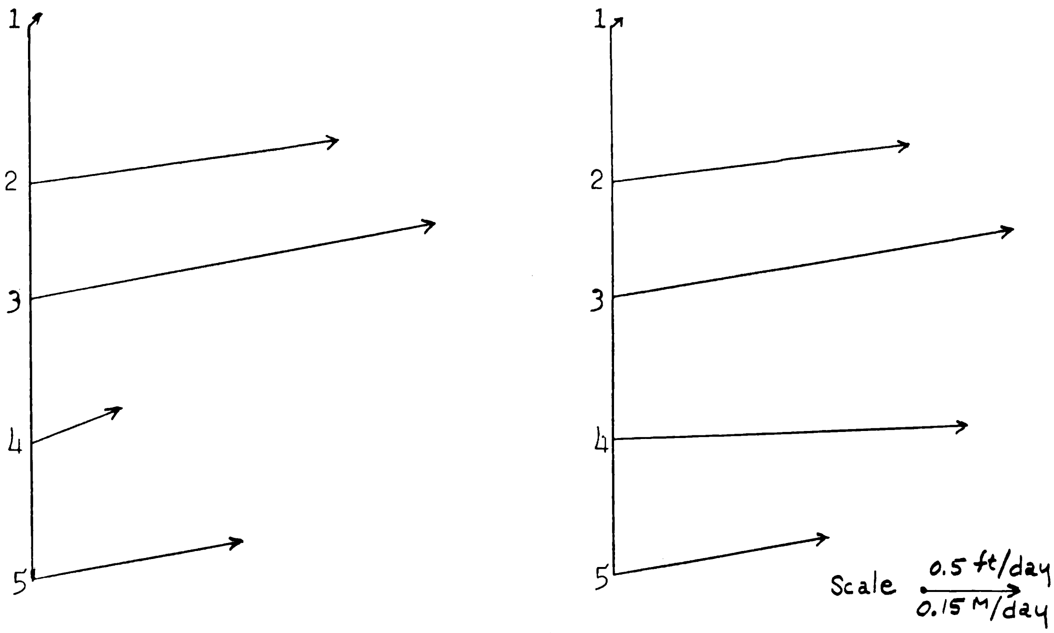

Figure 3. Results of 1963 Taku Galcier velocity measurements.

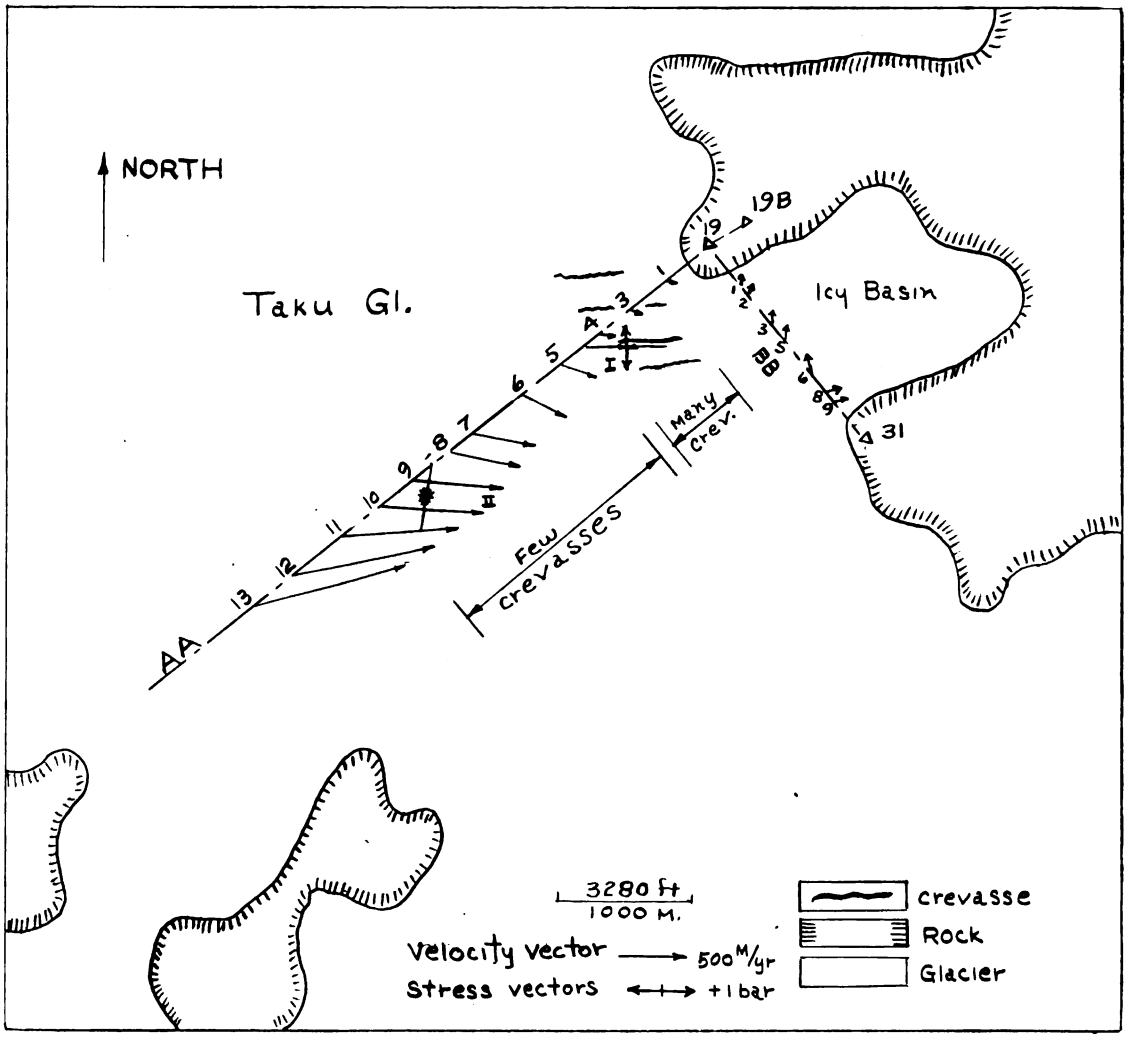

Figure 4a. Locations of 1964 glacier movement surveys and strain-rate measurements on Taku Glacier and Icy Basin.

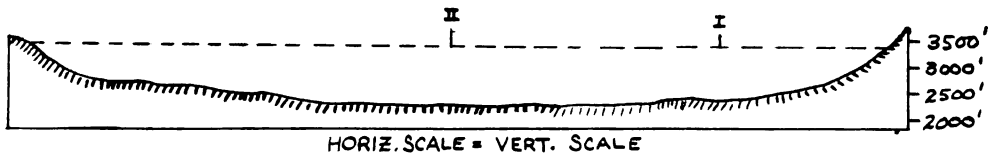

Figure 4b. Bedrock profile along AA.

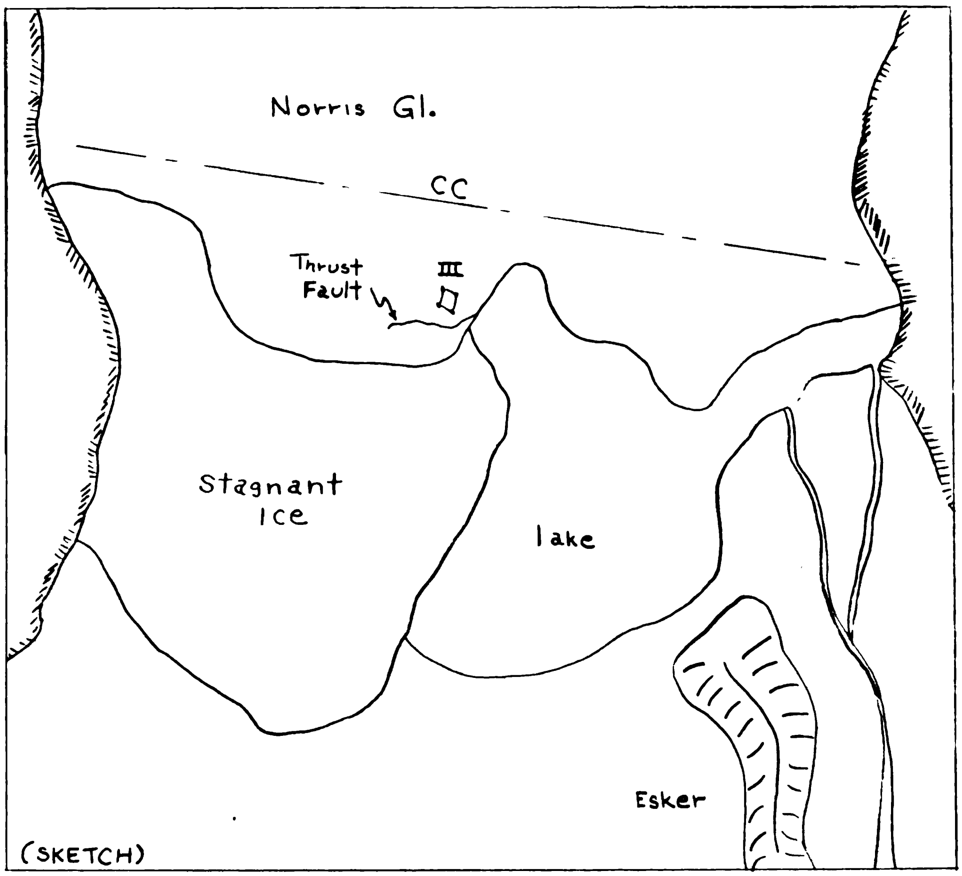

Figure 5a. Locations of 1964 strain-rate measurements on the Norris Glacier Terminus.

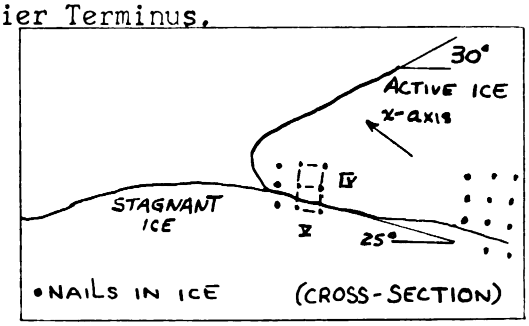

Figure 5b. Location of strain-rate measurements in an ice tunnel.

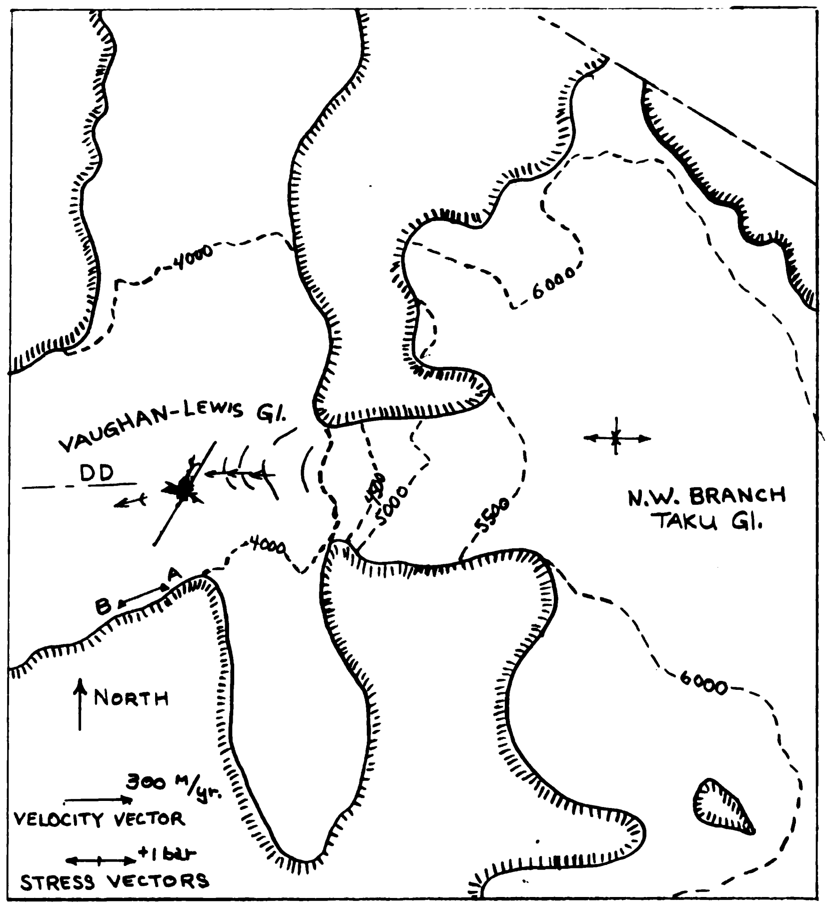

Figure 6. Locations of 1964 velocity and strain-rate measurements on the Vaughan-Lewis Glacier.

CHAPTER II

FLOW CHARACTERISTICS

The downhill movement of a glacier is the result of stresses in the ice. To study the distribution of stress and velocity, consider an ideal glacier that has a constant gradient and thickness over its entire length. The glacier has infinite width so that its movement is not restrained by valley walls. This can be represented by a sheet of ice sliding down an inclined plane. The glacier is assumed to have a constant yield stress (Figure 7, curve 3) and to obey the

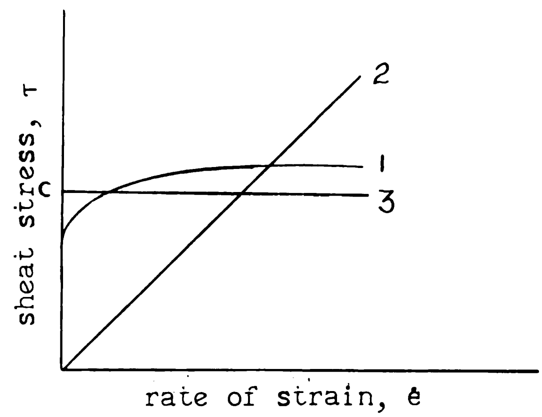

Figure 7. Relationship between applied shear stress and strain-rate (after Nye, 1951). Curves: 1, ice; 2. Newtonian liquid; 3. Plastic relationship assumed by Nye, 1951.

Levy-Mises yield criterion

$$\tau^2 = \frac{1}{4}(\sigma_x - \sigma_y)^2 + \tau_{xy}^2 = c^2 \qquad (1)$$

in which c is the yield stress in pure shear (Nye, 1951). The effective shear stress is τ and σ_x, σ_y, τ_{xy} are the components of stress acting on an element of glacier ice (Figure 8).

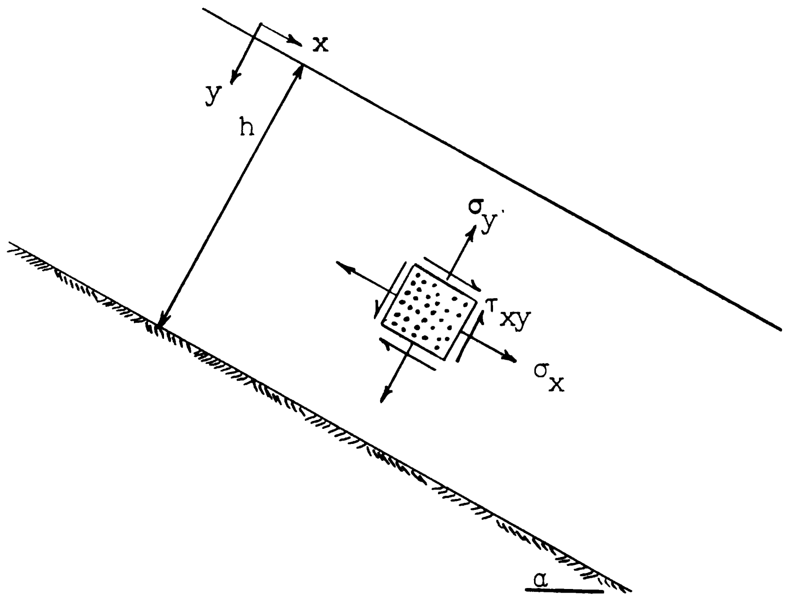

Figure 8. Stresses acting on an element of glacier ice.

Two limiting states of flow are possible. They are the extensive and the compressive flows which correspond to the active and passive Rankine states in soil mechanics. For the perfectly plastic material, there is no flow until the yield stress is developed everywhere along the slip lines (Figure 9).

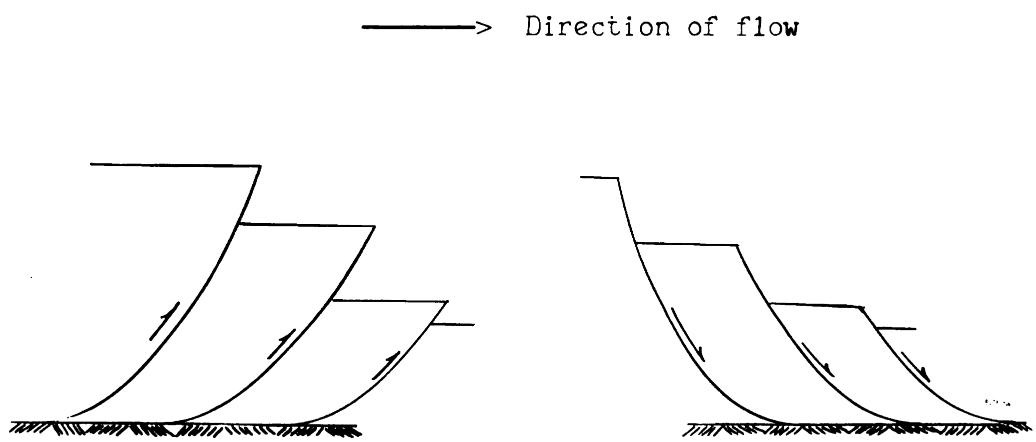

Figure 9. Types of glacier flow.

The limiting stresses that can be attained for the idealized glacier are shown in Figure 10. The actual stresses in a glacier may, however, lie anywhere between these limiting values.

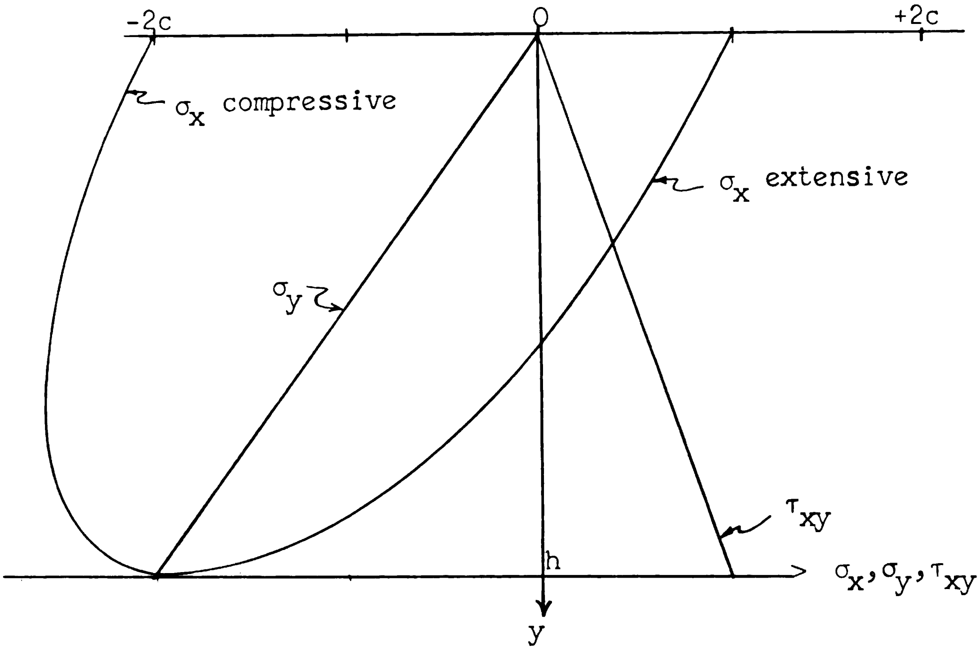

Figure 10. Limiting stresses in a glacier.

Glen (1955) from his laboratory tests on polycrystalline ice under uniaxial compression, has shown that the rate of deformation of ice is not a case of perfect plasticity (Figure 7, curve 1). He defined the strain-rate $\dot{e}$ as an exponential function of shear stress, or

$$\dot{e} = \left(\frac{\tau}{A}\right)^n = B\tau^n \qquad (2)$$

τ = Shear stress (bars)

n = Empirical constant

A, B = Empirical constants for a given temperature and water purity (yr^{-1} bar^{-n})

The borehole measurements of Miller (1958) have shown that values of B and n may vary over a considerable range. Nye (1957) has calculated values of B and n from results of field measurements and found the best values for temperate glaciers to be 0.148 and 4.2 respectively. The distribution of velocity in a glacier (Figure 11) can be approximated by using these values of B and n in the plasticity solution of Nye (1957[a]).

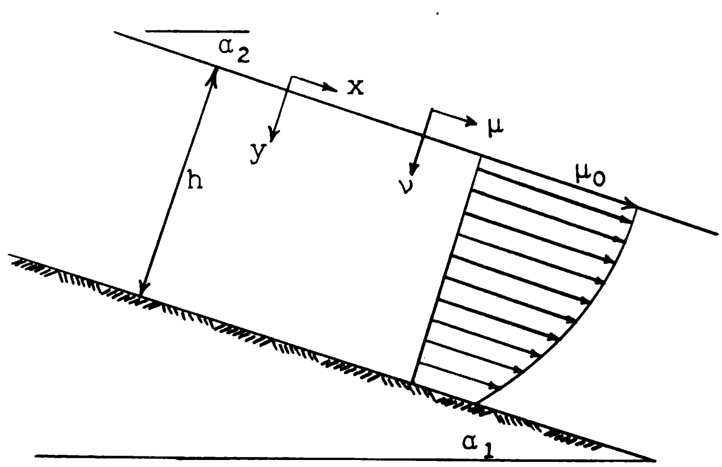

Figure 11. Variation of velocity μ with depth y.

In Nye's plasticity solution, the dimensionless velocities $\mathcal{U}$ and $\mathcal{V}$ are

$$\mathcal{U} = \mathcal{U}_0 - \frac{2}{n + 1} [\mathcal{T}^{n+1} - w^2(n + 1)\mathcal{T}^{1-n} + nw^{1+1/n}] \pm Xw \qquad (3)$$

and

$$\mathcal{V} = \pm w (Y - Y_{bed}) \qquad (4)$$

in which $\mathcal{T}$ is the dimensionless shear stress given by

$$\mathcal{T}^{n-1} = \frac{w}{[\mathcal{T}^2 - Y^2]^{1/2}} \qquad (5)$$

The dimensionless variables are

$$\mathcal{T} = \frac{\tau}{\tau_0} , \quad X = \frac{x}{l_0} , \quad Y = \frac{y}{l_0}, \quad \mathcal{U} = \frac{\mu}{n_0 l_0} , \quad \mathcal{V} = \frac{\nu}{n_0 l_0} \qquad (6)$$

in which

$$n_0 = B(\tau_0)^n , \quad l_0 = \frac{\tau_0}{\rho g_x} \qquad (7)$$

The term n_0 is the surface longitudinal strain-rate and ρg_x is the component of the gravity force along the bed (x-axis). The variables μ and ν are components of velocity along the x and y axis respectively and w is equal to unity for a solution in which the longitudinal strain-rate is non-zero.

In general, if $(\alpha_2 - \alpha_1) \approx 0$ or if the glacier surface is nearly parallel to the bed, it can be assumed that the displacement $\frac{\partial V}{\partial X}$ (see Appendix A, Figure 17) and the velocity ν are independent of x. The dimensionless velocity $\mathcal{V}$ may therefore be considered to have a constant value along the x-axis.

This solution can be simplified if laminar flow is assumed. Laminar flow occurs if an upper layer of ice slips over the lower layer so that each element of ice deforms in simple shear. The longitudinal strain-rate is assumed to be zero. The velocity solution can then be obtained by allowing w to equal zero in equations 3, 4, 5 which simplify to

$$\mathcal{U} = \mathcal{U}_0 - \frac{2}{n+1} Y^{n+1} , \quad \mathcal{V} = 0 \qquad (7)$$

or

$$\mu = \mu_0 - \frac{2B}{n+1} (\rho g_x)^n y^{n+1} , \quad \nu = 0 \qquad (8)$$

The assumptions made for the velocity distribution with depth can also be made for the velocity distribution across a valley glacier between parallel walls. The solution is symmetric about the center line (Figure 12).

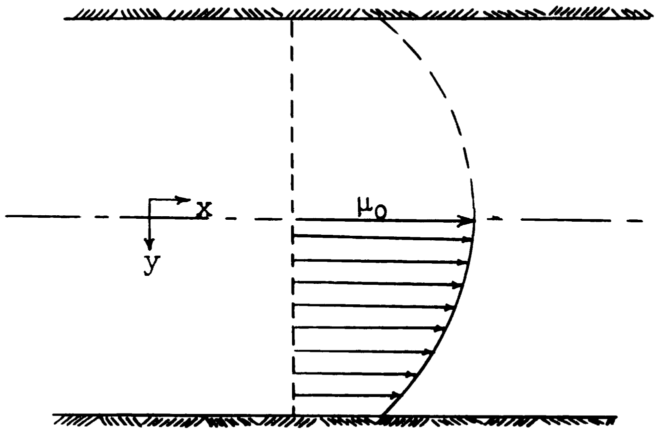

Figure 12. Variation of velocity across a glacier.

In this case, ρg_x in equation 7 is β which is the rate of change of τ_{xy} with y.

In real glaciers, there is also a boundary condition at some distance along the z-axis. However, Nye's solution is a good approximation when the z dimension of the glacier is very large compared to the y dimension (Nye, 1957[a]).

CHAPTER III

SURFACE VELOCITY

Surface velocity measurements were made at various locations on the Taku, Vaughan-Lewis, and Norris Glaciers (Figures 4, 5, and 6) by triangulation with Wild T-1 and T-2 Theodolites. Readings were made to an accuracy of ± 2.5 sec. and ± 0.5 sec. respectively.

Stakes were driven into the firn at approximately equal spacings across the glacier for transverse profiles and along the glacier for longitudinal profiles.

Several base lines were established to serve as reference points. The base line is the x'-axis which is approximately parallel to the down valley direction (x-axis) of the glaciers. The y'-axis is across the valley and perpendicular to the x'-axis. The z'-axis is vertical and is positive upward. From each base line, a coordinate system was established with the first station having (0, 0, z') as its coordinates. The first station is defined as the station farthest to the right if an observer stands on the base line facing the movement stakes.

The movements were calculated from a computer program and are given in Tables II. The general computer notations for movement are given in Figure 13.

Transverse Profiles

Icy Basin (Profile BB): The surface velocity surveys on the Taku Glacier during 1949-1953 (Figure 2) have shown that the direction

Table IIa. Measured surface velocities.

Group	Stake	B M.	C M/INT	D M/INT	E M/INT	V M/INT	ZETA DEGREES	EPSL DEGREES
1	1	228.2	.04	.00	.04		85.29	
1	2	337.5	-.07	-.01	.06		81.33	
1	3	478.6	.08	.03	.08		70.25	
1	4	683.4	59.18	3.00	-59.10		-87.10	
1	5	771.2	-.28	-.15	.24		56.82	
1	6	920.2	-.18	-.12	.14		49.05	
1	7	1090.0	-.45	-.18	.41		66.52	
1	8	1261.8	-.13	-.05	.12		64.55	
1	9	1446.7	-.17	-.05	-.17		-73.90	
1	10	1582.9	.50	.11	.49		77.83	
1	1	228.2	.77	.69	-.34		-26.42	
1	2	337.6	1.27	.98	-.81		-39.69	
1	3	478.7	2.20	1.43	-1.68		-49.55	
1	4	624.3	3.29	1.86	-2.72		-55.64	
1	5	771.5	4.98	2.40	-4.37		-61.25	
1	6	920.3	6.85	2.83	-6.24		-65.56	
1	7	1090.4	9.51	3.47	-8.86		-68.60	
1	8	1261.9	3.91	3.36	2.00		30.70	
1	9	1446.5	4.32	3.92	1.81		24.79	
1	10	1583.4	19.31	5.33	-18.56		-73.98	
2	1	384.6	4.51	.26	-4.50		-86.64	
2	2	575.0	-2.66	-.04	-2.66		-89.07	
2	3	NA	NA	NA	NA		NA	
2	4	1064.8	8.94	7.31	-5.14		-35.14	
2	5	1407.6	17.79	17.03	-5.13		-16.75	
2	6	1839.5	26.22	24.34	-9.75		-21.83	
2	7	2276.1	38.96	32.01	-22.21		-34.75	
2	8	2530.0	35.23	29.69	-18.95		-32.55	
2	9	2854.8	35.23	27.76	-21.68		-37.99	
2	10	3162.8	100.55	27.51	96.72		74.12	
2	11	NA	NA	NA	NA		NA	
2	12	NA	NA	NA	NA		NA	
2	13	NA	NA	NA	NA		NA	
2	14	NA	NA	NA	NA		NA	
2	15	NA	NA	NA	NA		NA	
2	1	380.1	-.45	-.10	.44		77.65	
2	2	572.3	1.08	1.05	.23		12.42	
2	3	NA	NA	NA	NA		NA	
2	4	1059.7	4.71	3.72	-2.89		-37.80	
2	5	1402.5	222.34	4.84	-222.29		-88.75	
2	6	1829.7	5.16	4.03	-3.23		-38.71	
2	7	2253.9	-5.73	-2.90	4.94		59.60	
2	8	2511.1	-14.47	-.34	14.46		88.67	
2	9	2833.1	15.97	1.70	15.88		83.89	
2	10	3259.5	100.56	1.11	-100.56		-89.37	

Table IIa (Cont.)

Group	Stake	B M.	C M/INT	D M/INT	E M/INT	V M/INT	ZETA DEGREES	EPSL DEGREES
2	11	NA	NA	NA	NA		NA	
2	12	NA	NA	NA	NA		NA	
2	13	NA	NA	NA	NA		NA	
2	14	NA	NA	NA	NA		NA	
2	15	NA	NA	NA	NA		NA	
2	1	380.5	5.56	5.48	-.99		-10.25	
2	2	572.6	104.70	6.91	-104.48		-86.22	
2	3	834.6	13.58	12.42	-5.50		-23.90	
2	4	1056.8	21.17	16.69	-13.02		-37.96	
2	5	1180.2	200.02	24.31	198.53		83.02	
2	6	1826.5	36.51	30.70	-19.76		-32.77	
2	7	2258.8	57.10	36.38	-44.01		-50.42	
2	8	2525.5	67.03	40.36	-53.51		-52.97	
2	9	2849.0	94.06	51.55	-78.67		-56.77	
2	10	3158.9	113.05	56.83	-97.72		-59.82	
2	11	NA	NA	NA	NA		NA	
2	12	NA	NA	NA	NA		NA	
2	13	NA	NA	NA	NA		NA	
2	14	NA	NA	NA	NA		NA	
2	15	NA	NA	NA	NA		NA	
3	1	NA	NA	NA	NA		NA	
3	2	1187.2	9.24	8.40	-3.84		-24.54	
3	3	1191.0	8.98	7.36	5.16		35.02	
3	4	1213.8	7.27	6.64	-2.95		-23.97	
3	5	NA	NA	NA	NA		NA	
3	6	NA	NA	NA	NA		NA	
3	7	NA	NA	NA	NA		NA	
3	8	NA	NA	NA	NA		NA	
3	9	NA	NA	NA	NA		NA	
3	10	NA	NA	NA	NA		NA	
3	11	2500.1	78.74	48.09	-62.35		-52.36	
3	12	2519.2	64.28	44.43	-46.45		-46.27	
3	13	2581.6	114.42	37.89	-107.97		-70.66	
3	14	2616.1	139.83	35.13	-135.34		-75.45	
3	15	2659.2	183.27	83.31	-163.24		-62.96	
3	16	NA	NA	NA	NA		NA	
3	17	2840.3	89.47	56.08	-69.71		-51.19	
3	18	2855.1	80.63	45.45	-66.60		-55.69	
3	19	NA	NA	NA	NA		NA	
3	20	NA	NA	NA	NA		NA	

Table IIa (Cont.)

Group	Stake	B M.	C M/INT	D M/INT	E M/INT	V M/INT	ZETA DEGREES	EPSL DEGREES
4	1	NA	NA	NA	NA		NA	
4	2	NA	NA	NA	NA		NA	
4	3	461.5	80.78	77.09	-24.16		-17.40	
4	4	514.7	9.54	9.22	2.44		14.80	
4	5	586.0	8.14	7.78	2.41		17.22	
4	6	615.6	7.91	7.63	2.09		15.31	
4	7	646.0	8.55	8.50	.90		6.06	
4	8	681.2	9.30	9.30	.36		2.19	

Group 1 = ICY BASIN

Group 2 = C-10, TAKU GLACIER

Group 3 = LONGTUDINAL STAKES, C-10, 1-5, ABOUT STAKE 4*6-10,5*11,8*16-20,9

Group 4 = VAUGHAN-LEWIS

Table IIb. Yearly velocities extrapolated from measured surface velocities of 6July - 3September.

GROUP	STAKE	C M/YR.	D M/YR.	E M/YR.	V M/YR.	ZETA DEGREES	EPSL DEGREES
1	1	9.51	8.72	-3.79		-23.48	
1	2	15.37	12.17	-9.39		-37.65	
1	3	27.25	18.37	-20.13		-47.61	
1	4	780.99	61.11	-778.59		-85.51	
1	5	59.23	28.25	-52.06		-61.52	
1	6	84.09	34.20	-76.83		-66.01	
1	7	114.11	41.45	-106.31		-68.70	
1	8	49.42	41.66	26.60		32.56	
1	9	53.03	48.81	20.74		23.02	
1	10	237.59	68.43	-227.53		-73.26	
2	1	46.12	34.36	-30.77		-41.84	
2	2	652.58	48.20	-650.80		-85.76	
2	3	117.66	100.11	-61.82		-31.69	
2	4	211.92	168.77	-128.17		-37.21	
2	5	331.57	281.13	-175.80		-32.02	
2	6	411.08	359.55	-199.29		-29.00	
2	7	546.01	398.69	-373.05		-43.10	
2	8	552.08	424.43	-353.05		-39.75	
2	9	712.52	493.19	-514.25		-46.20	
2	10	807.97	520.17	-618.25		-49.92	
2	11	889.07	463.09	-758.94		-58.61	
2	12	1101.98	466.60	-998.31		-64.95	
2	13	1272.85	490.29	*1174.63		-67.34	
2	14	NA	NA	NA		NA	
2	15	NA	NA	NA		NA	
3	1	NA	NA	NA		NA	
3	2	134.98	122.78	-56.07		-24.54	
3	3	131.23	107.46	75.32		35.02	
3	4	106.17	97.02	-43.13		-23.97	
3	5	NA	NA	NA		NA	
3	6	NA	NA	NA		NA	
3	7	NA	NA	NA		NA	
3	8	NA	NA	NA		NA	
3	9	NA	NA	NA		NA	
3	10	NA	NA	NA		NA	
3	11	1150.42	702.59	-910.96		-52.36	
3	12	939.12	649.15	-678.64		-46.27	
3	13	1671.72	553.59	*1577.40		-70.66	
3	14	2042.89	513.26	*1977.36		-75.45	
3	15	2677.57	1217.23	*2384.89		-62.96	
3	16	NA	NA	NA		NA	

Table IIb. (Cont.)

GROUP	STAKE	C M/YR.	D M/YR.	E M/YR.	V M/YR.	ZETA DEGREES	EPSL DEGREES
3	17	1307.17	819.34	*1018.51		-51.19	
3	18	1178.03	664.08	-973.01		-55.69	
3	19	NA	NA	NA		NA	
3	20	NA	NA	NA		NA	
4	1	NA	NA	NA		NA	
4	2	NA	NA	NA		NA	
4	3	1341.19	1279.81	-401.07		-17.40	
4	4	158.36	153.11	40.45		14.80	
4	5	135.16	129.11	40.00		17.22	
4	6	131.32	126.66	34.67		15.31	
4	7	141.92	141.13	14.97		6.06	
4	8	154.46	154.35	5.90		2.19	

Table IIc. Measured surface velocities of 6July - 22August and coordinate distances.

GROUP	STAKE	B M.	C M/INT	D M/INT	E M/INT	V M/INT	ZETA DEGREES	EPSL DEGREES	J	BO	AO	RO	TO
1	1	384.6	4.51	.26	-4.50		-86.64		1	384.59	380.09	-3.69	-3.43
1	2	575.0	-2.66	-.04	-2.66		-89.07		2	575.00	572.34	-2.06	-2.11
1	3	NA	NA	NA	NA		NA						
1	4	1064.8	8.94	7.31	-5.14		-35.14		4	1064.81	1059.66	-10.44	-3.13
1	5	1407.6	17.79	17.03	-5.13		-16.75		5	1407.63	1402.51	-18.32	-1.29
1	6	1839.5	26.22	24.34	-9.75		-21.83		6	1839.45	1829.70	-22.79	1.55
1	7	2276.1	38.96	32.01	-22.21		-34.75		7	2276.08	2253.87	-29.71	2.29
1	8	2530.0	35.23	29.69	-18.95		-32.55		8	2530.01	2511.06	-34.87	-5.17
1	9	2854.8	35.23	27.76	-21.68		-37.99		9	2854.79	2833.10	-38.44	-10.68
1	10	3162.8	100.55	27.51	96.72		74.12		10	3162.75	3259.47	-42.40	-14.89

Group 1 = TAKU,C-10.

Table IId. Special Listing of Measured Horizontal Angles (6July - 22 August).

(g)	STAKE	ANGLE
1	1	90.55
1	2	90.21
1	3	90.40
1	4	90.56
1	5	90.75
1	6	90.71
1	7	90.75
1	8	90.79
1	9	90.77
1	10	90.77
3	1	11.78
3	2	17.33
3	3	24.44
3	4	29.91
3	5	37.14
3	6	44.63
3	7	50.59
3	8	53.45
3	9	56.65
3	10	59.23
5	1	90.52
5	2	90.21
5	3	90.12
5	4	90.17
5	5	90.05
5	6	89.95
5	7	89.94
5	8	90.12
5	9	90.22
5	10	90.26
7	1	11.65
7	2	17.26
7	3	.00
7	4	29.89
7	5	37.29
7	6	44.86
7	7	50.80
7	8	53.68
7	9	56.84
7	10	60.35

Table IIe. Yearly velocities extrapolated from measured surface velocities of 6July - 22August.

GROUP	STAKE	C M/YR.	D M/YR.	E M/YR.	V M/YR.	ZETA DEGREES	EPSL DEGREES
1	1	33.62	1.97	-33.56		-86.64	
1	2	-19.84	-.32	-19.84		-89.07	
1	3	NA	NA	NA		NA	
1	4	66.61	54.47	-38.34		-35.14	
1	5	132.59	126.96	-38.22		-16.75	
1	6	195.43	181.42	-72.66		-21.83	
1	7	290.39	238.59	-165.53		-34.75	
1	8	262.57	221.34	-141.25		-32.55	
1	9	262.59	206.96	-161.62		-37.99	
1	10	749.53	205.03	720.94		74.12	

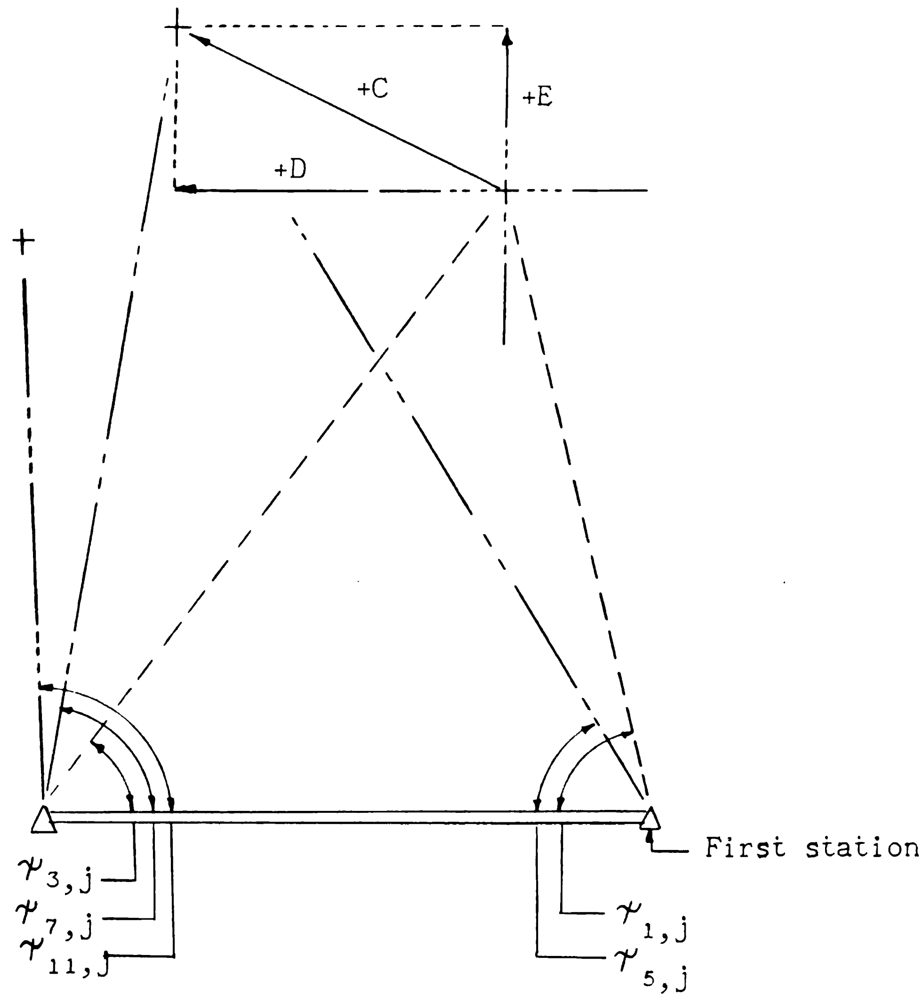

Figure 13a. Computer notations for glacier movements.

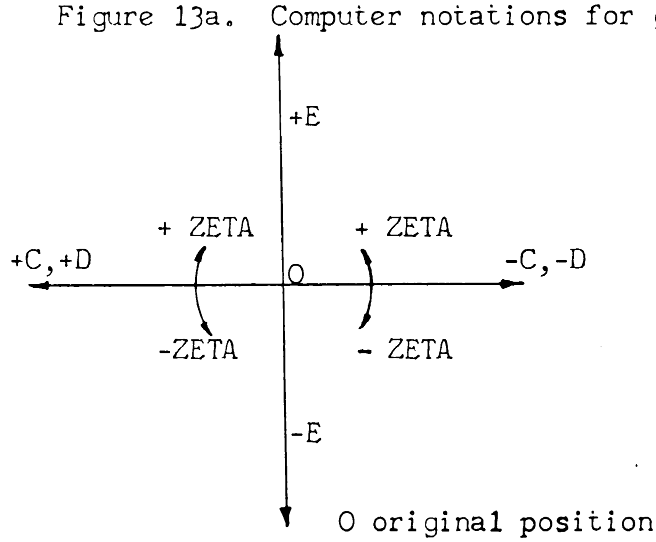

Figure 13b. Sign convention for horizontal velocity vectors.

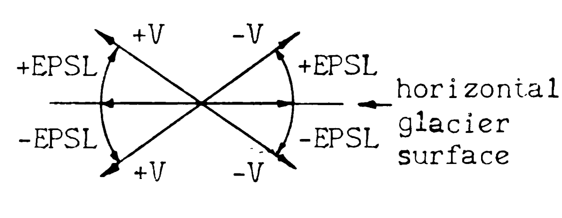

Figure 13c. Sign convention for vertical velocity vectors.

of the velocity vector may deviate appreciably from that of the valley. At several points the velocity vectors show large components towards the east (y'). This easterly movement has also been observed in the bore-hole measurements at site 10B (Miller, 1958). These observations suggest that a part of the glacier flow may be diverted into Icy Basin (Miller, 1963). However, the 1964 survey of Icy Basin (Figure 4) shows that the flow into this basin is negligible.

Taku Glacier (Profile AA): The down valley direction of the glacier at this profile is approximately S42°E (Figure 4). The average direction of the velocity vectors is S78°E. These vectors show large y' components particularly in an area 2000 to 4000 meters west of site 10B. Similar y' components of lesser magnitudes were also observed along this profile during 1952 in the vicinity of stakes 5 and 6 (Figure 2). In addition, the movements between two consecutive time intervals in 1964 show a change of 37 degrees in direction while in 1952, Miller (1963) observed a change of about 40 degrees. These variations in the velocity vectors indicate that the flow conditions may be quite different from that of the ideal glacier.

Since this behavior was not observed in 1963 (Wu and Chrintensen, 1964), the unusual flow direction cannot be attributed to bedrock configurations. The change in direction of flow on the Taku Glacier may have been influenced by the flow from some of the tributaries or basins on the west side of the valley. Also, one may question how accurately these firn measurements have reflected the actual ice movements.

The firn measurements of the Taku Glacier show that the x' component of the maximum velocity vector (Profile AA), during the interval 6July - 22August , is 238 M/yr. (2.14 ft/day). This is in reasonable agreement with 1963 value of 250 M/yr. (2.24 ft/day). The average velocity in this interval is 155 M/yr. (1.40 ft/day) which compares favorably with the 1963 value of 160 M/yr. (1.44 ft/day).

For the entire measurement period (6July - 3September) , a maximum velocity of 520 M/yr. (4.7 ft/day) was recorded. The only other record of comparable high velocity is 465 M/yr. (4.2 ft/day) which was obtained during a "short period" in 1952 (Miller, 1963).

These records show that the velocities flucuate yearly and also between individual measurement periods. A comparison of the measured velocities is given in Figure 14.

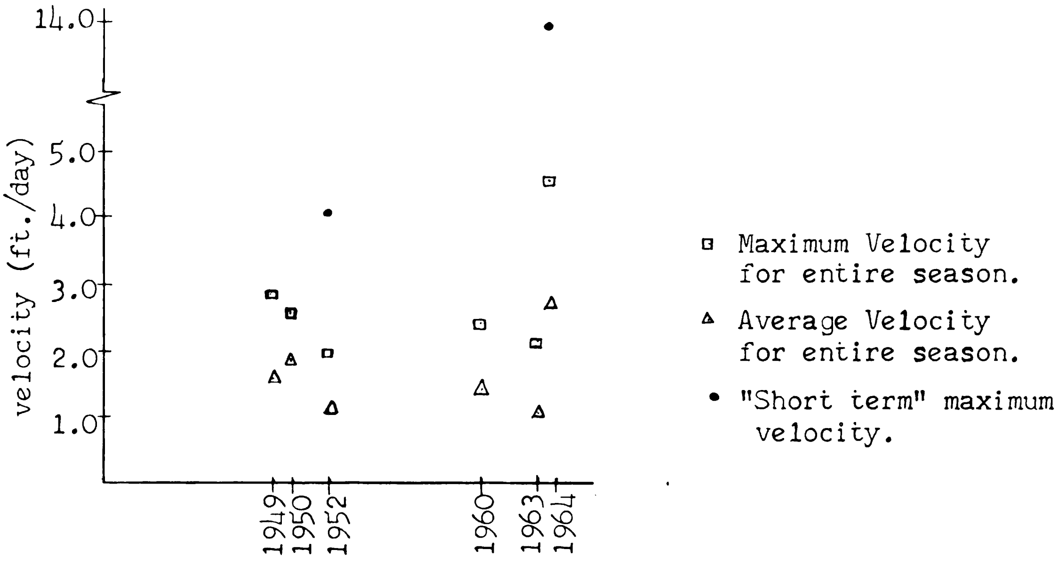

Figure 14. A comparison of measured surface velocities (x' components) along Profile AA.

Norris Glacier (Profile CC): The stakes on the Norris Glacier Terminus melted out during the 7 day interval between measurements. Hence no results were obtained.

Longitudinal Profiles

Taku Glacier (Profiles AA^1, AA^2, AA^3, AA^4): The few records that are available here show general agreement with the measured velocities along Profile AA.

Vaughan-Lewis Glacier (Profile DD): These stakes were placed on the crest of waves that originate at the foot of the Vaughan-Lewis Icefall. Starting downstream from the foot of the icefall, the velocity first decreases and then increases. The analysis of the velocity changes is given in Chapter IV.

CHAPTER IV

STRAIN-RATE MEASUREMENTS

The purpose of the strain-rate measurements was to determine the strain-rate tensor. The procedures used were the same as those outlined by Nye (1959). Stakes were driven into the firn and set in a square pattern (Figure 15). The square had equal sides for measurement of the normal strains in four directions making angles of 0°, 45°, 90°, and 135° with the y'' axis. For each location, the

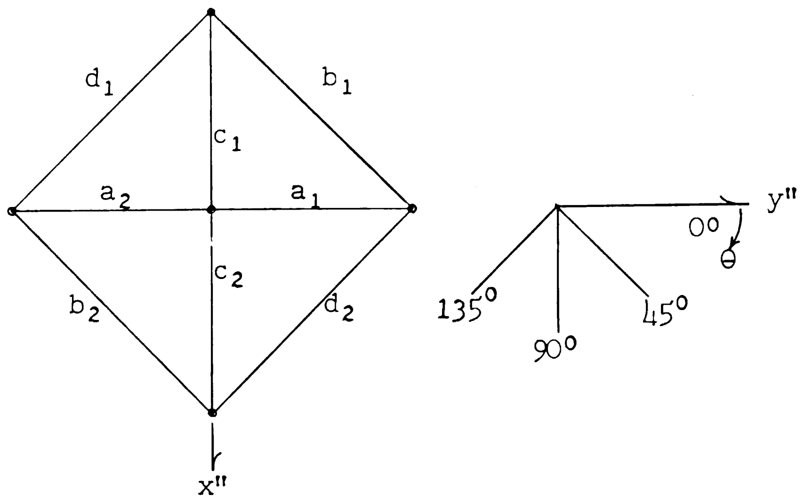

Figure 15. Square for strain-rate measurements.

stakes were oriented so that c_1 and c_2 (x''-axis) lie approximately along the longitudinal direction (x-axis) of the glacier.

Strain diamonds were constructed at locations on the Taku, Vaughan-Lewis, and Norris Glaciers (Figures 4, 5, and 6). On the Taku and Vaughan-Lewis Glaciers, the strain diamonds were marked by stakes which were driven into the firn. They had to be redriven after a 10 day interval because of ablation. On the Norris Glacier Terminus, holes 3 meters deep were drilled into the surface of the glacier in which no reference stakes were placed, It was found that all but 1-2 inches of the holes remained after ablation during a 7 day period. Strain diamonds were also located on the wall of an ice tunnel that was part of a thrust fault in the Norris Glacier Terminus. These strain diamonds were formed by nails driven into the ice. Measurements were made to an accuracy of ± 1/4 in. for the surface measurements and ± 1/16 in. for the ice tunnel measurements.

The measured strain rates are calculated with a computer program (Appendices B and C) and are summarized in Tables III. The strain-rates $\dot{e}_\theta$ are obtained by averaging the strain-rates of sides or diagonals of the square. The results are checked against the theoretical relationship

$$\dot{e}_0 + \dot{e}_{90} = \dot{e}_{45} + \dot{e}_{135} \qquad (9)$$

This equation holds if the material maintains a constant volume within the square.

The measured strain-rates are used to calculate the best values of $\dot{e}_{x''}$, $\dot{e}_{y''}$, and $\dot{e}_{x''y''}$ by the principal of least squares (Nye, 1959, 1957[b], see also Appendix B). They are given by

$$\begin{aligned} \dot{e}_{x''} &= -\frac{1}{4}\dot{e}_0 + \frac{1}{4}\dot{e}_{45} + \frac{3}{4}\dot{e}_{90} + \frac{1}{4}\dot{e}_{135} \\ \dot{e}_{y''} &= \frac{3}{4}\dot{e}_0 + \frac{1}{4}\dot{e}_{45} - \frac{1}{4}\dot{e}_{90} + \frac{1}{4}\dot{e}_{135} \qquad (10) \\ \dot{e}_{x''y''} &= -\frac{1}{2}\dot{e}_{45} + \frac{1}{2}\dot{e}_{135} \end{aligned}$$

From $\dot{e}_{x''}$, $\dot{e}_{y''}$, and $\dot{e}_{x''y''}$ the major and minor principal strain-rates $\dot{e}_1$ and $\dot{e}_3$ are calculated by means of Mohr's circle (Appendix A). Assuming no volume change, the intermediate principal strain $\dot{e}_2$

Table IIIa. Measured strain-rates(*10**-5*HR**-1)

STATION	T	E(0)	E(45)	E(90)	E(135)	RE
1	1	-.555	.271	.033	-.222	-.571
1	2	-.099	.044	.064	-.091	.012
2	1	-.510	-1.351	.136	1.158	-.181
2	2	-.387	-1.417	.237	1.129	.137
3	1	.595	-3.925	-8.138	-3.634	.017
3	2	-.218	7.093	12.891	5.577	.004
4	1	-37.063	65.026	111.696	1.633	7.973
5	1	-54.437	-2.024	-11.950	-92.268	27.905
6	1	-.488	.042	.800	-.094	.364
7	1	-1.747	-1.416	.766	-.152	.587

RE = E(0)+E(90)-E(45)-E(135)
T = SEQUENCE OF TIME

Table IIIb. Measured principal strain-rates.(*10**-5HR**-1)

EX	EZ	EXZ	E(1)	E(2)	E(3)	THETA
.176	-.413	-.246	.266	.236	-.502	70.04
.061	-.102	-.068	.085	.041	-.126	70.06
.182	-.465	1.255	1.154	.283	-1.437	127.77
.202	-.421	1.273	1.201	.219	-1.420	128.12
-8.142	.591	.145	.593	7.551	-8.144	-.95
12.891	-.219	-.758	12.934	-12.672	-.262	86.70
109.702	-39.057	-31.696	116.174	-70.645	-45.529	78.46
-18.926	-61.413	-45.122	9.703	80.339	-90.043	57.61
.709	-.579	-.068	.713	-.130	-.583	86.99
.619	-1.893	.632	.769	1.274	-2.044	103.36

Group 1 = STRAIN DIAMOND -D- AT CACHE
Group 2 = STRAIN DIAMOND -B-
Group 3 = NORRIS STRAIN DIAMOND
Group 4-5 = THRUST PLANE DIAMONDS, X AXIS UP AND TO LEFT
Group 4 = UPPER SET, UPPER RIGHT
Group 5 = UPPER SET, LOWER RIGHT
Group 6 = STRAIN DIAMOND ON VAUGHAN-LEWIS NEVE AREA
Group 7 = STRAIN DIAMOND ON WAVE#7, VAUGHAN-LEWIS

Table IIIc. Stresses calculated from measured strain-rates(YR**-1), Stress (BARS).

POINT	E(1)	E(2)	E(3)	E	THETA	TAU	SIGMA1	SIGMA3	TXZ	SIGMAX
1	.015	.012	-.028	.024	70.04	.648	.087	-1.076	-.373	-.048
2	.103	.022	-.125	.116	127.95	.944	.662	-1.200	.903	-.042
3	.212	-.225	.013	.219	82.18	1.097	2.192	1.191	-.135	2.173
4	10.195	-6.200	-3.996	8.898	78.46	2.652	4.886	.657	-.829	4.717
5	.852	7.051	-7.902	7.513	57.61	2.547	-2.102	-5.070	-1.343	-2.954
6	,063	-.011	-.051	.058	86.99	.799	1.025	-.550	-.082	1.020
7	.068	.112	-.179	.157	103.36	1.014	-.286	-1.882	.359	-.371

is found by

$$\dot{e}_1 + \dot{e}_2 + \dot{e}_3 = 0 \quad . \tag{11}$$

The stresses are calculated from the strain-rates by using Glen's flow law (Equation 2).

Nye (1953) has defined $\dot{e}$ and τ as

$$2\dot{e}^2 = \dot{e}_1{}^2 + \dot{e}_2{}^2 + \dot{e}_3{}^2 \quad . \tag{12}$$

and

$$2\tau^2 = \sigma_1{}'^2 + \sigma_2{}'^2 + \sigma_3{}'^2 \tag{13}$$

in which $\sigma_i{}'$ is the deviatoric stress tensor and is given by

$$\sigma_1{}' = \frac{\tau}{\dot{e}}\,\dot{e}_1 \ , \ \sigma_2{}' = \frac{\tau}{\dot{e}}\,\dot{e}_2 \ , \ \sigma_3{}' = \frac{\tau}{\dot{e}}\,\dot{e}_3 \tag{14}$$

Then the principal stresses are

$$\sigma_1 = 2\sigma_1{}' + \sigma_3{}' \ , \ \sigma_2 = 0 \ , \ \sigma_3 = \sigma_1{}' + 2\sigma_3{}' \tag{15}$$

and $\sigma_{x''}$, $\sigma_{y''}$, and $\tau_{x''y''}$ are calculated by Mohr's circle assuming that the principal axis of strain-rate and stress coincide.

The principal stresses at the individual sites are shown in Figures 4, 5, and 6.

Site I (same as site D, 1963): The velocity vectors in this vicinity (movement stakes 9 and 10) converge and show a transverse (y') compressive strain-rate of $0.54 \times 10^{-5} \times \text{hr}^{-1}$. This agrees with the compressive strain-rate of $0.15 \times 10^{-5} \times \text{hr}^{-1}$ at site I along the y'-axis.

Nye (1952, 1959) has shown that crevasses are formed perpendicular to the direction of maximum tensile stresses. This is not obvious at this site since only small tensile stresses exist and only fine cracks appeared in the firn.

Site II (same as site B, 1963): The direction of the maximum tensile stress (major principal stress) is in good agreement with the observed crevasse patterns (Figure 4).

The velocity vectors in this vicinity (movement stakes 3 and 4) show a transverse compressive strain-rate of $1.3 \times 10^{-5} \times hr^{-1}$. There is also a compressive strain-rate ($0.49 \times 10^{-5} \times hr^{-1}$) at site II along the y'-axis. The discrepancy in the strain-rates may be the result of comparing measurements made at locations that are not very close to each other (see Figure 4).

The strain-rate measurements of 1963 show a tensile stress of 1 ± bar for the Taku Glacier, while in 1964, the measurements made at nearly the same location show a small compressive stress of 0.05 ± bar. This may have resulted from an increased flow from an upper source area.

The measured strain-rates from sites I and II show that the average longitudinal (x"-axis) strain-rate (n_0) is $+0.16 \times 10^{-5} \times hr^{-1}$ and the shear stress ($\tau_{x''y''}$) between the glacier and the valley wall is between 1.5 to 1.9 bars.

These values are applied to Nye's plasticity equation and the results are given in Table IV. These results are compared with the measured velocities in Figure 16. Because of the irregularities in the valley and the sensitivity of the velocity μ to values of n_0 and $\tau_{x''y''}$, the approximate agreement with Nye's solution is considered satisfactory.

The maximum transverse velocity ν for stake 7 is 32 M/yr. by Nye's solution. The measured transverse velocity is 129 M/yr., at stake 7. These velocities are not in agreement. However, a more detailed analysis would be difficult since this glacier does not resemble the idealized glacier described in Chapter II.

Table IV. Calculated velocities

	TXY= 1.5BARS	BETA = .000627
	DISTANCE	VELOCITY, M./YR
PLOTTER CALLED		
	TXY= 1.9BARS	BETA = .000799
	DISTANCE	VELOCITY, M./YR
PLOTTER CALLED		
	TXY= 1.5BARS	BETA = .000627
	DISTANCE	VELOCITY, M./YR
	384.59	-66.66
	575.00	41.52
	839.24	132.0.
	1064.81	175.34
	1407.63	211.13
	1839.45	232.23
	2276.08	239.42
	2331.54	239.66
	TXY= 1.9BARS	BETA = .000799
	DISTANCE	VELOCITY, M./YR
	384.59	-509.72
	575.00	-215.75
	839.24	23.04
	1064.81	127.94
	1407.63	198.61
	1839.45	230.05
	2276.08	239.39
	2331.54	239.66

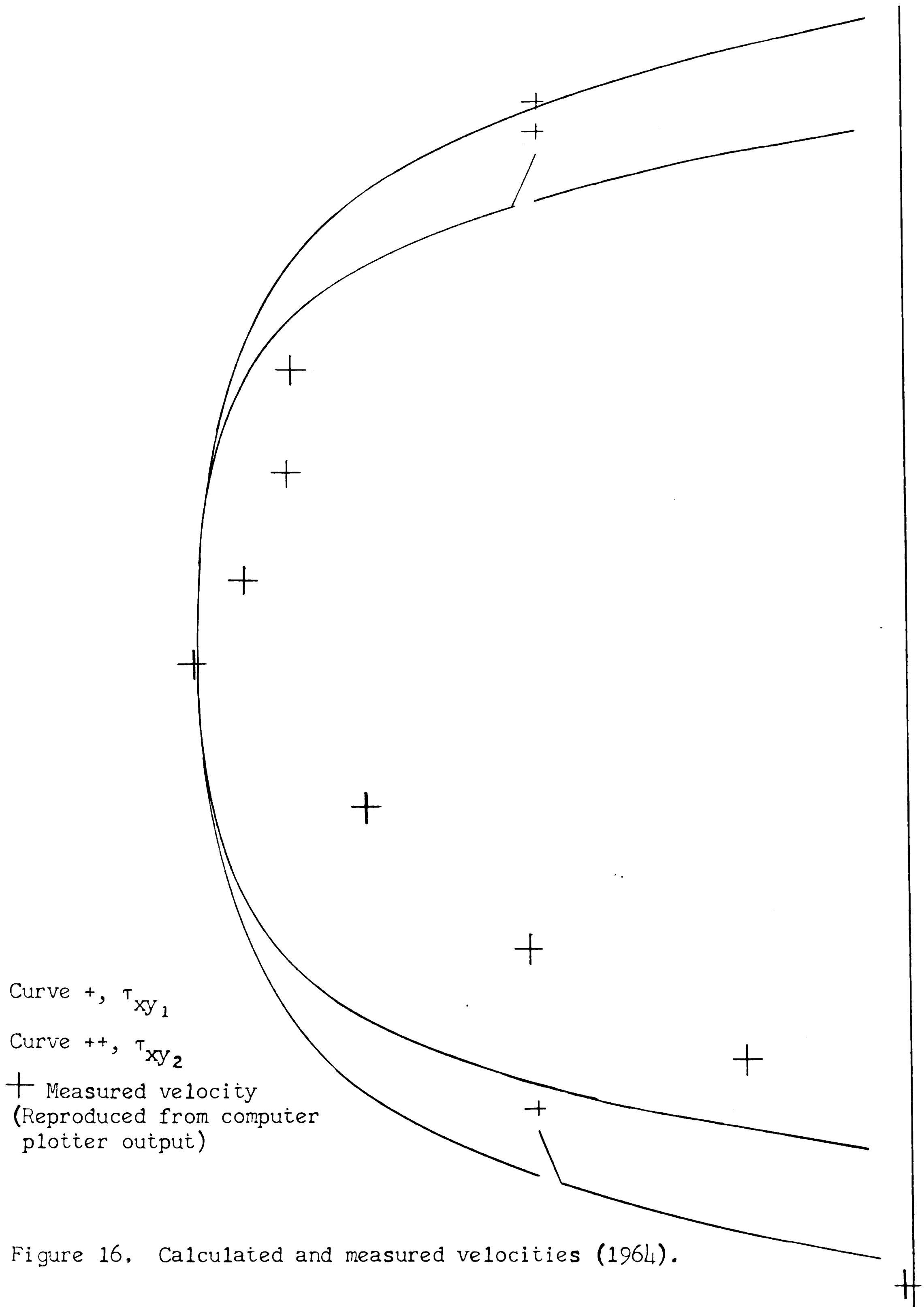

Figure 16. Calculated and measured velocities (1964).

Site III: This site is shown to have a tensile stress in the longitudinal (x''-axis) direction. This is inconsistent with the usual concept of compressive stresses in a glacier terminus that is pushing against stagnant ice. However, if only the first time interval is considered, there is a compressive longitudinal (x''-axis) strain-rate. At the end of the first interval, the holes were only 2 inches deep and were redrilled. The distances were not remeasured after redrilling and therefore the measurements which showed large tensile strains may not be reliable.

Sites IV and V: These sites are part of a series of strain diamonds located on the wall of an ice tunnel. The lengths of the sides of the strain diamonds were measured between centers of nails. The movement of the ice caused the nails to rotate and therefore made the distances difficult to measure. For this reason, the results may not be reliable. This is also suggested by the extremely high values of RE(volume loss) in the results. The nails of the other strain diamonds in the ice tunnel fell out because of melting of the ice.

Sites VI and VII: The strain-rates at these sites are in reasonable agreement with the stress conditions as indicated by the movement stakes. In general they indicate compressive stresses in the area immediately below the icefall and tensile stresses in areas further down glacier. These stress conditions can be associated with the formation and movement of the waves below the icefall. As these waves move down glacier, the amplitude decreases and the wave length increases. The velocity measurements show a faster movement of the ice further down glacier where tensile stresses are produced.

The strain diamond on wave #7 (Figure 6) shows a tensile strain-rate (x'-axis) of $0.64 \times 10^{-5} \times hr^{-1}$ and the movement stakes 7 and 8 show a tensile strain-rate (x'-axis) of $0.84 \times 10^{-5} \times hr^{-1}$.

CHAPTER V

SUMMARY

The measurements on the Taku Glacier in 1964 show surface velocities reaching a maximum of 520 M./yr. and a stress in the longitudinal direction of -0.05 bar with a shear stress of about 1.7 bars at the valley walls. The measured strain-rates are in general agreement with the crevasse patterns and the measured surface velocities. However, there are variations in the velocities and stress conditions of the Taku Glacier from year to year and also between measurement periods.

The change in direction of the measured velocities for 1964 is difficult to analyze with a simplified model of glacier flow. Another difficulty that still needs to be investigated is the relationship between measurements made in firn and the actual ice movements.

BIBLIOGRAPHY

Glen, J. W. 1955. The creep of polycrystalline ice. Proc. Roy. Soc. A, 228, 519.

Hill, R. 1950. Mathematical Theory of Plasticity, Chp. 1. Oxford, Clarendon Press.

Hoffmann and Sachs. 1953. Introduction Plasticity for Engineers, Chp. 1., McGraw-Hill.

Miller, M. M. 1958. Phenomena associated with the deformation of a glacier bore hole. Union Géodésique et Géophysique Internationale. Association Internationale d'Hydrologie Scientifique. Assemblée générale de Toronto, 1957. Tom. 4, 437.

Miller, M. M. 1963. Taku Glacier Evaluation Study. State of Alaska Department of Highways, 137.

Nye, J. F. 1951. The flow of Glaciers and ice sheets as a problem in pure plasticity. Proc. Roy. Soc. A, 207, 554.

Nye, J. F. 1952. The mechanics of glacier flow. J. Glaciol., 2, 82.

Nye, J. F. 1953. The flow law of ice from measurements in glacier tunnels, laboratory experiments and the Jungfraufirn bore hole experiment. Proc. Roy. Soc. A, 219, 477.

Nye, J. F. 1955. Comments on Dr. Loewe's letter and notes on crevasses. J. Glaciol. 2, 512.

Nye, J. F. 1957[a]. The distribution of stress and velocity in glaciers and ice-sheets. Proc. Roy. Soc. A, 239, 113.

Nye, J. F. 1957[b]. Physical properties of crystals. Oxford, Clarendon Press.

Nye, J. F. 1959. A method of determining the strain-rate tensor at the surface of a glacier. J. Glaciol., 3, 409.

Poulter, T. C., and others. 1949. Seismic measurements on the Taku Glacier, by T. C. Poulter, C. F. Allen and S. W. Miller. Standord, Calif., Stanford Research Institute.

Wu, T. H. and R. W. Christensen, 1964. Measurement of surface strain-rate on Taku Glacier, Alaska, J. Glaciol., 5, 305.

APPENDIX A

DETERMINATION OF PRINCIPAL STRAIN-RATES

The deformation of two sides of an element AOB is shown in Figure 17.

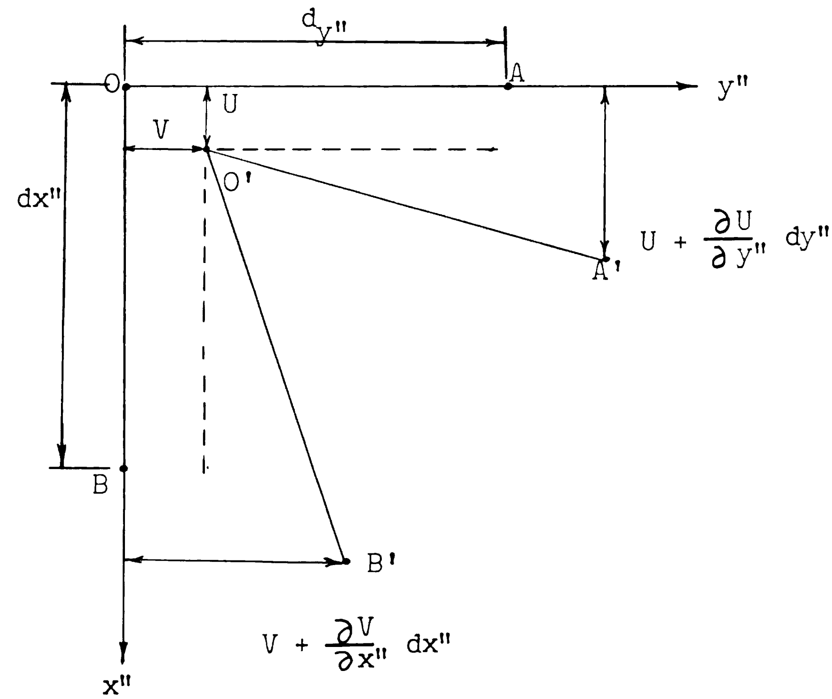

Figure 17. Components of strain in the x''-y'' plane.

The component of strain in the x'' direction is given by

$$e_{x''} = \frac{\partial U}{\partial x''} \tag{16}$$

and the change in angle AOB is defined by the shear strain $\gamma_{y''x''}$

$$\gamma_{y''x''} = \frac{\partial U}{\partial y''} + \frac{\partial V}{\partial x''} \tag{17}$$

If $\frac{\partial V}{\partial x''}$ is equal to zero, then the shear strain $e_{y''x''}$ is defined as

$$e_{y''x''} = \frac{1}{2}\left(\frac{\partial U}{\partial y}\right) = \frac{1}{2}\gamma_{y''x''} \tag{18}$$

The general notation of positive stress and strain for a strain diamond is shown in Figure 18.

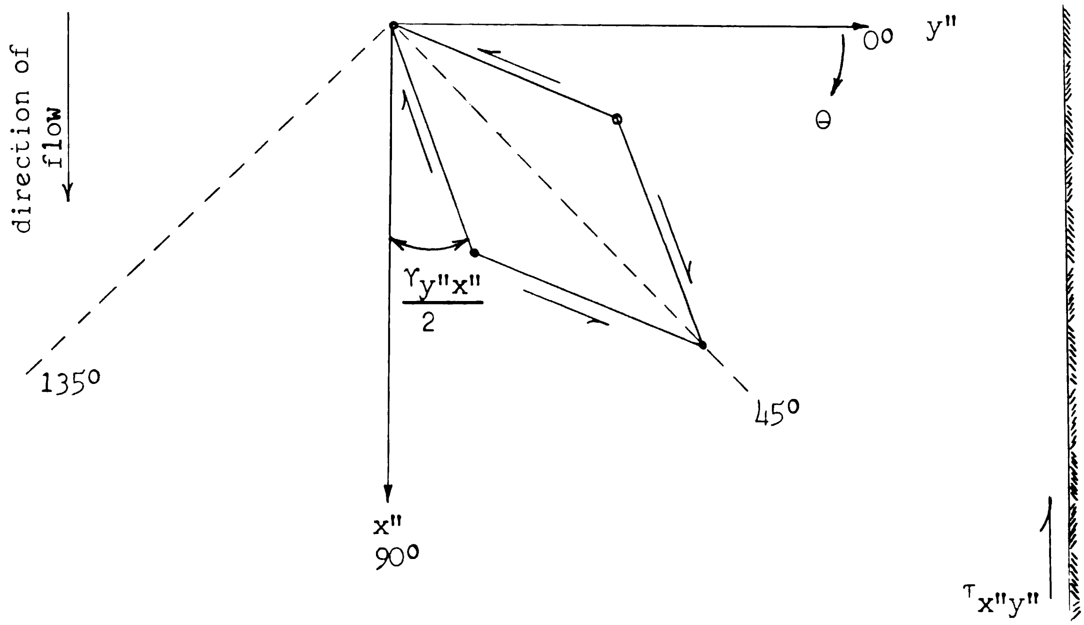

Figure 18. Deformation of a strain diamond.

The strain-rates in the direction 0°, 45°, 90°, 135° to the y" axis may be computed from the following equations.

$$\begin{aligned} \dot{e}_0 &= 0\dot{e}_{x''} + 0\dot{\gamma}_{y''x''} + \dot{e}_{y''} \\ \dot{e}_{45} &= \dot{e}_{x''}\sin^2\theta + \dot{\gamma}_{y''x''}\cos\theta\sin\theta + \dot{e}_{y''}\cos^2\theta \\ \dot{e}_{90} &= \dot{e}_{x''} + 0\dot{\gamma}_{y''x''} + 0\dot{e}_{y''} \\ \dot{e}_{135} &= \dot{e}_{x''}\sin^2\theta - \dot{\gamma}_{y''x''}\cos\theta\sin\theta + \dot{e}_{y''}\cos^2\theta \end{aligned} \tag{19}$$

These equations may be re-written in matrix notation as

$$\begin{bmatrix} \dot{e}_0 \\ \dot{e}_{45} \\ \dot{e}_{90} \\ \dot{e}_{135} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \\ 1 & 0 & 0 \\ \frac{1}{2} & -\frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} \dot{e}_{x''} \\ \dot{\gamma}_{y''x''} \\ \dot{e}_{y''} \end{bmatrix} \tag{20}$$

and the strain-rate along the x" and y" axis are then obtained from equation 25 as

$$\dot{e}_{x''} = -\frac{1}{4}\dot{e}_0 + \frac{1}{4}\dot{e}_{45} + \frac{3}{4}\dot{e}_{90} + \frac{1}{4}\dot{e}_{135}$$

$$\dot{e}_{y''x''} = \frac{1}{2}\dot{e}_{45} - \frac{1}{2}\dot{e}_{135} \qquad (28)$$

$$\dot{e}_{y''} = \frac{3}{4}\dot{e}_0 + \frac{1}{4}\dot{e}_{45} - \frac{1}{4}\dot{e}_{90} + \frac{1}{4}\dot{e}_{135}$$

The principal strain-rates may then be calculated from Mohr's Circle (Figure 19).

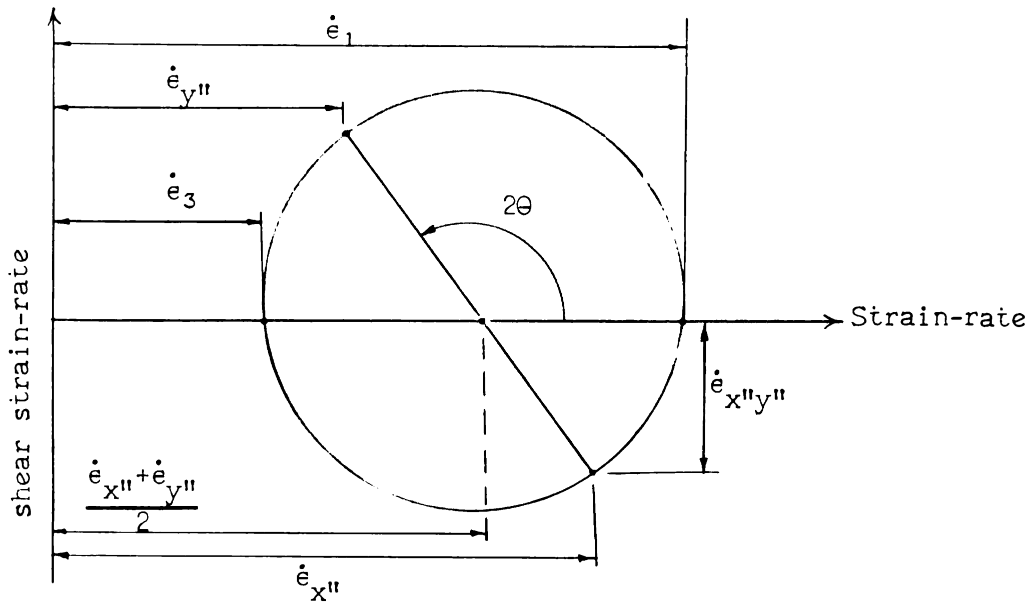

Figure 19. Mohr's Circle for strain-rate.

APPENDIX B

DESCRIPTION OF COMPUTER PROGRAMS

The methods of computer programming make possible fast and reliable computations. These methods were used to obtain the quantities in Tables II, III, and IV, and to plot Figure 16.

Three main subroutines[1] have been compiled on tape #400 (M.S.U. computer center). They are named JIRP, NORRIS, and PROFILE which consists of equations for calculations of surface velocities, strain-rates and stresses, and Nye's plasticity solution, respectively.

When using a tape, programming procedures must be altered by the use of control cards in the user's program. There should be between 3 to 5 control cards in the user's program for tape #400 (Appendix C, p. 60). The most important one of these has a FORTBIN,2,6. statement. This converts a program, written in Fortran 60, into the Binary language and compiles it on tape unit 2. Any subroutines needed for the program are then located on the tape unit corresponding to the second character, 6.

For a proper program execution, the computer cards should be arranged as shown in Figure 20. The data cards have a special format depending on the specific subroutine that is requiested (Appendix C).

---

[1]A subroutine is a sub-program which can be entered by a CALL statement with the subroutine's name and suitable variables for arguments.

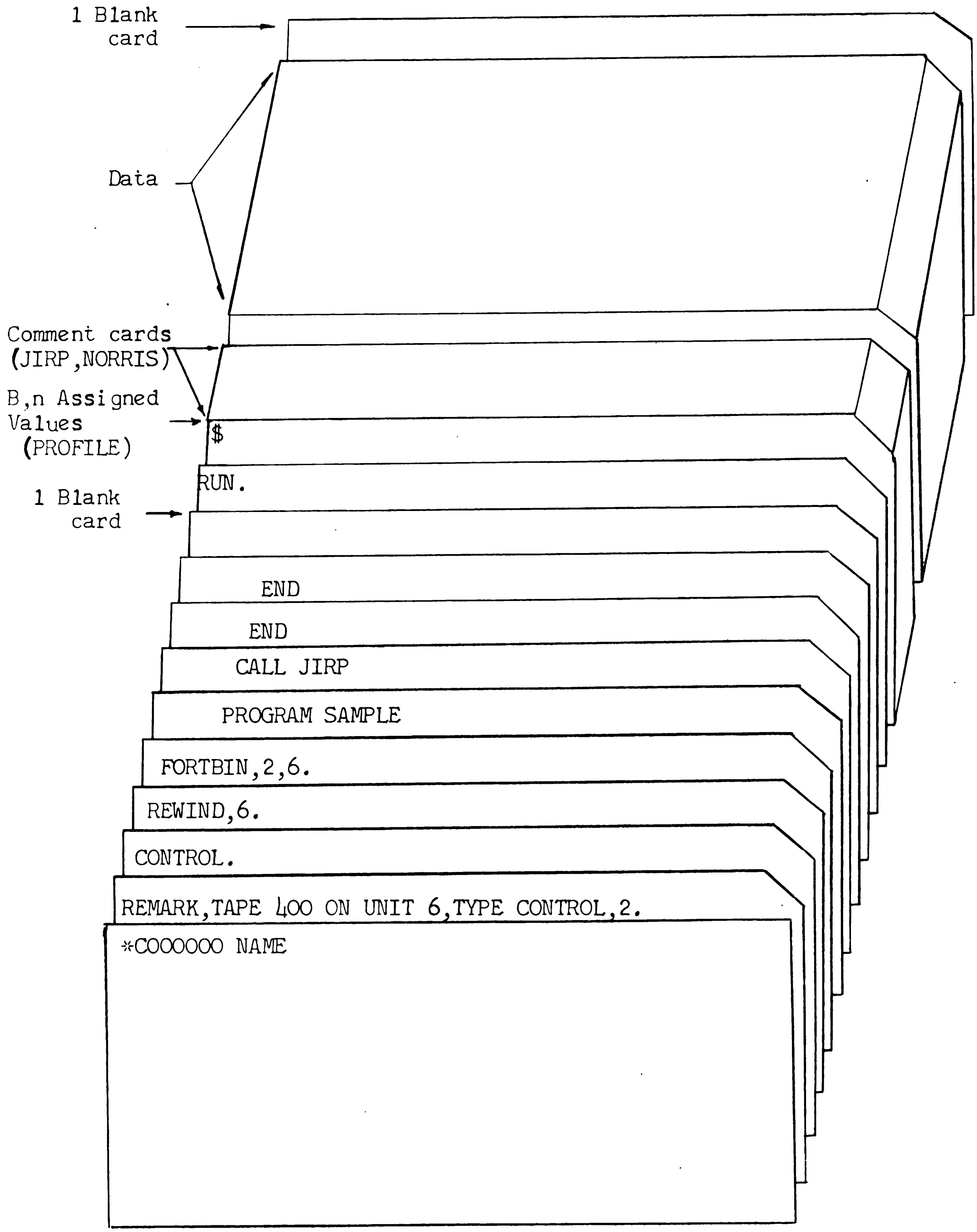

Figure 20. Sequence for computer cards.

Subroutine JIRP

This subroutine computes surface velocities from the measured angles between the base line and the movement stakes (Figure 13).

At the survey sites, certain readings were not made because of fog or the fact that a stake may have fallen over. For these conditions, a pseudo angle of 361° can be used in the data.

The measured angles from the data cards are stored in the memory. These angles give the stake locations based on the Cartesian Coordinate system. This location can be represented by

$$V(x', y', z')_{t,j} \qquad t = 1, 2, 3, 4, \ldots \quad j = 1, 2, 3, 4, \ldots$$

in which $V_{t,j}$ are the values of x', y', z' at time t for stake j. The measured angles needed to calculate $V_{t,j}$ are denoted by

$$\Upsilon_{g,j} \qquad g = 4t-3,\ 4t-2,\ 4t-1,\ 4t. \quad j = 1, 2, 3, 4, 5, \ldots \quad t = 1, 2, 3, 4, 5, \ldots \tag{29}$$

in which the values of g denote the four measured angles required to determine the coordinates for each stake at a given time (t).

The change in location or the stake movement (m) is given by

$$m_{t,j} = V_{t+1,j} - V_{t,j} \tag{30}$$

and the total movement (M) as

$$M_j = \sum_{t=1}^{t=T} m_{t,j} \tag{31}$$

in which the maximum value of t, (T), is determined by the maximum value of g, (G), on the data cards (refer to equation 29). Since there are four measured angles at each particular time, we have,

$$T = \frac{G}{4} \qquad (32)$$

in which the corresponding integer values of T and G are

$$T = 1,\ T = 2,\ T = 3,\ \ldots$$

and

$$G = 4,\ G = 8,\ G = 12,\ \ldots$$

Whenever $\Upsilon_{g,j}$ equals 361^{o}, the time is denoted by t'. In the following example, $\Upsilon_{11,2}$ is equal to 361^{o}, (g = 11, and t = 3) $V_{3,2}$ is indeterminate and t' is therefore equal to 3. The movements are represented by

$$\underbrace{V_{1,2},\ V_{2,2}}_{m_{1,2}},\ \underbrace{\ V_{t',2}}_{m_{t'-1,2}},\ \underbrace{V_{4,2}}_{m_{t',2}},\ \underbrace{V_{5,2}}_{m_{4,2}},\ \ldots\ \underbrace{V_{T,2}}_{m_{T-1,2}}$$

The two letters NA (not available) are printed on the output for the indeterminate movements $m_{t'-1,j}$ and $m_{t',j}$.

In order to compute the total movement (M), this subroutine considers the movement (m) ; however, to account for missing angles we introduce the movement N defined

$$N_{t',j} = V_{t+\ell,j} - V_{t,j} \qquad (33)$$

in which ℓ is the increment of time between two known values of $V_{t,j}$ (not considering pseudo angles of 361^{o}). Hence, $m_{t,j}$ is a special case of $N_{t',j}$ in which ℓ equals 1.

The movements in this example can now be represented by

$$\underbrace{V_{1,2}\ ,\ V_{2,2}}_{m_{1,2}}\ ,\ \underbrace{V_{t',2}\ ,\ V_{4,2}}_{N_{3,2}}\ ,\ \underbrace{V_{5,2}}_{m_{4,2}}\ ,\ \ldots\ \underbrace{V_{T,2}}_{m_{T-1,2}}$$

in which ℓ equals 2 . The total movement (M) is then revised to

$$M_j = \sum_{t=1}^{t=T} m_{t,j} + \sum_{t=1}^{t=T} N_{t,j} \tag{34}$$

in which

$$m_{t,j} = 0 \quad \text{if} \quad t = t' - 1 \;,\; t = t' \tag{35}$$

and

$$N_{t,j} = 0 \quad \text{if} \quad t \neq t' \tag{36}$$

In general, there may be any number of values of t' and $N_{t',j}$ provided that

$$\ell \leq 3 \tag{37}$$

Limiting the value of ℓ is an inherent quality of this subroutine. When the value of ℓ is the limiting case ($\ell = 3$), the value of T is also limited by this subroutine to

$$T = t_1' + 3 \tag{38}$$

in which t_1' is the first of the two successive values of t' .

If at a given time t' the values of $\Psi_{g,j}$ are 361 for all stakes j for a given g , that group may be omitted from the data. If the group that is omitted is G (or consecutive groups such as G, $G-1$, ...), the terminal g becomes G' and therefore does not yield an integer value for T in equation 32. In this case, the correct value of G for a given T is determined when values of G are chosen to satisfy

$$G - 1 \leq G' \leq G + 2 \tag{39}$$

A flow diagram for Subroutine JIRP is given in Figure 21 and format specifications are stated in Appendix C.

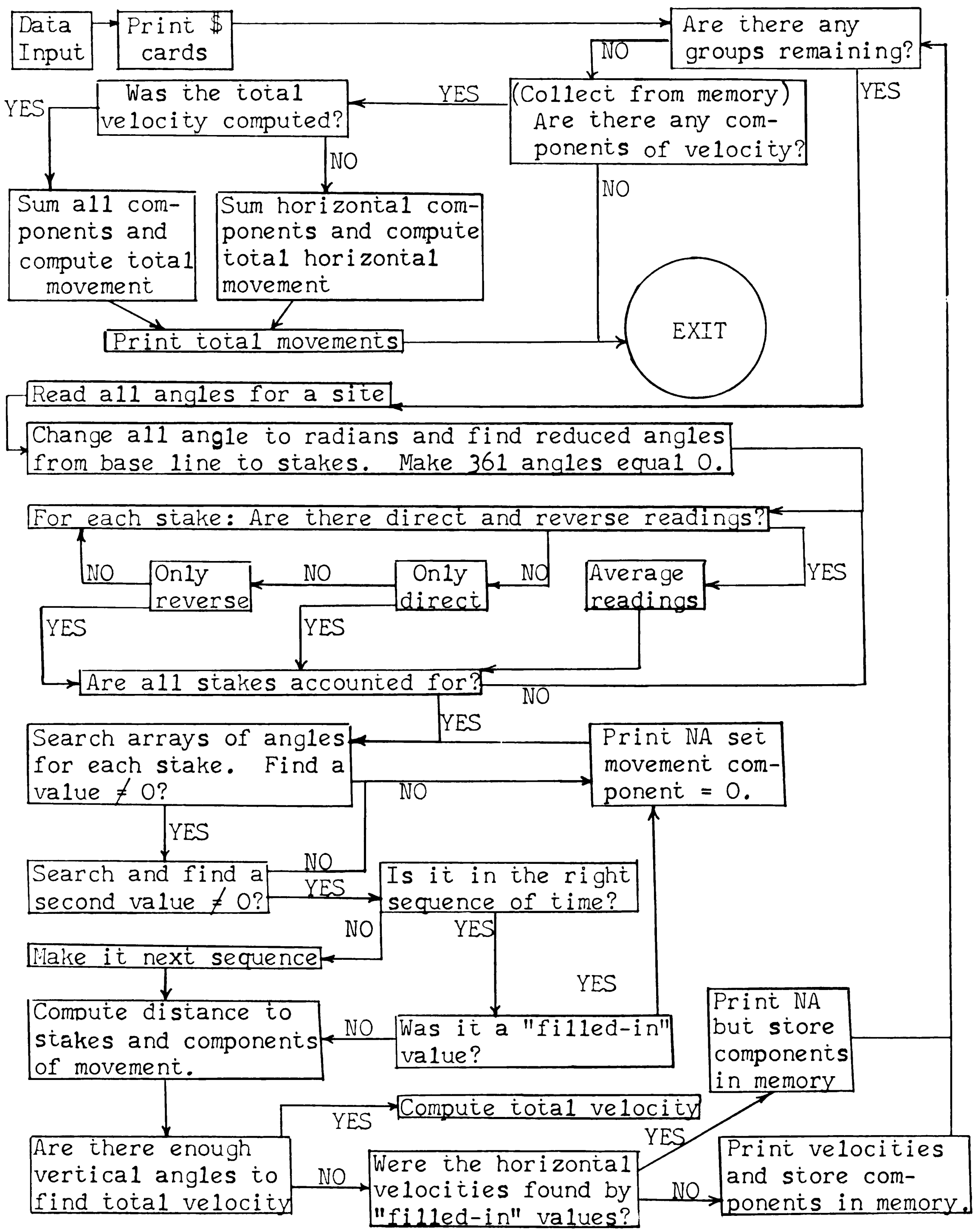

Figure 21. Flow diagram for Subroutine JIRP.

Subroutine NORRIS

This subroutine is designed to compute strain-rates and stresses from the strain diamond data described in Chapter IV. The calculations of strain-rates are based upon changes in lengths of the sides or diagonals of the strain diamond. This subroutine considers these lengths as

$$L_{t,k} \qquad k = 1, 2, 3, 4, 5, 6, 7, 8.$$
$$t = 1, 2, 3, \ldots$$

in which $L_{t,1}$ to $L_{t,8}$ are the lengths a_1, a_2, b_1, b_2, c_1, c_2, d_1, d_2 (Figure 15) respectively for time t.

The values of strain (F) are

$$F_{t,k} = \frac{L_{t+1,k} - L_{t,k}}{L_{t,k}} \tag{40}$$

and can be schematically represented by

$$\underbrace{L_{1,k} \;,\; L_{2,k}}_{F_{1,k}} \;,\; \underbrace{\quad}_{F_{2,k}} L_{3,k} \;,\; \underbrace{\quad}_{F_{3,k}} L_{4,k} \ldots$$

However, if the stakes are redriven after a measurement, the disturbances effect the quantity $(L_{t+1,k} - L_{t,k})$ for the time interval Δt. To eliminate this, the distances are remeasured after the stakes are reset. Whenever the stakes are redriven and remeasured, the time is denoted by S_i. The values of S_i (same as Skip value, Appendix C) are indicators to the computer that the strain between the interval $t = S_i$ and $t = S_{i+1}$ is not to be computed. This is represented by

$$\underbrace{L_{1,k} \;,\; L_{S_1,k}}_{F_{1,k}} \;,\; \underbrace{L_{S_1+1,k} \;,\; L_{S_2,k}}_{F_{2,k}} \;,\; \underbrace{L_{S_2+1,k} \;,\; L_{S_3,k}}_{F_{3,k}} \;,\; \ldots$$

in which the times for redriving are

$$S_1 = 2, \quad S_2 = 4, \quad S_3 = 6, \ \ldots$$

for

$$i = 1, \ i = 2, \ i = 3, \ \ldots$$

It is shown in Appendix C that if $i = -1$ on the data cards, the values of S_i are automatically taken as 2, 4, 6, ... However, other values of S_i can be obtained by specifying them on the data cards (Appendix C).

Once the values of strain (F) are determined, then the strain-rates ($\dot{e}$) can be calculated by

$$e_{t,n} = \frac{1}{2W_t}(F_{t,k-1} + F_{t,k}) \qquad \begin{aligned} n &= 1,2,3,4. \\ k &= 2n \\ t &= 1,2,3,\ldots \end{aligned} \quad (41)$$

in which W_t is the interval of time between successive values of t. The index n corresponds to values of Θ for 0°, 45°, 90°, 135°, respectively.

The calculations for stress are then carried out by Mohr's circle of stress and strain-rate.

A flow diagram for NORRIS is given in Figure 22 and format specifications are stated in Appendix C.

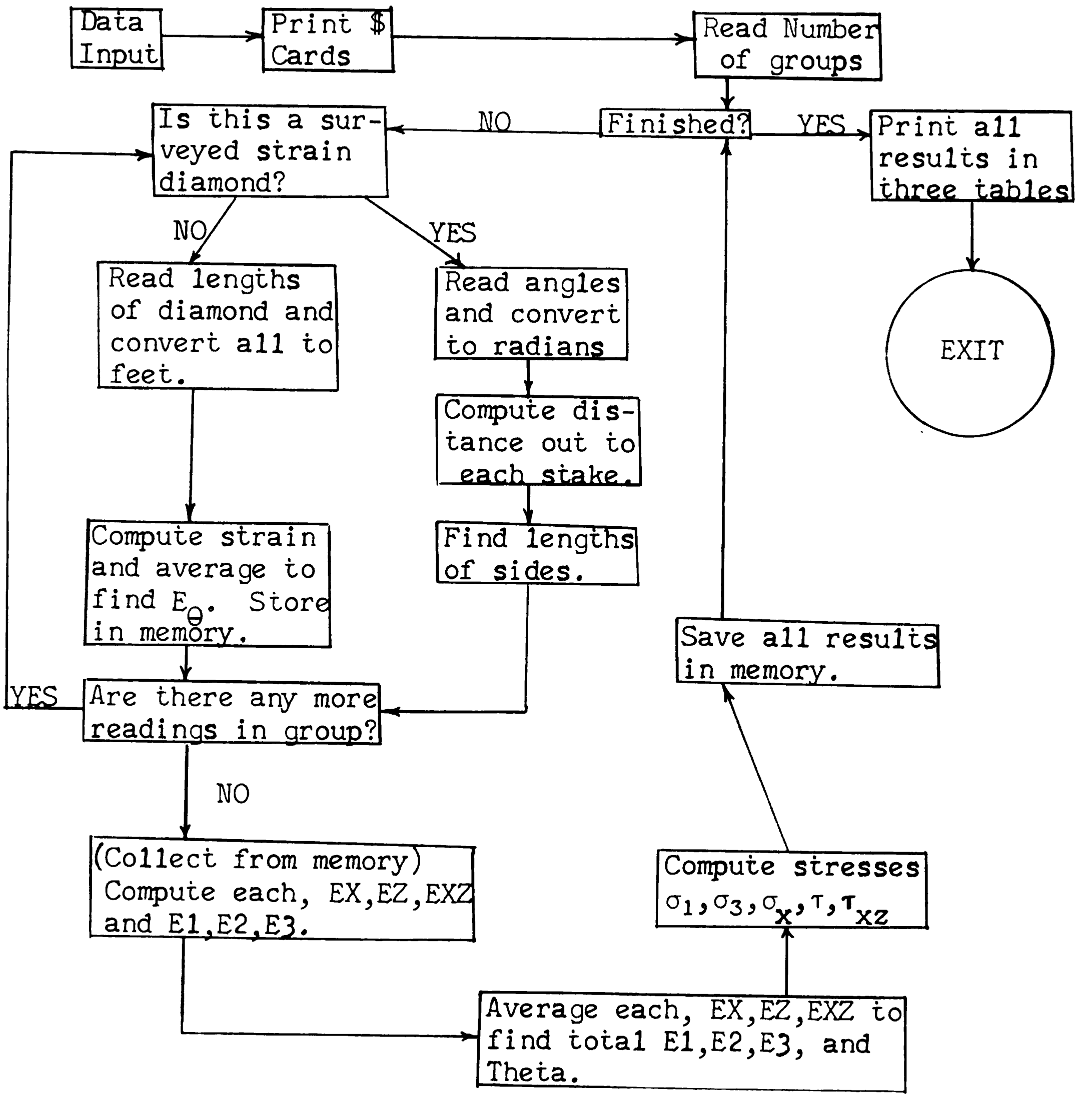

Figure 22. Flow diagram for subroutine NORRIS.

Subroutine PROFILE

This subroutine computes the solution to Nye's plasticity equation and plots the results together with measured velocities.

The results of Subroutines JIRP and NORRIS provide the data for Subroutine PROFILE. If the x' and x'' axes coincide, then the necessary data consists of the x' component of velocity (same as D, total movement, from JIRP), the shear stresses $\tau_{x''y''}$ (same as TXZ from NORRIS), the x'' component of strain-rate (same as EX from NORRIS), and the distances x', y' (same as RO and BO from JIRP, special listing).

If the two axes (x' and x'') do not coincide, then it is necessary to calculate the components of shear stress and strain-rate along the x'-axis. Subroutine PROFILE does not make a distinction between x' and x'', therefore in describing this subroutine, the x''-axis will be referred to as the x'-axis.

Subroutine PROFILE computes the shear stress at the valley wall $(\tau_{x'y'})_{y'=0}$ from the shear stresses at y'

$$\tau_{x'y'} = \beta y' + (\tau_{x'y'})_{y'=0} \tag{42}$$

in which

$$\beta = \frac{d}{dy'} (\tau_{x'y'}) \tag{43}$$

The shear stress and velocity diagrams are compared in Figures 23. The value y_τ is the distance from the valley wall to the point of zero shear stress. For the ideal glacier described in Chapter II, this point should coincide with the point of maximum velocity at distance y_0 from the valley wall. The distance (y_m) from the valley wall to the movement stake showing a maximum velocity

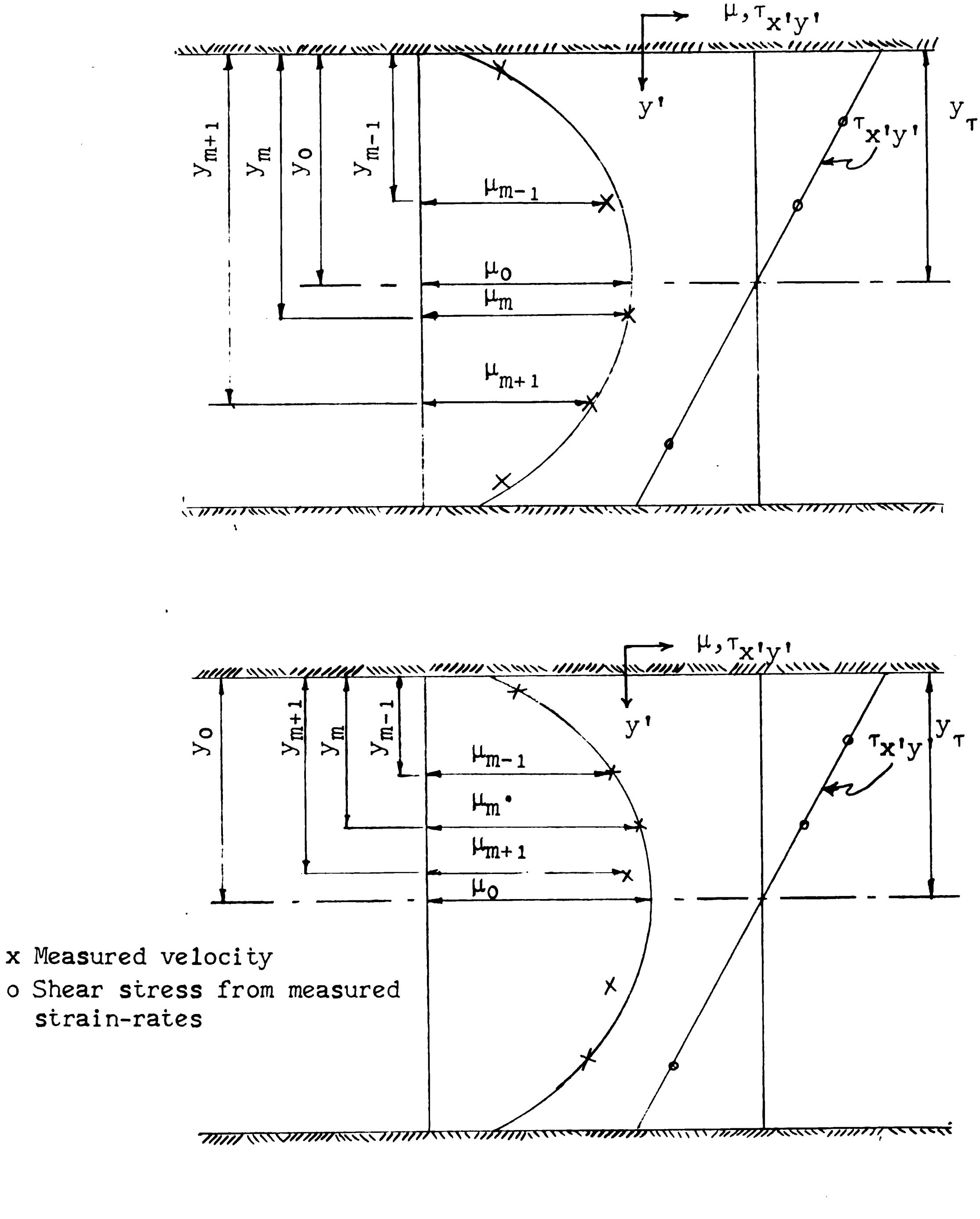

Figure 23. Relationship between velocity and shear stress.

is given on a data card (Appendix C).

The distance y_τ is computed from equation 42 and compared to the distances on the velocity profile. This subroutine considers y_τ to be an acceptable value if

$$y_{m-1} \leq y_\tau \leq y_{m+1} \tag{44}$$

If the computed value of y_τ does not satisfy equation 44, the computer will stop and print an error diagnostic.

Even with reliable data, the above discrepancy can occur if $y_{m-1} > y_0$ or $y_{m+1} < y_0$ (see Figure 23). This error can then be passed by if a certain code ($) is used on one of the data cards (Appendix C).

In Nye's solution, values of $\mathcal{T}$ are needed for each point. They are shown in Figure 24.

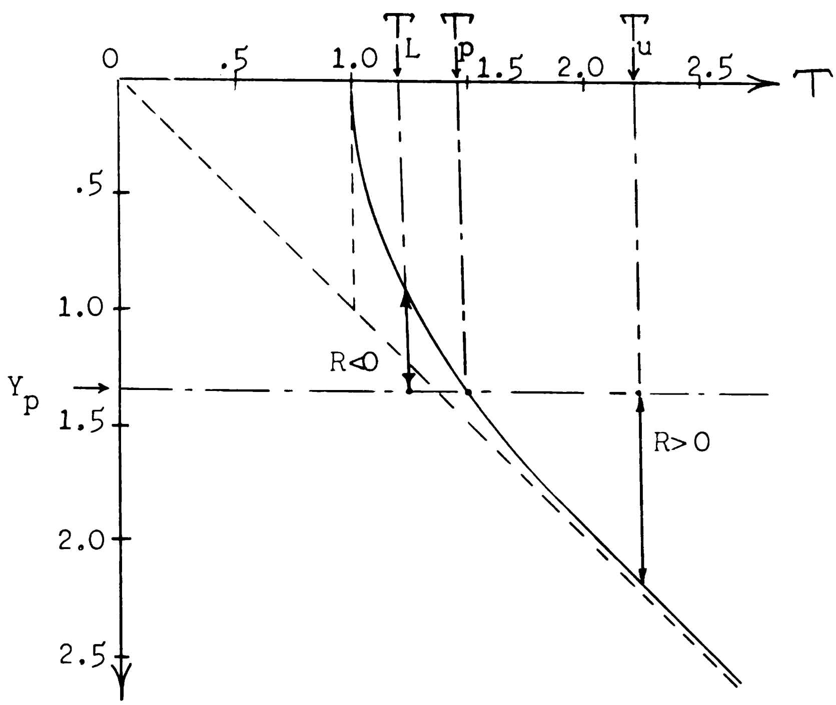

Figure 24. Relationship between dimensionless shear stress $\mathcal{T}$ and dimensionless distance Y. After Nye (1957[a]).

A function[1] named ROOT was incorporated to solve equation 5 for values of τ in

$$R = \tau^{2n} - Y^2\tau^{2n-2} - 1 \qquad (45)$$

in which R is a residual value and is equal to zero when values of τ (τ_p) and $Y(Y_p)$ satisfy equation 5. The procedure is to select a value for Y_p and choose two values for τ, an upper and lower limit (τ_u and τ_L). The corresponding values of R are

$$R_u > 0 \ , \quad R_L < 0 \ .$$

Then the subroutine evaluates the average value of τ (τ_A) as

$$\tau_A = \frac{\tau_u + \tau_L}{2} \qquad (46)$$

and evaluates a corresponding value of R (R_A) in equation 45. Then if $R_A < 0$, a new lower limit for τ_L is given the value of τ_A. Likewise, if $R_A > 0$, a new upper limit for τ_u is taken as τ_A.

The values of Y_p and τ_p are obtained by repeating this process until

$$(\tau_u - \tau_A)(\tau_A - \tau_L) = 0 \qquad (47)$$

which is limited to an accuracy of 10 decimal places on the computer.

A flow diagram for subroutine PROFILE is given in Figure 25 and format specifications are stated in Appendix C.

Apart from the calculations, there are extra features in each subroutine. General comments may be printed with the results in

---

[1]A function is similar to a subroutine except that it is entered when there is an equation containing the function's name and suitable expressions or variables for arguments.

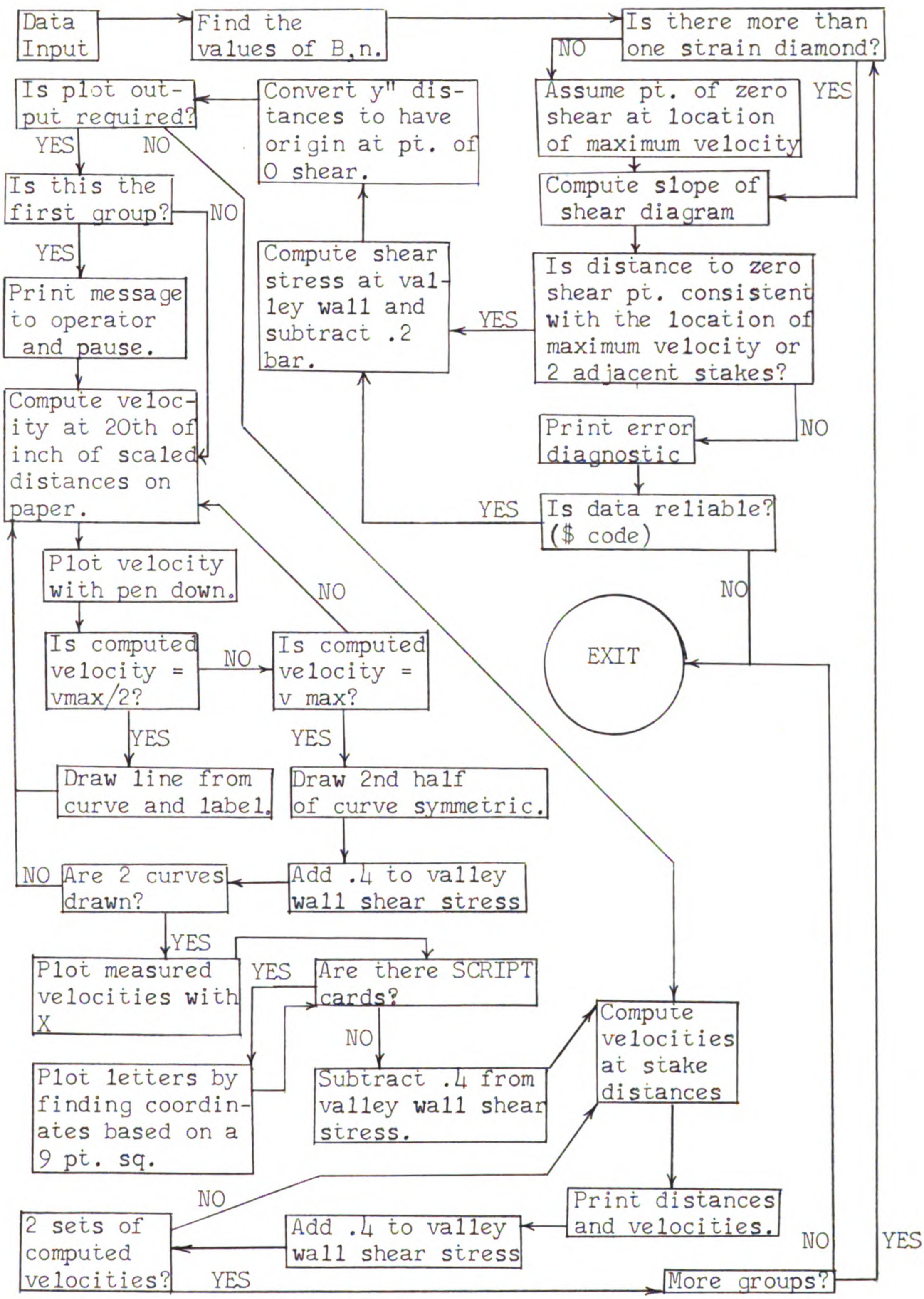

Figure 25. Flow diagram for Subroutine PROFILE

Subroutines JIRP and NORRIS. Subroutine JIRP also has a provision for a special listing of coordinates and angles. Subroutine PROFILE has two provisions. One is for assigning values to the constants in Glen's flow law other than those calculated by Nye. The other provision is a method of printing titles on the output from the plotter by using Script cards (Appendix C).

APPENDIX C

DETAILS OF COMPUTER SUBROUTINES AND PROGRAMS

A program for tape #400 is correctly prepared when the computer cards are arranged as shown in Figure 20. The statements begin in column 7 on the third through the sixth cards. The statements on the other cards begin in column 1 except for the data cards. These have a special format depending on which subroutine is requested.

Identification Card

The following symbols are punched in the appropriate columns of an ID Card.

Symbol	Columns
*	1
C	2
(a six digit problem number)	3,4,5,6,7,8
(last name of user beginning in ...)	10
(time limit in minutes)	31
(program name beginning in ...)	36

Control Cards

The control cards immediately follow the ID Card. Statements are punched for the control cards beginning in column 1 and are as follows:

Card	Statement
1	REMARK,TAPE 400 ON UNIT6,TYPE CONTROL,2.
2	CONTROL.
3	OUTPUT,G,27. <—(use only if plot output is requested in Subroutine PROFILE)
4	REWIND,6.
5	FORTBIN,2,6.

It is permissable to have several computer decks in a series. If more than one program at a time is to be executed, then a new ID Card followed by new control cards are necessary for each. Since the first two control cards listed above stop the computer in order that the operator may check tape units, they need not be included in any subsequent decks. However, one may choose to replace the first two cards by a single card punched as

REMARK,TAPE 400 ON UNIT 6.

for computer programs other than the first deck.

Program Cards

These statements follow the control cards and begin in column 7. They are

Card	Statement
1	PROGRAM _______ (any name, 7 letters or less, except JIRP, NORRIS, or PROFILE)
2	CALL _______ (choice of JIRP, NORRIS, or PROFILE)
3	END
4	END
5	Blank Card
6	RUN. <— (begins in column 1).

Comment Cards (JIRP, NORRIS)

These cards are designated by a dollar sign ($) in the first column and immediately follow the RUN. card. Any statement punched in columns 2-80 will then be printed with the computer output.

Subroutine JIRP

A sample of data is given in Figure 26 in which the columns for the computer cards have been designated by arrows.

The Index Card is the first data card on which there are three numbers. Column 4 is a number for a site (1,2,3, ...). Column 8 is the group index g to the angle $\psi_{g,j}$ (see Figure 13). The last number ends in column 12 which is the total number of cards to follow for a given group.

The cards following the Index Card are the Angle Cards. The first one contains the sighted angles to a base line station. The remaining cards in the group are the recorded angles to the movement stakes.

The angles are given in degrees, minutes, and seconds respectively for each direct and reverse reading. These values appear on the Angle Cards ending in columns 9, 19, 29, 39, 49, 59 respectively (see Figure 26). If there are any fractional parts of an angle, they may be given as a decimal value appearing in the tenth column 10,20, 30,40,50,60 (no decimal point). Angles that are in degrees, minutes, or seconds with a value of 00 need not be punched since blanks are read as zeros.

Columns

Data Card	0	4	89	12	19	29	39	49	59
1		1	1	3					
2			13		25	52	361		
3			106		21	17	361		
4			106		22	26	361		
5		1	2	3					
6			91		34		269	35	
7			112		20	10	248	20	15
8			361				361		

(Etc.)

Direct Readings (columns 9–29) ; Reverse Readings (columns 39–59)

0	4	89	12	19	29	39	49	59
	-1	8	3					
		90		29	40	270	29	40
		103		27	30	257	34	20
		100		44	40	259	17	35
		385.4						
	60							
	2	1	3					

(Etc.)

Figure 26. Example data dards for Subroutine JIRP.

The Index Card which precedes the last group (G) of Angle Cards must have a negative value for the site number. This indicates to the computer that this is the last group for that site.

After the last group of Angle Cards for each site, there are two remaining cards. They are the Base Line and Time Cards, respectively. The Base Line Card contains the base line length (meters) and is punched anywhere within the first 10 columns provided that a decimal point is also included. The Time card contains the time interval (days) between the first and last readings and should appear on a card ending in column 4 (no decimal point). This card completes one site.

The next cart to follow is an Index Card for another group of angles at a different site, or if there are no remaining sites, the next card is blank. A blank card after a Time card therefore terminates the program.

One may also obtain a special listing of all horizontal angles and distances of a coordinate system passing through the first station by punching a second dollar sign ($) in column 2 of any comment card in JIRP. It should be noted that if there are any values of 361^o for $\Upsilon_{g,j}$, the angles that are printed for the special listing will not be 361. They will be the values of $\Upsilon_{g,j}$ for the next g for that angle measured from the same station if there are enough values to compute a movement. Otherwise they will be zero. For example if $\Upsilon_{5,3} = 361^o$, $\Upsilon_{9,3} = 42^o$ then the special listing will give $\Upsilon_{5,3} = 42^o$, $\Upsilon_{9,3} = 42^o$. If $\Upsilon_{5,3} = 361^o$, $\Upsilon_{9,3} = 361^o$ and no values are obtained for $\Upsilon_{13,3}$, then $\Upsilon_{5,3} = 0$, $\Upsilon_{9,3} = 0$.

The values of y' for times t = 1 and t = 2 are given by BO and AO , respectively. The values of x' are given by RO and TO respectively.

These distances that are given in the special listing of JIRP are shown in Figure 27.

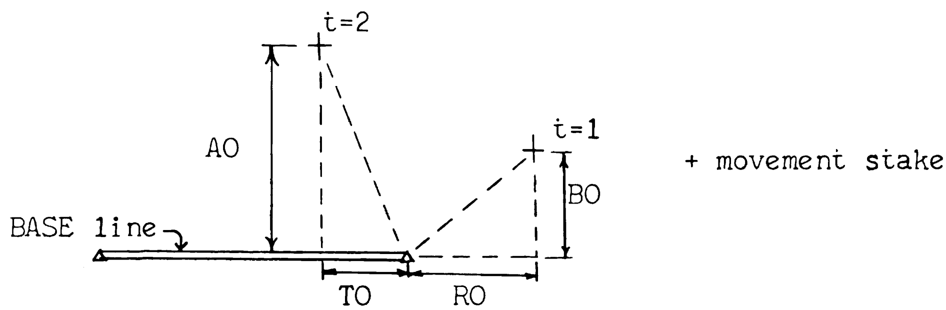

Figure 27. Notation for special listing of Subroutine JIRP

In this figure, TO is positive and RO is negative. The final tabulated results are based upon the same coordinate system (Figure 13) in which

$$
\begin{aligned}
B &= BO \\
D &= TO - RO \\
E &= AO - BO \\
C &= (D^2 + E^2)^{1/2}
\end{aligned}
\qquad (48)
$$

Subroutine NORRIS

Sample data are given in Figures 28. The first data card contains the total number of strain diamonds. This number ends in column 4.

The general order after the first data card depends on the method employed for the measurements.

Data Card	0 ↓	4 ↓	8 ↓	10	18 20 ↓	24 ↓	28 ↓	30	38 40 ↓	48 50 ↓ ↓	58 60 ↓ ↓	68 70 ↓	78 80 ↓ ↓
1		2											
2		1	4		2	1			(b_1 = 97.00' 10.75")				
3		129											
4		4											
5		2											
6			69		300		69		263	9700	1075	97	1075
7			69		338		69		300	97	1113	97	1125
8			69		213		69		150	97	1188	97	11
9	(Skip)		69		250		69		400	98		97	925
10			69		225		69		125	97	1125	97	1025
11			69		300		69		325	97	11	97	10
12			69		252		69		1188	97	1080	97	1140
13			69		408		69		288	97	1128	97	828
14		2	4		1	-1							

(Etc.)

Figure 28a. Example data (Case I) for Subroutine NORRIS.

Data Card	0 ↓	4 ↓	8 ↓	12 ↓	16 ↓	19 20 ↓↓	24 ↓	29 ↓	39 ↓	49	59
1		1									
2		1	4	5	1	2	-1				
3			13			25		52	361		
4			106			21		17	361		
5			108			37		43	361		
6			108			05			361		
7			110			22		20	361		
8		1	4	5	3	2	-1				
			385.4								
		129									
		4									

(Etc.)

Figure 28b. Example data (Case II) for Subroutine NORRIS.

CASE I (Measurements by taping)

Card	
(2)	INDEX CARD
(3)	SKIP CARD (optional)
(4)	TIME CARD
(5, ...)	DATA

The format of the Index Card is

Column	
4	strain diamond number (1,2,3, ...)
8	number of sets of readings
20	number of time intervals
24	skip index,

in which the skip index is a number which indicates the number of time intervals when the only movement was due to the redriving of the reference stakes. This number may be from -1 to 6 . A skip index with a value of zero (blank) indicates a comparison of data for consecutive intervals. A minus number indicates a comparison of data for every other interval. A positive number indicates the number of skipped intervals which appear on the next card. This next card is the Skip Card and contains these interval numbers (skip values). The numbers should end in columns 4,8,12,16,20,24. A maximum of 6 numbers may therefore be used. This card should not appear unless a positive number is used for the skip index.

The following cards contain the time intervals (weeks). One value is to appear on each card in columns 1 and 2 with decimal values in columns 3 and 4 (no decimal point).

The next card contains the measurement data. They may be given with decimal values of a foot or with inches and decimal parts of an inch. The lengths a_1, a_2, b_1, b_2 (Figure 15)(in feet) should end in columns 8,28,48,68. The next card contains the last 4 lengths c_1, c_2, d_1, d_2 (in feet). The numbers should end in columns 8,28, 48,68. If there are decimal parts of a foot, they can be included as the 9th and 10th columns (9,10; 29,30; 49,50; 69,70), with no decimal points. If the measurements are also in inches, the number of inches should end in columns 18,38,58,78, and decimal parts of an inch in the 19th and 20th columns (19,20; 39,40; 59,60; 79,80), respectively.

If the square is very large (as on adjacent longitudinal profiles), then it is more convenient to use CASE II.

<u>CASE II</u> (measurements by surveying).

The format of the Index Card is

Column	
4	strain diamond number (1,2,3, ...)
8	number of sets of readings
12	"5" (a constant)
16	group number (g)
20	number of time intervals
24	skip index.

Apart from the Index and Skip Cards, the formats for the angle and the Base Line Cards are the same as in Subroutine JIRP. The format for the Time Cards are the same as in Case I only they appear at the end of the group G for each site.

Case II is designed for 4 movementstakes with the order of angles as shown in Figure 29.

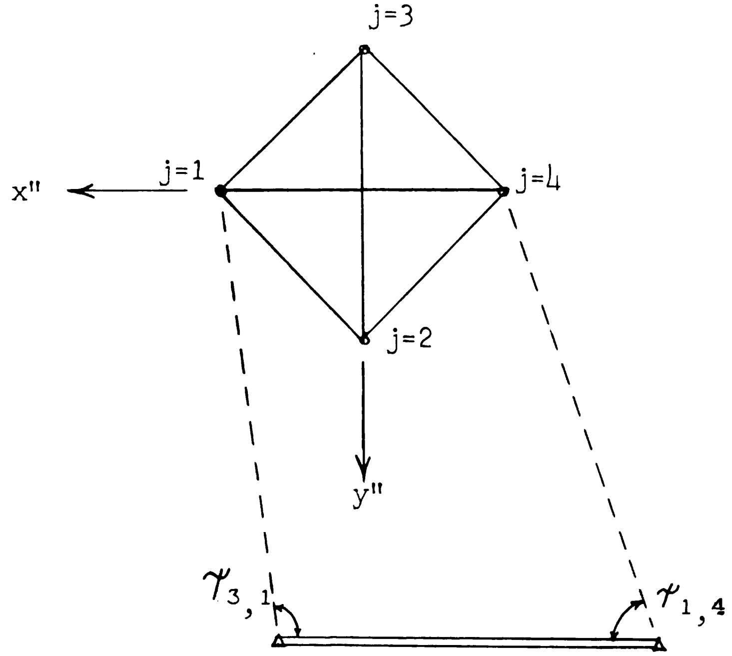

Figure 29. Notations for stakes in strain diamond.

Subroutine PROFILE

No Comment Cards are allowed in this subroutine. To change the constants B and n (equation 2), a card with a dollar sign ($) in column 1 is inserted after the RUN. card. The new values for B and n end in columns 7 and 14 (with decimal points), of this card. If this card is absent, the values of 0.148 and 4.2 are automatically taken for B and n.

The next (or first) card is the Index Card. It contains the following:

Numbers Ending in Columns

3	total number of strain diamonds
6	total number of measured velocity points
9	number of stake at which maximum velocity occurs
12	a code for the type of output. 0 = no plot, 1 = plot.
13	a code to by pass an error. 0 = stop, $ = continue.
17	number of distance units/inch along y'-axis
21	number of velocity units/inch along x'-axis
30	number of the strain diamond (STRAIN-RATE,EX)

to be used in the calculations. A zero or blank indicates an average EX to be used. If column 12 contains a one, then the OUTPUT,G,27. control card must be used (see p. 60). If this column contains a zero or a blank, then the OUTPUT,G,27. control card may be omitted as well as the scale factors in columns 17 and 21 of the Index Card.

The scale factors give the scales in the horizontal direction (same as x' and is limited to 11 inches, the width of the paper) and the vertical direction (same as y' and is not limited) of the plot output.

The next cards are the Strain Diamond Cards. These contain the following:

Numbers Ending in Columns

7	value of TXZ in bars (with decimal point)
14	distance (M.) from base line to strain diamond in decreasing order (no decimal pt. if 2 decimal places are used)
21	average EX (bars) for an individual strain diamond (with decimal pt.).

Following these are the Measured Velocity Cards. They contain the following:

Numbers Ending in Columns

7	X' distance (M.) of the movement stakes (RO from JIRP)
14	Y' distance (M.) (B or BO from JIRP)
21	x' components of velocity in m/yr. (D from total movement, JIRP).

No decimal points are needed in the above values provided that 2 decimal places are used in each. An example of the data cards is given in Figure 30.

The next card may be any one of the following three. If it is blank, the program terminates. It may be an Index Card for another group of data. Finally, it may be a card which puts a title on the plot output.

The last type of card is called a Script Card because it must contain the word SCRIPT beginning in Column 1. The format of a Script Card is as follows:

Ending in Column

6	the word SCRIPT
9	size of block letters (ie. .25 is 1/4 inch) with a decimal point.
10	number of inches above the maximum scaled y' value to start printing.
11-80	any title or name.

Column 11 is the first letter to be printed. A dollar sign ($) or an asterisk (*) must be punched immediately after a title on a Script Card. This marks the end of the title. The dollar sign

```
           01 3   67 9 1214 17   21
           ↓↓ ↓   ↓↓ ↓  ↓ ↓  ↓    ↓
Data
Card
  1           2  6  3  1  450 100
  2          -.373 285470    .119
  3           .903 106481    .192
  4          -1832 140763   12696
  5          -2279 183945   18142
  6          -2971 227608   23859
  7          -3487 253001   22134
  8          -3844 285479   20696
  9          -4240 316275   20503
 10        SCRIPT.502VELOCITY PROFILE$
 11        SCRIPT.25 NAME*
 12           2 10  7  0
                   (Etc.)
```

Figure 30. Example data for Subroutine PROFILE.

indicates that the printing begins with the contents of column 11 at a distance of 10.5 inches to the left of the right margin of the paper. The asterisk causes the plotter to print the title so that a blank space after the last letter ends at the right margin.

More than one Script Card may be used to print as many titles as desired.

Once a number in column 10 has been specified, another need not be given in additional Script Cards. A blank in column 10 of subsequent Script Cards will automatically indicate that the spacing between the lines of print is 1/2 the size of the letters of the previous title. However, if different spacings are desired then different values may be specified on each Script Card. A blank card after the Script Cards terminates the program.

The subroutines, functions, and programs, as they were written, are given by the following:

```
.051712 HAVAS                3    COMPILE-TAPE 400
:MARK,TAPE 400/WRITE RING
:MARK,TAPE 400 ON UNIT 6-TYPE CONTROL,2.
)NTROL.
:WIND,6.
)RTBIN,2,L,6,3.
      SUBROUTINE JIRP
      DIMENSION ANGLEA(50),ANGLEB(50),MP(50),NP(50),DEGS(50,50),
     1BASE(20),NONE(50,50),H(12),F(13,25,7),G(13,25,7),DA(13,25,7),FOG(2
     20),GOF(20),TIME(20),KPAR(50),MOP(30),KOM(30)
    4 FORMAT(80X,15HSPECIAL LISTING)
    5 FORMAT(2A1,A6,9A8)
    6 FORMAT(1H0,A1,A6,9A8)
   73 FORMAT(81X,1HJ,6X,2HB0,8X,2HA0,8X,2HR0,8X,2HT0)
   74 FORMAT(80X,I2,2X,F8.2,2X,F8.2,2X,F8.2,2X,F8.2)
   75 FORMAT(80X,I2,4X,I2,2X,F7.2)
   77 FORMAT(4X,I2,4X,I2,7X,2HNA,7X,2HNA,7X,2HNA,14X,2HNA)
   780FORMAT(2X,5HGROUP,2X,5HSTAKE,4X,1HC,8X,1HD,8X,1HE,7X,1HV,5X,4HZETA
     1,4X,4HEPSL)
   79 FORMAT(//,2X,39HB=PERPENDICULAR DISTANCE FROM BASE LINE)
   80 FORMAT(//,25X,14HTOTAL MOVEMENT)
   810FORMAT(16X,5HM/YR.,5X,5HM/YR.,4X,5HM/YR.,3X,5HM/YR.,1X,7HDEGREES,1
     1X,7HDEGREES)
   82 FORMAT(2X,47HC=MAGNITUDE OF TOTAL HORIZONTAL VELOCITY VECTOR)
   830FORMAT(2X,54HD=MAGNITUDE OF HORIZONTAL VELOCITY VECTOR IN DIRECTIO
     1N)
   84 FORMAT(15X,18HPERPENDICULAR TO B)
   850FORMAT(2X,59HE=MAGNITUDE OF HORIZONTAL VELOCITY VECTOR IN DIRECTIO
     1N OF B)
   86 FORMAT(2X,36HV=MAGNITUDE OF TOTAL VELOCITY VECTOR)
   870FORMAT(2X,57HZETA=POSITIVE ANGLE OF V, BETWEEN AND AWAY FROM BASE
     1LINE)
   880FORMAT(2X,53HEPSL=ANGLE BETWEEN V AND A HORIZONTAL GLACIER SURFACE
     1)
   89 FORMAT(2X,46HM/INT=METERS PER EFFECTIVE MEASUREMENT PERIODS)
   900FORMAT(4X,I2,4X,I2,1X,F7.1,2X,F7.2,2X,F7.2,2X,F7.2,1X,F7.2,2X,F6.2
     1,2X,F6.2)
   910FORMAT(2X,5HGROUP,2X,5HSTAKE,3X,1HB,9X,1HC,8X,1HD,8X,1HE,7X,1HV,4X
     1,4HZETA,4X,4HEPSL)
   92 FORMAT(4X,I2,4X,I2,1X,F7.1,2X,F7.2,2X,F7.2,2X,F7.2,10X,F6.2)
   930FORMAT(17X,2HM.,6X,5HM/INT,4X,5HM/INT,4X,5HM/INT,3X,5HM/INT,1X,7HD
     1EGREES,1X,7HDEGREES)
   94 FORMAT(F10.3)
   95 FORMAT(F4.0)
   960FORMAT(4X,I2,4X,I2,2X,F7.2,2X,F7.2,2X,F7.2,1X,F7.2,2X,F6.2,2X,F6.2
     1)
   97 FORMAT(4X,I2,4X,I2,2X,F7.2,2X,F7.2,2X,F7.2,10X,F6.2)
   98 FORMAT(4X,I2,4X,I2,6X,2HNA,7X,2HNA,7X,2HNA,7X,2HNA,14X,2HNA)
   99 FORMAT(//)
  100 FORMAT(3I4)
      COMMON ANGLEA,ANGLEB,MP,NP,DEGS,NONE,F,G,DA,FOG,GOF,TIME,KPAR,MOP,
     1KOM,BASE,H
      PRINT 99
      KEY=0
      DOL=5320202020202020
```

```
    9 READ 5,H
      IF(DOL-H(1)) 8,7,8
    7 PRINT 6, (H(J),J=2,12)
      IF(DOL-H(2)) 9,10,9
   10 KEY=1
      GO TO 9
    8 BACKSPACE 2
      IF(KEY) 798,799,798
  798 PRINT 4
      PRINT 99
      PRINT 73
  799 PRINT 91
      PRINT 93
      GO TO 101
 7000 READ 94, EXIT
      READ 94, EXIT
  101 READ 100,(JCOUNT,LCOUNT,MCOUNT)
      IF(MCOUNT) 102,115,102
  102 CALL DEGRAD(LCOUNT,MCOUNT)
      IF(JCOUNT) 103,101,101
  103 DO 4020 J=8,808,4
      IF(LCOUNT-J+1) 4017,4019,4020
 4017 IF(J-8) 7000,4018,4018
 4018 LCOUNT=J-4
      GO TO 4021
 4019 LCOUNT=J
      GO TO 4021
 4020 CONTINUE
 4021 JCOUNT=-JCOUNT
      NCOUNT=LCOUNT+1
      JT=JCOUNT
      LC=LCOUNT/4-1
      MC=MCOUNT-1
      READ 94, BASE(JCOUNT)
      READ 95,TIME(JCOUNT)
      LOP=LCOUNT-1
      LCPQ=LCOUNT+3
      LCOUNT=1
      DO 420 J=1,MC
      DO 419 I=NCOUNT,47
  419 DEGS(J,I)=0.
  420 KPAR(J)=0
      DO 114 K=1,LC
      DO 113 J=1,MC
      IF(LCOUNT-KPAR(J)) 5000,13,5000
 5000 IF(K-1) 801,800,801
  800 NAK=1
      NAC=3
      IF(DEGS(J,1)*DEGS(J,3)) 802,4000,802
 4000 KOM(J)=1
      MOP(J)=3
      GO TO 13
  801 NAK=KOM(J)+4
  802 IF(KPAR(J)) 12,899,899
  899 DO 900 M=NAK,41,4
```

```
      JAK=M
      KOM(J)=JAK
      IF(DEGS(J,M)) 901,900,901
  900 CONTINUE
  901 LAK=JAK+4
      DO 902 M=LAK,45,4
      MAK=M
      IF(DEGS(J,M)) 903,902,903
  902 CONTINUE
  903 IF(MAK-45) 904,12,904
  904 IF(K-1) 805,806,805
  805 NAC=MOP(J)+4
  806 DO 905 M=NAC,39,4
      JAC=M
      MOP(J)=JAC
      IF(DEGS(J,M)) 906,905,906
  905 CONTINUE
  906 LAC=JAC+4
      DO 907 M=LAC,47,4
      MAC=M
      IF(DEGS(J,M)) 908,907,908
  907 CONTINUE
      IF(MAC-47) 908,12,908
  908 IF(MAC-JAC-4) 909,1000,909
  909 DEGS(J,JAC+4)=DEGS(J,MAC)
      DEGS(J,JAC+2)=DEGS(J,MAC-2)
      KPAR(J)=JAC+2
      DEGS(J,JAC+5)=DEGS(J,MAC+1)
      DEGS(J,JAC+3)=DEGS(J,MAC-1)
      NONE(J,JAC+5)=NONE(J,MAC+1)
      NONE(J,JAC+3)=NONE(J,MAC-1)
      IF(DEGS(J,JAC+4)) 998,12,998
  998 IF(DEGS(J,JAC+2)) 1002,12,1002
 1000 IF(MAK-JAK-4) 1001,1002,1001
 1001 DEGS(J,JAK+4)=DEGS(J,MAK)
      DEGS(J,JAK+6)=DEGS(J,MAK+2)
      KPAR(J)=JAK+4
      DEGS(J,JAK+5)=DEGS(J,MAK+1)
      DEGS(J,JAK+7)=DEGS(J,MAK+3)
      NONE(J,JAK+5)=NONE(J,MAK+1)
      NONE(J,JAK+7)=NONE(J,MAK+3)
      IF(DEGS(J,JAK+4)) 999,12,999
  999 IF(DEGS(J,JAK+6)) 1002,12,1002
 1002 IF(LCOUNT-KPAR(J)) 104,13,104
  104 ALPHA=3.14159-DEGS(J,LCOUNT+4)-DEGS(J,LCOUNT+6)
      ALPHA=SINF(ALPHA)
      A=SINF(DEGS(J,LCOUNT+6))*BASE(JCOUNT)/ALPHA
      BETA=3.14159-DEGS(J,LCOUNT)-DEGS(J,LCOUNT+2)
      BETA=SINF(BETA)
      B=SINF(DEGS(J,LCOUNT+2))*BASE(JCOUNT)/BETA
      BO=B*SINF(DEGS(J,LCOUNT))
      AO=A*SINF(DEGS(J,LCOUNT+4))
      RO=B*COSF(DEGS(J,LCOUNT))
      TO=A*COSF(DEGS(J,LCOUNT+4))
      IF(KEY) 790,791,790
```

79
79

10
10

11

3

3
3

3
3
4

4
4

11

3

3

1
11
11

600
600

79

300

```
790 PRINT 74,J,BO,AO,RO,TO
791 DO=TO-RO
    EO=AO-BO
    F(JCOUNT,J,K)=DO
    G(JCOUNT,J,K)=EO
    C=SQRTF(DO**2+EO**2)
    ZETA=ASINF(EO/C)*57.29578
    IF(DO) 105,106,106
105 C=-C
106 II=0
    DO 110 L=1,7,2
110 II=NONE(J,LCOUNT+L)+II
    IF(II-4) 40,39,40
 39 DELTA=B*TANF(DEGS(J,LCOUNT+1))-A*TANF(DEGS(J,LCOUNT+5))
    V=SQRTF(DELTA**2+C**2)
    IF(C) 30,31,31
 30 V=-V
 31 EPSL=ACOSF(C/V)*57.29578
    IF(DELTA) 32,40,33
 32 EPSL=-EPSL
 33 IF(KPAR(J)) 16,46,16
 46 PRINT 90,JCOUNT,J,BO,C,DO,EO,V,ZETA,EPSL
    GO TO 118
 40 IF(KPAR(J)) 16,47,16
 47 PRINT 92, JCOUNT,J,BO,C,DO,EO,ZETA
    V=0.0
    DELTA=0.0
118 DA(JCOUNT,J,K)=DELTA
    GO TO 113
 12 PRINT 98,JCOUNT,J
    F(JCOUNT,J,K)=0.
    G(JCOUNT,J,K)=0.
    KPAR(J)=-1
    GO TO 113
 13 PRINT 98,JCOUNT,J
    F(JCOUNT,J,K)=0.
    G(JCOUNT,J,K)=0.
    KPAR(J)=0
    GO TO 113
 16 PRINT 98,JCOUNT,J
113 CONTINUE
114 LCOUNT=LCOUNT+4
    DO 6001 K=1,LCPQ
    DO 6000 J=1,MC
6000 NONE(J,K)=0
6001 CONTINUE
    FOG(JCOUNT)=MC
    GOF(JCOUNT)=LC
    PRINT 99
    IF(KEY) 792,101,792
792 DO 3001 L=1,LOP,2
    DO 3000 I=1,MC
    PX=DEGS(I,L)*57.29578
3000 PRINT 75,L,I,PX
    PRINT 99
```

```
3001 CONTINUE
      GO TO 101
  115 PRINT 99
      PRINT 80
      PRINT 78
      PRINT 81
      DO 207 M=1,JT
      MC=FOG(M)
      LC=GOF(M)
      DO  206 J=1,MC
      TVO=0.
      TOT=0.
      OTO=0.
      DO 201 K=1,LC
      TOT=F(M,J,K)+TOT
      OTO=G(M,J,K)+OTO
  201 TVO=DA(M,J,K)+TVO
      IF(TOT) 203,600,203
  600 IF(OTO) 203,400,203
  203 TVO=TVO/TIME(M)*365.25
      TOT=TOT/TIME(M)*365.25
      OTO=OTO/TIME(M)*365.25
      CO=SQRTF(TOT**2+OTO**2)
      VO=SQRTF(TVO**2+CO**2)
      ZETA=ASINF(OTO/CO)*57.29578
      IF(TOT) 498,499,499
  498 CO=-CO
      VO=-VO
  499 IF(TVO) 38,41,38
   38 EPSL=ACOSF(CO/VO)*57.29578
  717 IF(TVO) 711,712,712
  711 EPSL=-EPSL
  712 PRINT 96, M,J,CO,TOT,OTO,VO,ZETA,EPSL
      GO TO 206
   41 PRINT 97, M,J,CO,TOT,OTO,ZETA
      GO TO 206
  400 PRINT 77, M,J
  206 CONTINUE
      PRINT 99
  207 CONTINUE
      PRINT 79
      PRINT 82
      PRINT 83
      PRINT 84
      PRINT 85
      PRINT 86
      PRINT 87
      PRINT 88
      PRINT 89
      PRINT 99
      END
      SUBROUTINE DEGRAD(LCOUNT,MCOUNT)
      DIMENSION ANGLEA(50),ANGLEB(50),MP(50),NP(50),DEGS(50,50),
     1BASE(20),NONE(50,50),H(12),F(13,25,7),G(13,25,7),DA(13,25,7),FOG(2
     20),GOF(20),TIME(20),KPAR(50),MOP(30),KOM(30)
```

```
101 FORMAT (6F10.1)
    COMMON ANGLEA,ANGLEB,MP,NP,DEGS,NONE,F,G,DA,FOG,GOF,TIME,KPAR,MOP,
   1KOM,BASE,H
    KO=0
    LO=KO
    DO 109 J=1,MCOUNT
    READ 101, (U,V,W,X,Y,Z)
    IF (U-361.) 105,104,104
104 ANGLEA(J)=U
    NP(J)=1
    GO TO 106
105 CALL DEGD(KO,U,V,W)
    NP(J)=2
106 IF (X-361.) 108,107,107
107 MP(J)=6
    GO TO 109
108 CALL DEGR(LO,X,Y,Z)
    MP(J)=4
109 CONTINUE
    MO=1
    MC=MCOUNT-1
    DO 116 J=1,MC
    IF (NP(J+1)+MP(J+1)-6) 113,112,110
110 IF (NP(J+1)+MP(J+1)-8) 111,114,114
111 NONE(J,LCOUNT)=0
    DEGS(J,LCOUNT)=0.
    GO TO 116
112 CALL BOTH(DEGA,DEGB,MO)
    NONE(J,LCOUNT)=1
    GO TO 115
113 CALL REV(DEGA,DEGB,MO)
    NONE(J,LCOUNT)=1
    GO TO 115
114 CALL DIR(DEGA,DEGB,MO)
    NONE(J,LCOUNT)=1
115 DEGS(J,LCOUNT)=.5*(DEGA+DEGB)/57.29578
116 CONTINUE
    END
    SUBROUTINE BOTH(DEGA,DEGB,MO)
    DIMENSION ANGLEA(50),ANGLEB(50),MP(50),NP(50),DEGS(50,50),
   1BASE(20),NONE(50,50),H(12),F(13,25,7),G(13,25,7),DA(13,25,7),FOG(2
   20),GOF(20),TIME(20),KPAR(50),MOP(30),KOM(30)
    COMMON ANGLEA,ANGLEB,MP,NP,DEGS,NONE,F,G,DA,FOG,GOF,TIME,KPAR,MOP,
   1KOM,BASE,H
    MO=MO+1
    DEGA=ABSF(ANGLEA(MO)-ANGLEA(1))
    DEGB=ABSF(ANGLEB(MO)-ANGLEB(1))
    END
    SUBROUTINE REV(DEGA,DEGB,MO)
    DIMENSION ANGLEA(50),ANGLEB(50),MP(50),NP(50),DEGS(50,50),
   1BASE(20),NONE(50,50),H(12),F(13,25,7),G(13,25,7),DA(13,25,7),FOG(2
   20),GOF(20),TIME(20),KPAR(50),MOP(30),KOM(30)
    COMMON ANGLEA,ANGLEB,MP,NP,DEGS,NONE,F,G,DA,FOG,GOF,TIME,KPAR,MOP,
   1KOM,BASE,H
    MO=MO+1
```

```
      DEGB=ABSF(ANGLEB(MO)-ANGLEB(1))
  101 DEGA=DEGB
      END
      SUBROUTINE DIR(DEGA•DEGB•MO)
      DIMENSION ANGLEA(50)•ANGLEB(50)•MP(50)•NP(50)•DEGS(50•50)•
     1BASE(20)•NONE(50•50)•H(12)•F(13•25•7)•G(13•25•7)•DA(13•25•7)•FOG(2
     20)•GOF(20)•TIME(20)•KPAR(50)•MOP(30)•KOM(30)
      COMMON ANGLEA•ANGLEB•MP•NP•DEGS•NONE•F•G•DA•FOG•GOF•TIME•KPAR•MOP•
     1KOM•BASE•H
      MO=MO+1
      DEGA=ABSF(ANGLEA(MO)-ANGLEA(1))
  101 DEGB=DEGA
      END
      SUBROUTINE DEGD(KO•U•V•W)
      DIMENSION ANGLEA(50)•ANGLEB(50)•MP(50)•NP(50)•DEGS(50•50)•
     1BASE(20)•NONE(50•50)•H(12)•F(13•25•7)•G(13•25•7)•DA(13•25•7)•FOG(2
     20)•GOF(20)•TIME(20)•KPAR(50)•MOP(30)•KOM(30)
      COMMON ANGLEA•ANGLEB•MP•NP•DEGS•NONE•F•G•DA•FOG•GOF•TIME•KPAR•MOP•
     1KOM•BASE•H
      KO=KO+1
      SECA=W/3600•
      AMIN=V/60•
      ANGLEA(KO)=U+AMIN+SECA
      END
      SUBROUTINE DEGR(LO•X•Y•Z)
      DIMENSION ANGLEA(50)•ANGLEB(50)•MP(50)•NP(50)•DEGS(50•50)•
     1BASE(20)•NONE(50•50)•H(12)•F(13•25•7)•G(13•25•7)•DA(13•25•7)•FOG(2
     20)•GOF(20)•TIME(20)•KPAR(50)•MOP(30)•KOM(30)
      COMMON ANGLEA•ANGLEB•MP•NP•DEGS•NONE•F•G•DA•FOG•GOF•TIME•KPAR•MOP•
     1KOM•BASE•H
      LO=LO+1
      SECB=Z/3600•
      BMIN=Y/60•
      ANGLEB(LO)=X+BMIN+SECB
      END
      END

:ALL•L•FORTBIN•
'ORTBIN•2•L•6•3•
      SUBROUTINE NORRIS
      DIMENSION A(8•8)•B(8•8)•E(4•20•20)•SIGMAP(20•20)•RE(20•20)•EX(20•2
     10)•EXZ(20•20)•EDOT(20)•STRESSA(20)•STRESSB(20)•SIGMAX(20)•TXZ(20)•
     2TAU(20)•PE(3•20•20)•THETA(20•20)•TIME(4)•EZ(20•20)•LOT(20)•ANGLEA(
     350)•ANGLEB(50)•MP(50)•NP(50)•DEGS(50•50)•BASE(20)•T(500)•NONE(50•5
     40)•H(11)•KIP(6•20)•JMP(20)
    1 FORMAT(30HOERROR--COL•20•TIME CARD SPEC•)
    5 FORMAT (A1•A7•9A8)
    6 FORMAT (1H0•A7•9A8)
   14 FORMAT(12X•21HSTRAIN RATES (YR**-1)•30X•13HSTRESS (BARS))
   15 FORMAT(3X•18HT=SEQUENCE OF TIME)
   50 FORMAT(//•2X•48HMEASURED PRINCIPAL STRAIN RATES (*10**-5*HR**-1))
   51 FORMAT(//•2X•56HSTRESSES CALCULATED FROM MEASURED PRINCIPAL STRAIN
     1 RATES)
   52 FORMAT (//•2X•38HMEASURED STRAIN RATES (*10**-5*HR**-1))
   69 FORMAT(I4)
```

```
 70 FORMAT(6I4)
 71 FORMAT(F4.2)
 75 FORMAT(2X,F7.3,2X,F7.3,2X,F7.3,2X,F7.3,2X,F7.3,2X,F7.3,2X,F6.2)
760FORMAT(6X,2HEX,7X,2HEZ,6X,3HEXZ,6X,4HE(1),5X,4HE(2),5X,4HE(3),3X,5
   1HTHETA)
 78 FORMAT(//,3X,26HRE=E(0)+E(90)-E(45)-E(135))
790FORMAT(3X,7HSTATION,1X,1HT,4X,4HE(0),5X,5HE(45),4X,5HE(90),3X,6HE(
   1135),5X,2HRE)
 80 FORMAT(8F10.2)
 81 FORMAT(5X,I2,3X,I2,2X,F7.3,2X,F7.3,2X,F7.3,2X,F7.3,2X,F7.3)
 82 FORMAT    (1X,5HPOINT,7X,4HE(1),5X,4HE(2),5X,4HE(3),6X,1HE,5X,5HTHE
   1TA,4X,3HTAU,4X,6HSIGMA1,2X,6HSIGMA3,4X,3HTXZ,3X,6HSIGMAX)
830FORMAT(2X,I2,6X,F7.3,2X,F7.3,2X,F7.3,2X,F7.3,2X,F6.2,2X,F6.3,2X,F6
   1.3,2X,F6.3,2X,F6.3,2X,F6.3)
 99 FORMAT(//)
    COMMON EX,EZ,EXZ,THETA,PE,ANGLEA,ANGLEB,MP,NP,DEGS,NONE,T,E
    EQUIVALENCE(LCNT,LCT)
    DOL=532020202020202O
    PRINT 99
  9 READ 5,H
    IF(DOL-H(1)) 8,7,8
  7 PRINT 6, (H(J),J=2,11)
    GO TO 9
  8 BACKSPACE 2
    PRINT 99
    READ 69, NCOUNT
    JD=0
    LB=0
    DO 111 N=1,NCOUNT
    LB=LB+1
    JD=JD+1
 85 READ 70,MCOUNT,LCOUNT,NATION,NOON,JZ,NK
    IF(NK) 500,291,290
500 JUMP=2
    GO TO 292
290 READ 70,(KIP(J,N),J=1,NK)
291 JUMP=1
292 IF(JZ) 900,900,199
900 PRINT 1
901 RETURN
199 IF(NATION) 86,87,86
 86 CALL LITE(MCOUNT,NOON,NATION,LCOUNT,JD)
    IF(MCOUNT) 87,85,85
 87 READ 71,(TIME(M),M=1,JZ)
    IF(MCOUNT) 91,95,95
 95 DO 90 K=1,LCOUNT
    DO 88 J=1,5,4
880READ 80,(A(J,K),B(J,K),A(J+1,K),B(J+1,K),A(J+2,K),B(J+2,K),
   1A(J+3,K),B(J+3,K))
    DO 89 J=1,8
 89 A(J,K)=A(J,K)+B(J,K)/12.
 90 CONTINUE
 91 LA=0
    LCNT=LCOUNT-1
    LOT(N)=LCNT
```

```
      EDX=0.
      EDZ=0.
      EDXZ=0.
      JMP(N)=JUMP
      MT=1
      IV=0
      DO 102 I=1,LCNT,JUMP
      GO TO (1001,1002),JUMP
 1002 LA=I-1
 1001 IF(I-KIP(MT,N))200,222,200
  200 IV=IV+1
      IF(MCOUNT) 20,92,92
   92 X=.5*((A(1,I+1)-A(1,I))/A(1,I)+(A(2,I+1)-A(2,I))/A(2,I))
      Y=.5*((A(3,I+1)-A(3,I))/A(3,I)+(A(4,I+1)-A(4,I))/A(4,I))
      Z=.5*((A(5,I+1)-A(5,I))/A(5,I)+(A(6,I+1)-A(6,I))/A(6,I))
      W=.5*((A(7,I+1)-A(7,I))/A(7,I)+(A(8,I+1)-A(8,I))/A(8,I))
      E(1,I,N)=X*10.E4/(TIME(IV)*168.)
      E(2,I,N)=Y*10.E4/(TIME(IV)*168.)
      E(3,I,N)=Z*10.E4/(TIME(IV)*168.)
  101 E(4,I,N)=W*10.E4/(TIME(IV)*168.)
      GO TO 22
   20 DO 21 M=1,4
   21 E(M,I,N)=E(M,I,N)*10.E4/(TIME(IV)*168.)
   22 RE(I,N)=E(1,I,N)+E(3,I,N)-E(2,I,N)-E(4,I,N)
      EX(I,N)=-.25*E(1,I,N)+.25*E(2,I,N)+.75*E(3,I,N)+.25*E(4,I,N)
      EZ(I,N)=.75*E(1,I,N)+.25*E(2,I,N)-.25*E(3,I,N)+.25*E(4,I,N)
      EXZ(I,N)=.5*E(4,I,N)-.5*E(2,I,N)
      CALL DOT(LA,LB)
      EDX=EX(I,N)+EDX
      EDZ=EZ(I,N)+EDZ
      EDXZ=EXZ(I,N)+EDXZ
      GO TO 102
  222 LA=LA+1
      MT=MT+1
  102 CONTINUE
      PCOUNT=JZ
      EX(LCOUNT,N)=EDX/PCOUNT
      EZ(LCOUNT,N)=EDZ/PCOUNT
      EXZ(LCOUNT,N)=EDXZ/PCOUNT
      CALL DOT(LA,LB)
      DO 23 J=1,3
   23 PE(J,LCOUNT,N)=PE(J,LCOUNT,N)*.08776
     0EDOT(N)=.70711*SQRTF(PE(1,LCOUNT,N)**2+PE(2,LCOUNT,N)**2+PE(3,LCOU
     1NT,N)**2)
      TAU(N)=(EDOT(N)/.148)**.23809
      EFOT=TAU(N)/EDOT(N)
      DO 103 J=1,3
  103 SIGMAP(J,N)=EFOT*PE(J,LCOUNT,N)
      STRESSA(N)=(2.*SIGMAP(1,N)+SIGMAP(3,N))
      STRESSB(N)=(SIGMAP(1,N)+2.*SIGMAP(3,N))
      TMAX=.5*(STRESSA(N)-STRESSB(N))
      OC=TMAX+STRESSB(N)
      IF(EX(LCOUNT,N)-EZ(LCOUNT,N)) 7001,7001,7000
 7000 ALPHA=2.*(THETA(LCOUNT,N)-90.0)/57.29578
      TXZ(N)=TMAX*SINF(ALPHA)
```

```
      OX=SQRTF(TMAX**2-TXZ(N)**2)
      GO TO 110
7001  ALPHA=2.*THETA(LCOUNT,N)/57.29578
      TXZ(N)=-TMAX*SINF(ALPHA)
      OX=-SQRTF(TMAX**2-TXZ(N)**2)
 110  SIGMAX(N)=OC+OX
 111  CONTINUE
      PRINT 52
      PRINT 79
      DO 112 N=1,NCOUNT
      JUMP=JMP(N)
      MCT=LOT(N)
      MT=1
      KZ=0
      DO 203 I=1,MCT,JUMP
      IF(I-KIP(MT,N)) 201,202,201
 201  GO TO (501,502),JUMP
 501  KZ=I
      GO TO 503
 502  KZ=KZ+1
 503  PRINT 81,N,KZ,E(1,I,N),E(2,I,N),E(3,I,N),E(4,I,N),RE(I,N)
      GO TO 203
 202  MT=MT+1
 203  CONTINUE
 112  CONTINUE
      PRINT 50
      PRINT 76
      DO 113 N=1,NCOUNT
      JUMP=JMP(N)
      MCT=LOT(N)
      MT=1
      DO 206 I=1,MCT,JUMP
      IF(I-KIP(MT,N)) 204,205,204
 2040PRINT 75, EX(I,N),EZ(I,N),EXZ(I,N),PE(1,I,N),PE(2,I,N),PE(3,I,N),T
     1HETA(I,N)
      GO TO 206
 205  MT=MT+1
 206  CONTINUE
 113  CONTINUE
      PRINT 51
      PRINT 14
      PRINT 82
      DO 105 N=1,NCOUNT
      LCOUNT=LOT(N)+1
 1040PRINT 83, N,PE(1,LCOUNT,N),PE(2,LCOUNT,N),PE(3,LCOUNT,N),EDOT(N),T
     1HETA(LCOUNT,N),TAU(N),STRESSA(N),STRESSB(N),TXZ(N),SIGMAX(N)
 105  CONTINUE
      PRINT 78
      PRINT 15
      END
      SUBROUTINE DOT (LA,LB)
      DIMENSION A(8,8),B(8,8),E(4,20,20),SIGMAP(20,20),RE(20,20),EX(20,2
     10),EXZ(20,20),EDOT(20),STRESSA(20),STRESSB(20),SIGMAX(20),TXZ(20),
     2TAU(20),PE(3,20,20),THETA(20,20),TIME(4),EZ(20,20),LOT(20),ANGLEA(
     350),ANGLEB(50),MP(50),NP(50),DEGS(50,50),BASE(20),T(500),NONE(50,5
```

```
     40),H(11),R(4,20,20),HA(10,10),G(10,10),AO(10,10),BO(10,10)
      COMMON EX,EZ,EXZ,THETA,PE,ANGLEA,ANGLEB,MP,NP,DEGS,NONE,T,E
      LA=LA+1
      PRE=.5*(EX(LA,LB)+EZ(LA,LB))
      QUAD=SQRTF(.25*(EX(LA,LB)-EZ(LA,LB))**2+EXZ(LA,LB)**2)
      PE(1,LA,LB)=PRE+QUAD
      PE(3,LA,LB)=PRE-QUAD
      PE(2,LA,LB)=-PE(1,LA,LB)-PE(3,LA,LB)
      THETA(LA,LB)=28.64789*ATANF(2.*EXZ(LA,LB)/(EX(LA,LB)-EZ(LA,LB)))
      IF(EX(LA,LB)-EZ(LA,LB)) 2,2,1
    1 THETA(LA,LB)=THETA(LA,LB)+90.0
    2 CONTINUE
      END
      SUBROUTINE LITE (JCOUNT,LCOUNT,MCOUNT,NC,JD)
      DIMENSION A(8,8),B(8,8),E(4,20,20),SIGMAP(20,20),RE(20,20),EX(20,2
     10),EXZ(20,20),EDOT(20),STRESSA(20),STRESSB(20),SIGMAX(20),TXZ(20),
     2TAU(20),PE(3,20,20),THETA(20,20),TIME(4),EZ(20,20),LOT(20),ANGLEA(
     350),ANGLEB(50),MP(50),NP(50),DEGS(50,50),BASE(20),T(500),NONE(50,5
     40),H(11),R(4,20,20),HA(10,10),G(10,10),AO(10,10),BO(10,10)
   94 FORMAT(F10.3)
      COMMON EX,EZ,EXZ,THETA,PE,ANGLEA,ANGLEB,MP,NP,DEGS,NONE,T,E
      NCT=NC-1
      CALL DEGRAD(LCOUNT,MCOUNT)
      IF(JCOUNT) 103,102,102
  102 RETURN
  103 DO 4020 J=8,808,4
      IF(LCOUNT-J+1) 4017,4019,4020
 4017 IF(J-8) 7000,4018,4018
 7000 READ 94, EXIT
      READ 94, EXIT
      RETURN
 4018 LCOUNT=J-4
      GO TO 4021
 4019 LCOUNT=J
      GO TO 4021
 4020 CONTINUE
 4021 JCOUNT=-JCOUNT
      LC=LCOUNT/4-1
      MC=MCOUNT-1
      READ 94, BASE(JCOUNT)
      LCOUNT=1
      DO 114 K=1,LC
      DO 113 J=1,MC
      BETA=3.14159-ABSF(DEGS(J,LCOUNT))-ABSF(DEGS(J,LCOUNT+2))
      BETA=SINF(BETA)
      BO(J,K)=SINF(ABSF(DEGS(J,LCOUNT+2)))*(BASE(JCOUNT)/BETA)
      ALPHA=3.14159-ABSF(DEGS(J,LCOUNT+4))-ABSF(DEGS(J,LCOUNT+6))
      ALPHA=SINF(ALPHA)
      AO(J,K)=SINF(ABSF(DEGS(J,LCOUNT+6)))*(BASE(JCOUNT)/ALPHA)
      HA(J,K)=BO(J,K)*SINF(ABSF(DEGS(J,LCOUNT)))
      G(J,K)=BO(J,K)*COSF(ABSF(DEGS(J,LCOUNT)))
      HA(J,K+1)=AO(J,K)*SINF(ABSF(DEGS(J,LCOUNT+4)))
  113 G(J,K+1)=AO(J,K)*COSF(ABSF(DEGS(J,LCOUNT+4)))
  114 LCOUNT=LCOUNT+4
      DO 16 M=1,NC
```

```
      DO 20 J=1,3
      HSA=HA(J+1,M)-HA(J,M)
      GSA=G(J+1,M)-G(J,M)
   20 R(J,M,JD)=SQRTF(HSA**2+GSA**2)
      R(4,M,JD)=SQRTF((HA(4,M)-HA(1,M))**2+(G(4,M)-G(1,M))**2)
      R(5,M,JD)=SQRTF((HA(4,M)-HA(2,M))**2+(G(4,M)-G(2,M))**2)
   16 R(6,M,JD)=SQRTF((HA(3,M)-HA(1,M))**2+(G(3,M)-G(1,M))**2)
      DO 40 M=1,NCT
      E(1,M,JD)=(R(2,M+1,JD)-R(2,M,JD))/R(2,M,JD)
      E(2,M,JD)=.5*((R(6,M+1,JD)-R(6,M,JD))/R(6,M,JD))+.5*((R(5,M+1,JD)-
     1R(5,M,JD))/R(5,M,JD))
      E(3,M,JD)=(R(4,M+1,JD)-R(4,M,JD))/R(4,M,JD)
   40 E(4,M,JD)=.5*((R(3,M+1,JD)-R(3,M,JD))/R(3,M,JD))+.5*((R(1,M+1,JD)-
     1R(1,M,JD))/R(1,M,JD))
   50 JCOUNT=-JCOUNT
      END
      SUBROUTINE DEGRAD(LCOUNT,MCOUNT)
      DIMENSION ANGLEA(50),ANGLEB(50),MP(50),NP(50),DEGS(50,50),
     1BASE(20),T(500),NONE(50,50),H(11),EX(20,20),EXZ(20,20),THETA(20,20
     2),PE(3,20,20),E(4,20,20),EZ(20,20)
  101 FORMAT (7F10.1)
      COMMON EX,EZ,EXZ,THETA,PE,ANGLEA,ANGLEB,MP,NP,DEGS,NONE,T,E
      KO=0
      LO=KO
      DO 109 J=1,MCOUNT
      READ 101, (U,V,W,X,Y,Z,T(J))
      IF (U-361.) 105,104,104
  104 ANGLEA(J)=U
      NP(J)=1
      GO TO 106
  105 CALL DEGD(KO,U,V,W)
      NP(J)=2
  106 IF (X-361.) 108,107,107
  107 MP(J)=6
      GO TO 109
  108 CALL DEGR(LO,X,Y,Z)
      MP(J)=4
  109 CONTINUE
      MO=1
      MC=MCOUNT-1
      DO 116 J=1,MC
      IF (NP(J+1)+MP(J+1)-6) 113,112,110
  110 IF (NP(J+1)+MP(J+1)-8) 111,114,114
  111 NONE(J,LCOUNT)=1
      DEGS(J,LCOUNT)=0.0
      GO TO 116
  112 CALL BOTH(DEGA,DEGB,MO)
      NONE(J,LCOUNT)=0
      GO TO 115
  113 CALL REV(DEGA,DEGB,MO)
      NONE(J,LCOUNT)=0
      GO TO 115
  114 CALL DIR(DEGA,DEGB,MO)
      NONE(J,LCOUNT)=0
  115 DEGS(J,LCOUNT)=.5*(DEGA+DEGB)/57.29578
```

```
116 CONTINUE
      END
      SUBROUTINE BOTH(DEGA,DEGB,MO)
      DIMENSION ANGLEA(50),ANGLEB(50),MP(50),NP(50),DEGS(50,50),
     1BASE(20),T(500),NONE(50,50),H(11),EX(20,20),EXZ(20,20),THETA(20,20
     2),PE(3,20,20),E(4,20,20),EZ(20,20)
      COMMON EX,EZ,EXZ,THETA,PE,ANGLEA,ANGLEB,MP,NP,DEGS,NONE,T,E
      MO=MO+1
      DEGA=ABSF(ANGLEA(MO)-ANGLEA(1))
      DEGB=ABSF(ANGLEB(MO)-ANGLEB(1))
      END
      SUBROUTINE REV(DEGA,DEGB,MO)
      DIMENSION ANGLEA(50),ANGLEB(50),MP(50),NP(50),DEGS(50,50),
     1BASE(20),T(500),NONE(50,50),H(11),EX(20,20),EXZ(20,20),THETA(20,20
     2),PE(3,20,20),E(4,20,20),EZ(20,20)
      COMMON EX,EZ,EXZ,THETA,PE,ANGLEA,ANGLEB,MP,NP,DEGS,NONE,T,E
      MO=MO+1
      DEGB=ABSF(ANGLEB(MO)-ANGLEB(1))
 101  DEGA=DEGB
      END
      SUBROUTINE DIR(DEGA,DEGB,MO)
      DIMENSION ANGLEA(50),ANGLEB(50),MP(50),NP(50),DEGS(50,50),
     1BASE(20),T(500),NONE(50,50),H(11),EX(20,20),EXZ(20,20),THETA(20,20
     2),PE(3,20,20),E(4,20,20),EZ(20,20)
      COMMON EX,EZ,EXZ,THETA,PE,ANGLEA,ANGLEB,MP,NP,DEGS,NONE,T,E
      MO=MO+1
      DEGA=ABSF(ANGLEA(MO)-ANGLEA(1))
 101  DEGB=DEGA
      END
      SUBROUTINE DEGD(KO,U,V,W)
      DIMENSION ANGLEA(50),ANGLEB(50),MP(50),NP(50),DEGS(50,50),
     1BASE(20),T(500),NONE(50,50),H(11),EX(20,20),EXZ(20,20),THETA(20,20
     2),PE(3,20,20),E(4,20,20),EZ(20,20)
      COMMON EX,EZ,EXZ,THETA,PE,ANGLEA,ANGLEB,MP,NP,DEGS,NONE,T,E
      KO=KO+1
      SECA=W/3600.
      AMIN=V/60.
      ANGLEA(KO)=U+AMIN+SECA
      END
      SUBROUTINE DEGR(LO,X,Y,Z)
      DIMENSION ANGLEA(50),ANGLEB(50),MP(50),NP(50),DEGS(50,50),
     1BASE(20),T(500),NONE(50,50),H(11),EX(20,20),EXZ(20,20),THETA(20,20
     2),PE(3,20,20),E(4,20,20),EZ(20,20)
      COMMON EX,EZ,EXZ,THETA,PE,ANGLEA,ANGLEB,MP,NP,DEGS,NONE,T,E
      LO=LO+1
      SECB=Z/3600.
      BMIN=Y/60.
      ANGLEB(LO)=X+BMIN+SECB
      END
      END

ALL.L.FORTBIN.
ORTBIN.2.L.6.3.
      SUBROUTINE PROFILE
      DIMENSION U(5000),X(30),Y(30),BAR(30),DIST(30),V(30),EDX(30),G(30)
```

```
   1,TXZ(30),KM(60),KRT(60)
  1 FORMAT(3F7.2)
  2 FORMAT(//,12X,4HTXY=,F3.1,4HBARS,6X,5HBETA=,F7.6,/)
  3 FORMAT(12X,8HDISTANCE,7X,14HVELOCITY,M./YR)
  4 FORMAT(12X,F8.2,8X,F7.2)
  5 FORMAT(4I3,A1,2F4.0,I9,I2)
100 FORMAT(2X,12HBOUNDS ERROR,//,15X,81HCALCULATED ZERO SHEAR POINT IN
   1CONSISTANT WITH LOCATION OF MAXIMUM VELOCITY (STAKE,I2,3H TO,I2,1H
   2))
101 FORMAT(2X,14HPLOTTER CALLED)
102 FORMAT(2X,13HERROR--COL.30)
103 FORMAT(2X,24HPLOT SCALE NOT SPECIFIED)
104 FORMAT(A1,F6.3,F7.1)
605 FORMAT(A6,F3.2,F1.0,60A1)
999 FORMAT(20H PLOT OUTPUT, UNIT 7)
    DOL=532020202020202020
    READ 104, GQ,B,AN
    IF(DOL-GQ) 106,105,106
105 IF(B+AN) 70,70,107
106 BACKSPACE 2
    B=.148
    AN=4.2
107 BN=1./AN
    ABLE=0.0
    LT=0
  7 READ 5, NS,NP,LA,NX,H,CY,CX,LB,LD
    LT=LT+1
    IF(NX) 6,6,99
 99 ABLE=ABLE+1.0
  6 AS=0.0
    MS=NS-1
    IF(MS) 70,8,8
 70 RETURN
  8 RMS=MS
    READ 1,(BAR(J),DIST(J),EDX(J),J=1,NS)
    READ 1,(X(L),Y(L),V(L),L=1,NP)
    IF(MS) 70,16,9
  9 DO 10 J=1,MS
 10 AS=(BAR(J)-BAR(J+1))/(DIST(J)-DIST(J+1))+AS
    AS=AS/RMS
    PL=BAR(1)/AS
    XETA=DIST(1)-PL
 16 VMAX=V(LA)
    DX=0.0
    IF(MS) 70,17,19
 17 XETA=Y(LA)
    AS=BAR(1)/(DIST(1)-XETA)
 19 IF(XETA-Y(LA-1)) 13,15,14
 13 MT=LA-1
    MTA=LA+1
    PRINT 100,MT,MTA
    IF(DOL-H) 70,15,70
 14 IF(Y(LA+1)-XETA) 13,15,15
 15 TB=ABSF(BAR(1)-AS*DIST(1))-.6
    JAC=0
```

```
      DO 75 J=1,NP
      JCT=J
      G(J)=XETA-Y(J)
      IF(G(J)) 200,29,75
  200 G(J)=0.0
      GO TO 29
   75 CONTINUE
   29 IF(LD) 90,898,90
  898 IF(LB) 90,901,899
  899 IF(LB-NS) 900,900,90
  900 DX=ABSF(EDX(LB))
      GO TO 903
  901 DO 902 N=1,NS
  902 DX=DX+ABSF(EDX(N))
      DA=NS
      DX=DX/DA
  903 IF(NX) 30,30,33
   33 FY=CY/20.
      NY=FY
      YET=XETA-FY
      MAX = YET
      MAX=MAX/NY
      MAX=MAX*NY
      IF(CY) 31,31,32
   31 PRINT 103
      RETURN
   32 IF(CX) 31,31,34
   34 SY=100./CY
      SX=100./CX
      IF(ABLE-1.0) 801,800,801
  800 WRITE OUTPUT TAPE 19,999
      PAUSE
  801 CALL PLOT(CY,.0,0,SY,SX)
   30 JAC=JAC+1
      TB=TB+.4
      BETA=TB/XETA
      CNO=DX*24.*365.25/10.E4
      TO=(CNO/B)**BN
      CLO=TO/BETA
      PRINT 2,TB,BETA
      PRINT 3
      IF(NX) 61,61,22
   22 NBI=NY
      LC=1
      PRINT 101
      KEY=0
      XM=X(1)
      VLINE=VMAX/40.+VMAX/2.
      CALL PLOT(.0,.0,2,SY,SX)
      NQ=0
      DO 802 M=NBI,MAX,NY
      TVY=M
      Z=(XETA-TVY)/CLO
      IF(Y(LC)-TVY) 40,40,41
   40 XM=X(LC)
```

```
      LC=LC+1
   41 T=ROOT(Z,AN)
      ARGA=T**(AN+1.)
      ARGB=-(AN+1.)*T**(1.-AN)
      U(M)=VMAX-2.*CLO*CNO*(ARGA+ARGB+AN)/(AN+1.)+ABSF(XM*CNO)
      UNIV=-U(M)
      IF(U(M)) 802,802,83
   83 IF(KEY) 84,84,43
   84 IF(U(M)-VLINE) 43,85,85
   85 IF(JAC-2) 46,43,43
   46 CALL LABEL(TVY,SY,SX,UNIV,CY,CX,JAC)
      KEY=1
   43 IF(NQ) 6666,6666,6667
 6666 CALL PLOT(TVY,UNIV,2,SY,SX)
      NQ=1
      GO TO 802
 6667 CALL PLOT(TVY,UNIV,1,SY,SX)
  802 CONTINUE
      OTO=XETA
      CALL PLOT(OTO,UNIV,1,SY,SX)
      TVO=2.*OTO-TVY
      NAC=TVO
      LIM=MAX+NAC
      KEY=0
      LEV=MAX+NY
      DO 803 M=NAC,LIM,NY
      LEV=LEV-NY
      UNIV=-U(LEV)
      TVY=M
      IF(UNIV)132,803,803
  132 IF(KEY) 44,44,48
   44 IF(U(LEV)-VLINE) 45,48,48
   45 IF(JAC-2) 48,47,47
   47 CALL LABEL(TVY,SY,SX,UNIV,CY,CX,JAC)
      KEY=1
   48 CALL PLOT(TVY,UNIV,1,SY,SX)
  803 CONTINUE
      IF(JAC-2) 30,49,49
   49 CALL PLOT(TVY,.0,2,SY,SX)
      CALL PLOT(.0,.0,1,SY,SX)
      DO 60 K=1,NP
      SC=Y(K)
      SD=-V(K)
      IF(SD) 59,60,60
   59 CALL MARKX(SC,SD,SY,SX,CY,CX)
   60 CONTINUE
      F=-10.5*CX
 1000 READ 605,METRM,SQ,PQ,KRT
      IF(8HSCRIPT  -METRM) 51,1175,51
 1175 IF(PQ) 1001,50,1001
 1001 Q=TVY+PQ*CY
   50 CALL NAME(KRT,KM,SQ,F,SY,SX,CY,CX)
      CALL SCRIPT(SQ,Q,F,KM,SY,SX,CY,CX)
      F=-10.5*CX
      GO TO 1000
```

```
51 BACKSPACE 2
   CALL PLOT(.0,.0,-1,SY,SX)
   TB=TB-.8
   JAC=0
   NX=0
   GO TO 30
61 DO 63 L=1,JCT
   Z=G(L)/CLO
   T=ROOT(Z,AN)
   ARGA=T**(AN+1.)
   ARGB=-(AN+1.)*T**(1.-AN)
   UNIV=VMAX-2.*CLO*CNO*(ARGA+ARGB+AN)/(AN+1.)+ABSF(X(L)*CNO)
   DP=XETA-G(L)
63 PRINT 4,DP,UNIV
   IF(JAC-2) 30,7,7
90 PRINT 102
   END
   FUNCTION ROOT(Z,AN)
   DIMENSION FT(3),A(2)
   A(1)=1.0
   A(2)=3.0
19 DO 20 M=1,2
   X=A(M)
   FT(M)=X**(2.*AN)-Z**2*X**(2.*AN-2.)-1.0
   IF(FT(M)) 20,70,20
20 CONTINUE
   X=.5*(A(2)+A(1))
   FT(3)=X**(2.*AN)-Z**2*X**(2.*AN-2.)-1.0
   IF(FT(3)) 28,70,29
28 A(1)=X
   GO TO 30
29 A(2)=X
30 IF((FT(2)-FT(3))*(FT(1)-FT(3)))19,70,19
70 ROOT=X
   END
   SUBROUTINE MARKX(SC,SD,SY,SX,CY,CX)
   SD=SD-.1*CX
   CALL PLOT(SC,SD,2,SY,SX)
   SD=SD+.2*CX
   CALL PLOT(SC,SD,1,SY,SX)
   SC=SC-.1*CY
   SD=SD-.1*CX
   CALL PLOT(SC,SD,2,SY,SX)
   SC=SC+.2*CY
   CALL PLOT(SC,SD,1,SY,SX)
   END
   SUBROUTINE LABEL(TVY,SY,SX,UNIV,CY,CX,JAC)
45 SC=TVY+.3*CY
   CALL PLOT(SC,UNIV,1,SY,SX)
   DO 46 K=1,JAC
   SC=.1*CY+SC
   CALL PLOT(SC,UNIV,2,SY,SX)
   SC=.1*CY+SC
46 CALL PLOT(SC,UNIV,1,SY,SX)
   DO 47 K=1,JAC
```

```
      SC=SC-.05*CY
      SD=UNIV+.05*CX
      CALL PLOT(SC,SD,2,SY,SX)
      SD=UNIV-.1*CX
      CALL PLOT(SC,SD,1,SY,SX)
   47 SC=SC-.15*CY
      CALL PLOT(TVY,UNIV,2,SY,SX)
      END
      SUBROUTINE SCRIPT(SQ,Y,X,KM,SY,SX,CY,CX)
      DIMENSION KM(60),NPR(20),NU(20),KCODE(20)
      TX=X
      DO 12 M=1,60
      CALL PLOT(Y,X,2,SY,SX)
      KF=KM(M)
      KA=KF
      DO 100 I=1,20
      KA=KF/(10**I)
      IC=I
      IF(KA) 100,101,100
  100 CONTINUE
      STOP
  101 LA=IC
      KFO=KF
      DO 102 I=1,IC
      NPR(I)=KFO
      KCODE(I)=KF/(10**I)
      NU(LA)=NPR(I)-10*KCODE(I)
      KFO=KCODE(I)
  102 LA=LA-1
      IF(NU(1)-1) 107,107,108
  107 NS=2
      GO TO 109
  108 NS=1
  109 DO 11 I=NS,IC
      LT=NU(I)
      IF(MX-2) 103,106,103
  103 IF(LT) 105,104,105
  104 MX=2
      GO TO 11
  105 MX=1
  106 GO TO (1,2,3,4,5,6,7,8,9),LT
C     PEN FINDS COORDINATES BASED ON 9 POINT SQUARE
    1 YA=Y
      XA=X
      GO TO 10
    2 YA=Y-.5*SQ*CY
      XA=X
      GO TO 10
    3 YA=Y-SQ*CY
      XA=X
      GO TO 10
    4 YA=Y-SQ*CY
      XA=X+.5*SQ*CX
      GO TO 10
    5 YA=Y-SQ*CY
```

6

7

8

9

10

11

12

13

```
      XA=X+SQ*CX
      GO TO 10
    6 YA=Y-.5*SQ*CY
      XA=X+SQ*CX
      GO TO 10
    7 YA=Y
      XA=X+SQ*CX
      GO TO 10
    8 YA=Y
      XA=X+.5*SQ*CX
      GO TO 10
    9 YA=Y-.5*SQ*CY
      XA=X+.5*SQ*CX
   10 CALL PLOT(YA,XA,MX,SY,SX)
      MX=1
   11 CONTINUE
      X=X+1.25*SQ*CX
      IF(KM(M+1)) 13,13,12
   12 CONTINUE
   13 X=TX
      Y=Y-1.5*SQ*CY
      END
      SUBROUTINE NAME(KRT,KM,SQ,F,SY,SX,CY,CX)
      DIMENSION KM(60),KRT(60)
      DO 42 N=1,60
      NA=N
      TIC=N
      IF(8HA        -KRT(N)) 11,1,11
   11 IF(8HB        -KRT(N)) 12,2,12
   12 IF(8HC        -KRT(N)) 13,3,13
   13 IF(8HD        -KRT(N)) 14,4,14
   14 IF(8HE        -KRT(N)) 15,5,15
   15 IF(8HF        -KRT(N)) 16,6,16
   16 IF(8HG        -KRT(N)) 17,7,17
   17 IF(8HH        -KRT(N)) 18,8,18
   18 IF(8HI        -KRT(N)) 19,9,19
   19 IF(8HJ        -KRT(N)) 20,10,20
   20 IF(8HK        -KRT(N)) 51,61,51
   51 IF(8HL        -KRT(N)) 52,62,52
   52 IF(8HM        -KRT(N)) 53,63,53
   53 IF(8HN        -KRT(N)) 54,64,54
   54 IF(8HO        -KRT(N)) 55,65,55
   55 IF(8HP        -KRT(N)) 56,66,56
   56 IF(8HQ        -KRT(N)) 57,67,57
   57 IF(8HR        -KRT(N)) 58,68,58
   58 IF(8HS        -KRT(N)) 59,69,59
   59 IF(8HT        -KRT(N)) 70,80,70
   70 IF(8HU        -KRT(N)) 71,81,71
   71 IF(8HV        -KRT(N)) 72,82,72
   72 IF(8HW        -KRT(N)) 73,83,73
   73 IF(8HX        -KRT(N)) 74,84,74
   74 IF(8HY        -KRT(N)) 75,85,75
   75 IF(8HZ        -KRT(N)) 76,86,76
   76 IF(8H+        -KRT(N)) 77,87,77
   77 IF(8H1        -KRT(N)) 78,88,78
```

```
78 IF(8H2        -KRT(N)) 79,89,79
79 IF(8H         -KRT(N)) 90,100,90
90 IF(8H*        -KRT(N)) 92,102,92
92 IF(8H$        -KRT(N)) 100,101,100
 1 KM(N)=10385026
   GO TO 42
 2 KM(N)=3571062
   GO TO 42
 3 KM(N)=35071
   GO TO 42
 4 KM(N)=631
   GO TO 42
 5 KM(N)=35071092
   GO TO 42
 6 KM(N)=3071092
   GO TO 42
 7 KM(N)=10713569
   GO TO 42
 8 KM(N)=3075026
   GO TO 42
 9 KM(N)=7084035
   GO TO 42
10 KM(N)=70842
   GO TO 42
61 KM(N)=30725
   GO TO 42
62 KM(N)=35
   GO TO 42
63 KM(N)=301475
   GO TO 42
64 KM(N)=30157
   GO TO 42
65 KM(N)=3571
   GO TO 42
66 KM(N)=1031762
   GO TO 42
67 KM(N)=3571095
   GO TO 42
68 KM(N)=1031762095
   GO TO 42
69 KM(N)=10712653
   GO TO 42
80 KM(N)=7084
   GO TO 42
81 KM(N)=357
   GO TO 42
82 KM(N)=47
   GO TO 42
83 KM(N)=3857
   GO TO 42
84 KM(N)=5073
   GO TO 42
85 KM(N)=97094
   GO TO 42
86 KM(N)=735
```

```
      GO TO 42                                                          1070
   87 KM(N)=1084026                                                     1071
      GO TO 42                                                          1072
   88 KM(N)=1094                                                        1073
      GO TO 42                                                          1074
   89 KM(N)=109645                                                      1075
      GO TO 42                                                          1076
  100 KM(N)=107                                                         1077
   42 CONTINUE                                                          1078
  102 F=-1.25*TIC*SQ*CX                                                01079
  101 KM(NA)=0                                                          1080
      END                                                              01081
      END                                                               1082

*C051712 HAVAS                 3    PART 1
REMARK.TAPE 400 UNIT 6.INPUT
REWIND.6.
FORTBIN.2.6.
      PROGRAM TAKUMM
      CALL JIRP
      END
      END

RUN.
$GROUP1= ICY BASIN
$GROUP2= C-10. TAKU GLACIER
$GROUP3= LONGTUDINAL STAKES.C-10.
$         1-5.ABOUT STAKE 4*6-10.5*11-15.8*16-20.9
$GROUP4= VAUGHAN-LEWIS
$GROUP5= SW BRANCH. TAKU  (BASE LINE LENGTH NOT KNOWN)
    1   1  11                                                            304
                                   361                                   305
       92        55        30      361                                  0306
       92        55        30      361                                   307
       92        55        30      361                                  0308
       92        55        30      361                                   309
       92        55        30      361                                   310
       92        55        30      361                                   311
       92        55        30      361                                  0312
       92        55        30      361                                   313
       92        55        30      361                                  0314
       92        55        30      361                                  0315
    1   3  11                                                            328
                                   180                                   329
       29        52        58      361                                  0330
       39        58        21      361                                  0331
       49        25        33      361                                  0332
       58        24        30      361                                  0333
       61        09        10      361                                  0334
       64        49        45      361
       67        58        04      361                                  0336
       70        22        37      361                                  0337
       72        23        08      361                                 00338
       73        35        10      361                                  -339
    1   5  11                                                            352
```

	13		25	52	361			0353
	106		21	17	361			0354
	106		21	26	361			00355
	106		21	08	361			00356
	106		21	30	361			0357
	106		22	00	361			00358
	106		21	47	361			00359
	106		21	52	361			00360
	106		21	30	361			00361
	106		21	30	361			00362
	106		21	05	361			00363
1	6	11						364
	90				270			365
	112		17	02	247	45	20	00366
	106		26	00	253	36	00	00367
	102		09	08	257	53	20	00368
	99		27	38	260	36	20	00369
	97		40	00	262	22	45	00370
	96		22	40	263	39	15	00371
	95		22	00	264	39	40	00372
	94		38	40	265	23	45	00373
	94		03	40	265	58	20	00374
	93		36	20	266	25	40	00375
1	7	11						376
	162		57	35	361			00377
	133		04	20	361			00378
	122		58	57	361			00379
	113		31	38	361			00380
	106		43	10	361			00381
	101		48	30	361			00382
	98		08	00	361			00383
	94		59	33	361			00384
	92		35		361			00385
	90		34	40	361			00386
	89		21	55	361			00387
1	8	11						388
	90		00	00	270			389
	103		29	40	256	32	10	00390
	102		27	30	257	34	20	00391
	100		44	40	259	17	35	00392
	99		07	00	268	55	00	00393
	97		46	20	262	16	10	00394
	96		41	50	263	20	20	00395
	95		46	40	264	15	30	00396
	95		05	00	264	57	20	00397
	94		30	00	265	32	15	00398
	94		01	50	266			00399
1	9	11						400
					180			00401
	92		45	13	272	45	24	00402
	92		45	56	272	46	10	00403
	92		45	30	272	45	42	00404
	92		46	03	272	46	16	00405
	92		46	20	272	46	30	00406
	92		46	22	272	46	36	00407

92	46	21	272	46	31	00408
92	46	04	272	46	24	00409
92	46		272	46	15	00410
92	45	22	272	45	52	00411
-1 11 11						
360			179	59	11	00425
330	06	27	150	05	32	00426
320	01	04	140		46	00427
310	33	49	130	33	31	00428
303	45	11	123	44	51	00429
298	50	41	118	50	24	00430
295	10	28	115	10	09	00431
292	01	54	112	01	50	00432
289	27	16	109	27	04	00433
287	27	05	107	26	51	00434
286	24	14	106	24	10	00435
385.4						448
29						449
2 1 16						450
28	53		208	50	25	00451
119	26	05	299	23	20	00452
119	05	45	299	02	20	00453
119	17	40	299	14	20	00454
119	27	05	299	23	45	00455
119	36	55	299	36		00456
119	34	40	299	33	55	00457
119	37	40	299	35	30	00458
119	40	15	299	37	55	00459
119	39	05	299	36	55	00460
119	38	50	299	36	45	00461
119	37	50	299	30		00462
119	33	05	299	30	45	00463
119	23	55	299	21	55	00464
119	12	05	299	09	45	00465
118	55		298	52	50	00466
2 3 16						484
			361			
11	46	47	361			
17	19	53	361			
24	26	34	361			
29	54	39	361			
37	8	8	361			
44	37	52	361			
50	35	26	361			
53	27	8	361			
56	38	53	361			
59	13	59	361			
62		23	361			
64	45	36	361			
67	1	44	361			
361			361			
361			361			
2 5 16						518
106	21	30	-73	-38	-30	00519
196	52	20	016	52	40	00520

	196		34	18	016	34		00521
	196		28	37	016	28	35	00522
	196		31	40	016	31	40	00523
	196		24	40	016	24	40	00524
	196		18	35	016	18	35	00525
	196		18		016	18		00526
	196		28	40	016	28	30	00527
	196		34	35	016	34	20	00528
	196		37	20	016	37	05	00529
	196		40	50	016	40	40	00530
	196		43	50	016	43	40	00531
	196		47	40	016	47	20	00532
	196		48	15	016	48		00533
	361				361			00534
2	7	16						552
	335		40	20	361			00553
	324		01	30	361			00554
	318		25		361			00555
	361				361			00556
	305		47		361			00557
	298		23		361			00558
	290		49		361			0559
	284		52	20	361			0560
	281		59	20	361			0561
	278		50		361			0562
	275		19	20	361			0563
	361				361			00564
	361				361			00565
	361				361			00566
	361				361			00567
	361				361			00568
2	9	16						586
	10		06		361			
	100		37	50	361			
	100		12	20	361			
	100		13	50	361			
	100		04	05	361			
	99		55	40	361			
	99		55	30	361			
	100		06	55	361			
	100		13	30	361			
	100		16	50	361			
	100		21		361			
	361				361			
	361				361			
	361				361			
	361				361			
	361				361			
2	10	16						603
	92		02	50	361			
	102		14	55	361			
	97		40	30	361			
	95		17		361			
	94		12	20	361			
	93		08	35	361			

	92		25	35	361			
	92				361			
	91		44	10	361			
	91		24	35	361			
	91		10	50	361			
	361				361			
	361				361			
	361				361			
	361				361			
	361				361			
2	11	16						620
	97		20	52	361			
	85		41	17	361			
	80		04	35	361			
	72		58	40	361			
	67		28	35	361			
	64		37	39	361			
	52		28	48	361			
	46		31	50	361			
	43		30	45	361			
	40		20	18	361			
	37		45	39	361			
	361				361			
	361				361			
	361				361			
	361				361			
	361				361			
2	12	16						
	91		58	53	361			
	89		28		361			
	89		39	05	361			
	89		39	50	361			
	89		40		361			
	89		34	26	361			
	89		44	25	361			
	89		44	35	361			
	89		49	18	361			
	89		56	43	361			
	91		43		361			
	361				361			
	361				361			
	361				361			
	361				361			
	361				361			
2	13	16						
	270		17	53	090	17	59	00587
	360				180		30	00588
	359		34	53	179	35		00589
	359		34	14	179	34	26	00590
	359		20	54	179	21	08	00591
	359		08	20	179	08	38	00592
	359		08	50	179	09		00593
	359		22	15	179	22	33	00594
	359		29	47	179	29	09	00595
	359		25	08	179	25	05	00596

	359	29	13	179	29	58	00597
	359	45	15	179	45	10	00598
	359	51	28	179	51		00599
	359	45	29	179	45	10	00600
	359	50	25	179	50	49	00601
	359	33	54	179	34	24	00602
-2 15 16							
	89	59	58	270			00621
	78	20	06	258	20	12	00622
	73	11	08	258	11	15	00623
	65	37	20	245	37	51	00624
	60	12	25	240	12	44	00625
	52	44	19	232	44	43	00626
	44	57	21	224	57	53	00627
	39	10	12	219	10	45	00628
	36	08	28	216	09		00629
	32	58	51	212	59	09	00630
	30	25	10	210	25	15	00631
	27	51	45	207	52	04	00632
	25	14	47	205	14	57	00633
	22	58	58	202	59	15	00634
	21	08	46	201	09		00635
	18	53	16	198	53	32	00636
1840.5							
60							
3 1 21							655
	-88	-18	-35	361			00656
	361			361			00657
	1	50	40	361			00658
	-07	-2	-10	361			0659
	-14	-46	-20	361			00660
	361			361			00661
	361			361			0662
	361			361			0663
	361			361			0664
	361			361			0665
	361			361			00666
	5	41		361			00667
	1	54	50	361			0668
	-1	-52	-40	361			0669
	-5	-45	-10	361			00670
	-8	-3	-20	361			00671
	361			361			00672
	1	57	50	361			00673
	-1	-24	-10	361			00674
	361			361			00675
	361			361			00676
3 3 21							699
	97	12	10	361			0 700
	67	16	47	361			0701
	64	25	25	361			00702
	61	30	28	361			00703
	57	52	48	361			00704
	53	49		361			00705
	53	43	43	361			00706

	52		12	10	361	*707
	50		34		361	00708
	46		7	23	361	00709
	43		29	48	361	00710
	46		4	16	361	0711
	43		30		361	0712
	40		15		361	0713
	37			38	361	0714
	34		41	40	361	715
	43		30	33	361	716
	40		20	16	361	717
	37		46	7	361	00718
	35		1	49	361	719
	32		22	40	361	720
3	4	21				721
	90				361	0722
	89		40		361	0723
	89		34	34	361	00724
	89		36	36	361	00725
	89		14	33	361	00726
	89		36	35	361	00727
	89		36		361	00728
	89		44	50	361	00729
	89		36	35	361	0730
	89		51	40	361	0731
	89		48	43	361	732
	89		52	10	361	0733
	89		9	20	361	734
	89		56	50	361	0735
	89		41	50	361	-736
	89		37	20	361	0737
	89		46	28	361	738
	89		53	34	361	739
	89		59	27	361	740
	90		1	37	361	741
	90		2	57	361	742
3	5	21				743
	142		47	40	361	0744
	241		20	30	361	0745
	232		32	32	361	0746
	223		45	40	361	*747
	216			20	361	0748
	209		10	20	361	749
	238		7		361	0750
	232		15	40	361	0751
	229		49	40	361	0752
	220		14	40	361	0753
	215		5	20	361	0754
	235		45	48	361	0755
	231		59	34	361	0756
	228		11	53	361	0757
	224		9	20	361	*758
	220		35	8	361	0759
	235		21	51	361	760
	231		54	55	361	761

	228		41	51	361			762
	225		10	9	361			763
	222		2	49	361			764
-3	7	21						
	217		31	50	361			788
	189		2		361			0789
	184		43		361			790
	181		35	50	361			791
	178		9		361			792
	361				361			*793
	182		31		361			0794
	180		6	40	361			795
	177		6		361			0796
	174		4	20	361			0797
	170		48		361			0798
	166		25	47	361			00799
	163		40	20	361			800
	161		6	4	361			00801
	158		4	13	361			0802
	155		3	6	361			0803
	361				361			0804
	160		30	43	361			00805
	158			11	361			00806
	361				361			00807
	361				361			00808
	1840.5							831
25								832
4	1	9						
					361			0917
	361				361			00918
	161		46	15	361			00919
	156		54	55	361			00920
	149		05	25	361			921
	140		43	25	361			0922
	133		35	45	361			00923
	124		41	25	361			0924
	112		59	30	361			00925
4	3	9						
	360				361			00937
	344		03	50	361			0938
	361				361			00939
	340		03	40	361			0940
	333		52		361			00941
	327		06	15	361			0942
	321		33	30	361			0943
	314		34	40	361			00944
	305		04	55	361			00945
4	5	9						
					180		20	00957
	361				361			00958
	160		45	35	340	56	40	00959
	156		30	10	336	29	50	00960
	148		42	10	328	41	50	00961
	140		18	30	320	18		00962
	133		07	25	313	07	50	00963

```
     124          08          45        304         08          25                     00964
     112          19          25        292         18          45                     00965
   4    6    9
      90                                361                                            00967
     361                                361                                            00968
      89          59          50        361                                            00969
      91          10          55        361                                            00970
      92          19          40        361                                            00971
      93          16          40        361                                            00972
      94          02          10        361                                            00973
      94          51                    361                                            00974
      95          48          10        361                                            00975
   4    7    9
     360                                180                     30                     00977
     361                                361                                            00978
     361                                361                                            00979
     339          54          10        159         54          20                     00980
     333          33          35        153         33          55                     00981
     326          46          20        146         46          40                     00982
     321          11          20        141         11          40                     00983
     314          09          10        134         09          40                     00984
     304          32          35        124         32          50                     00985
  -4    8    9
      90                                361                                            00987
     361                                361                                            00988
     361                                361                                            00989
      90          27                    361                                             0990
      91          22          10        361                                            00991
      92          08                    361                                            00992
      92          44          05        361                                            00993
      93          23          45        361                                            00994
      94          17                    361                                            00995
    189.4                                                                                996
  22                                                                                     997

+C051712 HAVAS                  3    PART 1A
REMARK.TAPE 400 UNIT 6.INPUT
REWIND.6.
FORTBIN.2.6.
      PROGRAM TAKUM
      CALL JIRP
      END
      END

RUN.
$GROUP 1= TAKU.C-10. (SPECIAL LISTING FOR SUB-PROFILE FOR FIRST TIME INTERVAL)
$$PRINT ANGLES AND COORDINATES
   1    1   11
      28          53                    208         50          25                     00451
     119          26          05        299         23          20                     00452
     119          05          45        299         02          20                     00453
     119          17          40        299         14          20                     00454
     119          27          05        299         23          45                     00455
     119          36          55        299         36                                 00456
     119          34          40        299         33          55                     00457
```

```
    119     37     40     299     35     30              00458
    119     40     15     299     37     55              00459
    119     39     05     299     36     55              00460
    119     38     50     299     36     45              00461
  1   3  11
                          361
     11     46     47     361
     17     19     53     361
     24     26     34     361
     29     54     39     361
     37      8      8     361
     44     37     52     361
     50     35     26     361
     53     27      8     361
     56     38     53     361
     59     13     59     361
  1   5  11
    106     21     30     -73    -38    -30              00519
    196     52     20     016     52     40              00520
    196     34     18     016     34                    00521
    196     28     37     016     28     35              00522
    196     31     40     016     31     40              00523
    196     24     40     016     24     40              00524
    196     18     35     016     18     35              00525
    196     18            016     18                    00526
    196     28     40     016     28     30              00527
    196     34     35     016     34     20              00528
    196     37     20     016     37     05              00529
 -1   7  11
    335     40     20     361                           00553
    324     01     30     361                           00554
    318     25            361                           00555
    361                   361                           00556
    305     47            361                           00557
    298     23            361                           00558
    290     49            361                           00559
    284     52     20     361                           00560
    281     59     20     361                           00561
    278     50            361                           00562
    275     19     20     361                            0563
  1840.5                                                  654
 49

+C051712 HAVAS              3    PART 2
REMARK.TAPE 400 UNIT 6.INPUT
REWIND.6.
FORTBIN.2.6.
      PROGRAM LEWIS
      CALL NORRIS
      END
      END

RUN.
6CORRECTIONS DUE TO ERROR IN SIGN CONVENTION USED AND RESET OF STAKES.
6
```

```
ƂGROUP1= STRAIN DIAMOND 'D' AT CACHE
ƂGROUP2= STRAIN DIAMOND 'B'
ƂGROUP3= NORRIS STRAIN DIAMOND
ƂGROUPS 4-5, THRUST PLANE DIAMONDS, X AXIS UP AND TO LEFT
ƂGROUP4= UPPER SET, UPPER RIGHT
ƂGROUP5= UPPER SET, LOWER RIGHT
ƂGROUP6= STRAIN DIAMOND ON VAUGHAN-LEWIS NEVE AREA
ƂGROUP7= STRAIN DIAMOND ON OGIVE 7, VAUGHAN-LEWIS
   7
   1   4             2  -1
 129
 4
      69        3       69      263      97     1075      97     1075
      69      338       69        3      97     1113      97     1125
      69      213       69      150      97     1188      97       11
      69      250       69        4      98               97      925
      69      225       69      125      97     1125      97     1025
      69        3       69      325      97       11      97       10
      69      252       68     1188      97     1080      97     1140
      69      408       69      288      97     1128      97      828
   2   4             2  -1
 143
 386
      63      675       63      675      89     1013      89     1063
      63        7       63      675      89     1013      89     1025
      63      625       63      538      89      788      89      588
      63        7       63      725      90       75      90      163
      63      613       63      513      89      813      89      550
      63      650       63      688      90       88      90        2
      63       66       63       84      88     1152      88      636
      63      696       63      876      90      792      90     1080
   3   3             2
 1
 114
      5997              6001             8254             8135
      5991              5998             8754             8763
      6000              6010             8135             8145
      5990              5835             8750             8660
      5991              6014             8365             8136
      5985              6128             8750             8845
   4   2             1
 1
              803              803              1131             1281
              842              842              1159               11
              753              753              1394             1263
             1000             1000              1119             1144
   5   2             1
 1
              667              667              1281             1241
              797              797               844              703
              606              606              1263             1250
              781              781               706                6
   6   2             1
 329
      63       75       63       75      89     1125      89     1075
```

```
      63          825       63         75       90        5       90        1
      63          538       63         55       89       95       90        1
      64          213       63        838       90      113       89     1125
   7   2            1
 229
      63            7       63        625       89     1050       89     1025
      63           65       63          8       89       10       90       25
      63            1       63          2       89        4       89        5
      63           85       63       1050       89        5       90        4

*C051712 HAVAS                  4     PART 3
REMARK,TAPE 400 UNIT 6,INPUT
OUTPUT,G,27.
REWIND,6.
FORTBIN,2,6.
      PROGRAM SEVEN
      CALL PROFILE
      END
      END

RUN.
  2 10  7  1  450  50
  -.373 285479   .119
   .903 106481   .192
   -369  38459    197
   -206  57500    -32
   -593  83924
  -1044 106481   5447
  -1832 140763  12696
  -2279 183945  18142
  -2971 227608  23859
  -3487 253001  22134
  -3844 285479  20696
  -4240 316275  20503
SCRIPT.501VELOCITY PROFILE$
SCRIPT.25 TXY1 GRAPH +$
SCRIPT.25 TXY2 GRAPH ++$
SCRIPT.253HAVAS*
```