Veðurstofa Íslands
Report

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Pilot Project in Siglufjörður
Observations from the winter 1997/98

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CONTENTS

SUMMARY

Suitable design parameters for supporting structures under Icelandic conditions are being investigated in an experimental installation of steel bridges and snow nets constructed in Siglufjörður in Northern Iceland in the autumn of 1996. Snow height in the test area, snow density, gliding of the snow pack and the loading of the structures have not been monitored for two winters. The snow depth in a part of the test area became very high during the winter 1996/97 and the structures were partly buried and heavily loaded. The snow depth during the winter 1997/98 was 1-2 m lower in the gully than in the first winter of the experiment, and the loading of the structures was correspondingly smaller. The results of the second winter were by and large consistent with the results of the first winter when the lower snow depth is taken into account. The equivalent average snow density for loading computations was measured to be close to 400 kg/m^3 during the middle of the winter when the snow depth was at a maximum. It increased to close to 500 kg/m^3 after the snow pack had become isothermal in the spring. The gliding of the snow pack along the slope was low, less than 1 cm during the winter. The maximum loading of the structures, as monitored in two of the uphill anchors of the snow nets, occurred around the time of maximum snow depth. The onset of melting led to a sharp decrease in the loading of the snow nets. There were no indications of an increase in the loading due to deformation or gliding introduced by melting. Measured loads on the supporting structures were in general within the corresponding design loads of the structures, with the exception of the moment load on net posts which turned out to be substantially larger than assumed in the Swiss Guidelines according to strain measurements on one of the net posts.

With regard to the design of supporting structures, the main results of the first two winters of the experiment are that corrosion protection of snow nets needs to be improved for Icelandic conditions, Austrian-type ground plates need to be anchored to the slope in order for the structures to withstand wind pressure caused by uphill winds, and the feasibility of micropile anchoring of snow nets in loose materials needs to be evaluated. An appropriate mid winter snow density for the design of supporting structures for Icelandic conditions is estimated to be 400-450 kg/m^3 and the effect of gliding on snow loading appears to be small. There are no indications of a variation in density or snow loading with height above sea level or with the aspect of the slope under Icelandic conditions. Strength requirements for supporting structures in Iceland should therefore be independent of the height above sea level and the aspect of the slope. Apart from this, traditional formulations for snow loading of supporting structures, which are used in Alpine countries, appear to be adequate for Icelandic conditions when proper account has been taken of the higher snow density in Iceland.

New types of nets with an improved aluminium/zinc corrosion protection were installed in both the Geobrugg and the EI net lines in the late summer of 1998. Laboratory tests indicate that this type of corrosion protection is a substantial improvement compared with the older design where wire ropes with a traditional hot dip galvanisation are used. The new nets will be monitored during the next years in order to evaluate this new corrosion protection technique.

The results of the experiment after the first two winters will be reevaluated during the next years as more data become available. The consistency of the observations of the two winters and similar observations from Norway, which are described in a report about the first winter of the experiment, indicate that the data obtained from Siglufjörður give a representative picture of the conditions for supporting structures encountered in starting zones in Iceland.

1. INTRODUCTION

The Icelandic Meteorological Office (IMO) has implemented a pilot project for testing the feasibility of supporting structures for avalanche protection in Iceland and for obtaining data which will be used to define an optimal setup of such structures under Icelandic conditions. The project is financed by the Icelandic Avalanche Fund. About 200 m of supporting structures, both stiff steel constructions and snow nets, were installed for experimental purposes in Hafnarfjall above the village Siglufjörður in northern Iceland in 1996.

The background of the project and the results from the winter 1996/97 are described in a report by Jóhannesson (1997) and Jóhannesson, Larsen and Hopf (1998), and compared with similar observations from Alpine countries and Norway (*cf.* Larsen (1982) and Larsen and others (1984)). The following report describes observations of snow height, snow density, gliding and the loading of the supporting structures from the winter 1997/98.

The structures in Siglufjörður are located at 490-530 m a.s.l. They are arranged in four rows which are labelled I, II, III and IV from above (Fig. 1). The types of structures of each row are given in Table 1.

Table 1: Types of supporting structures in Siglufjörður.

Row	Type	Producer	Length (m)	Number of posts	Height (D_k, m)
I and IV	bridges	J. Martin	110	38=24+14	3-5
II	nets	Geobrugg	50	14	3-4
III	nets	EI	41.5	15	3-4

The posts in each row are numbered starting with 1 from north to south and each post can therefore be identified with its row number and the sequential number within the row, *e.g.* II-8 for the eighth post from the north in the Geobrugg nets in row II.

The present report documents the observations from the winter 1997/98 which are by and large consistent with the observations from the winter 1996/97. The reader is referred to the report by Jóhannesson, Larsen and Hopf (1998) for a more detailed description of the experiment and an interpretation of the results from the first winter.

2. SNOW HEIGHT

The extreme vertical snow height is the most important design parameter for supporting structures. As discussed in the introduction in Jóhannesson, Larsen and Hopf (1998), there are special problems associated with the determination of design snow depths for supporting structures in Iceland. The pilot project in Siglufjörður will not address these problems in general, but the observations in the test area will show what problems are encountered in that particular area. The purpose of snow depth observations in the pilot project is primarily to gather data for the interpretation of the loading measurements described later in the report.

Snow depth perpendicular to the slope was measured at each post in the test area on several days during the winter. The results are shown in figures 2a-d below. The numbers at the top of each figure are sequential post numbers starting with 1 at the northern end of each row. Snow depth values at four stakes, which were buried by the snow or where measurements are missing for other reasons, were inferred from the measurements at other stakes. This was done by assuming that the melting of the snow cover proceeds at approximately the same rate at each location after the maximum snow depth of the winter has been reached. Such inferred values are indicated with symbols (stars) in the figures. Missing snow depth values were fewer than in the previous winter because of the lower snow depths.

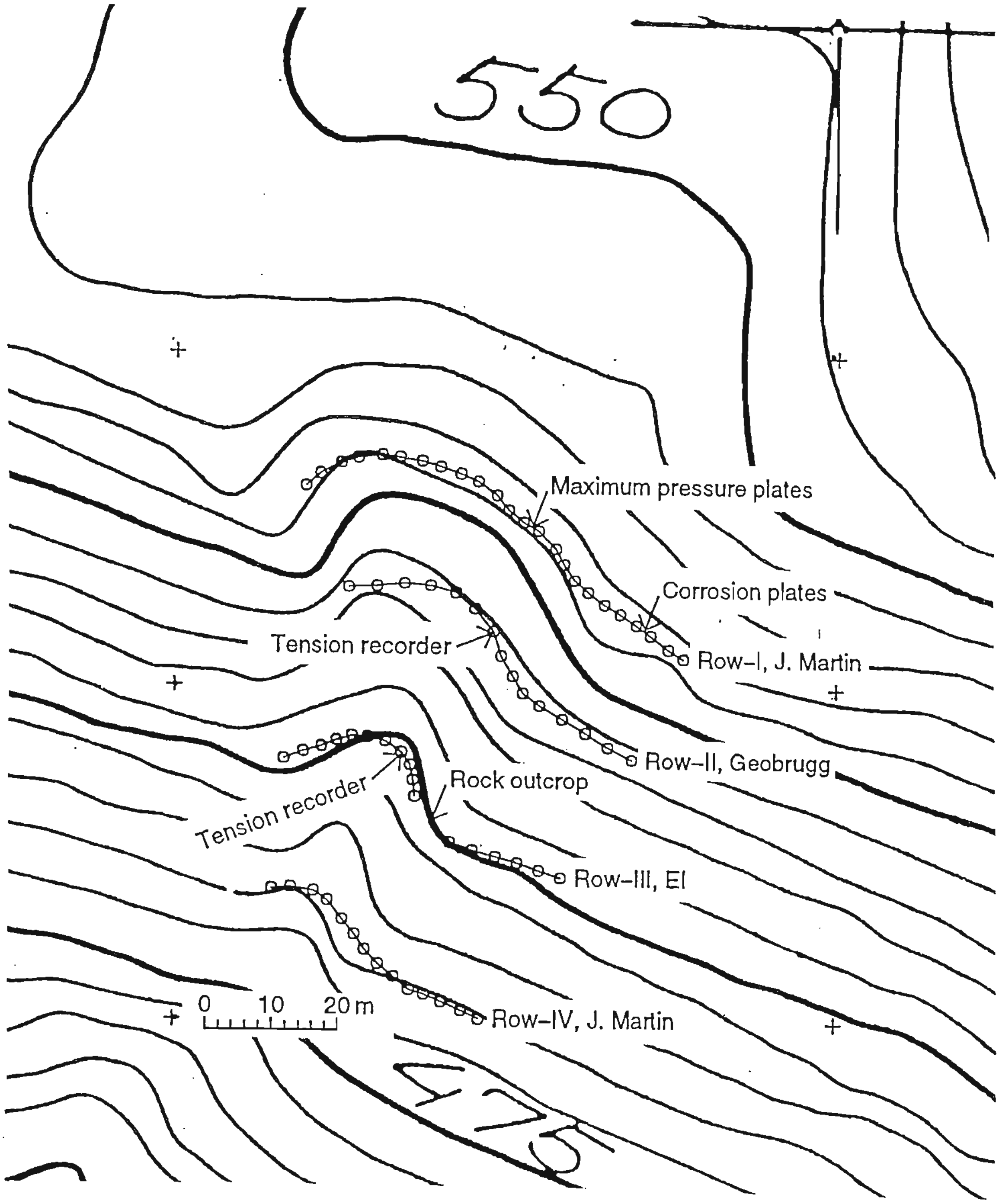

Figure 1. Location map of the supporting structures in Siglufjörður in scale 1:1000 showing the location of the uphill anchors in each row together with the placement of measuring instruments in the rows. The contours, which are taken from a map in scale 1:5000, are not accurate in every detail but they give a picture of the general landscape in the test area.

The maximum snow depth at the posts in the gully reached about 4 m perpendicular to the slope and remained high until late in the spring. This corresponds to 4.9 m vertical snow height. The maximum observed depths were 4.2, 5.0, 3.5 and 5.2 m for rows I, II, III and IV, respectively. The snow depth to the north of the gully was never higher than approximately 1 m and started to go down early in the spring. At its maximum, the snow depth was about equal to the height the structures in much

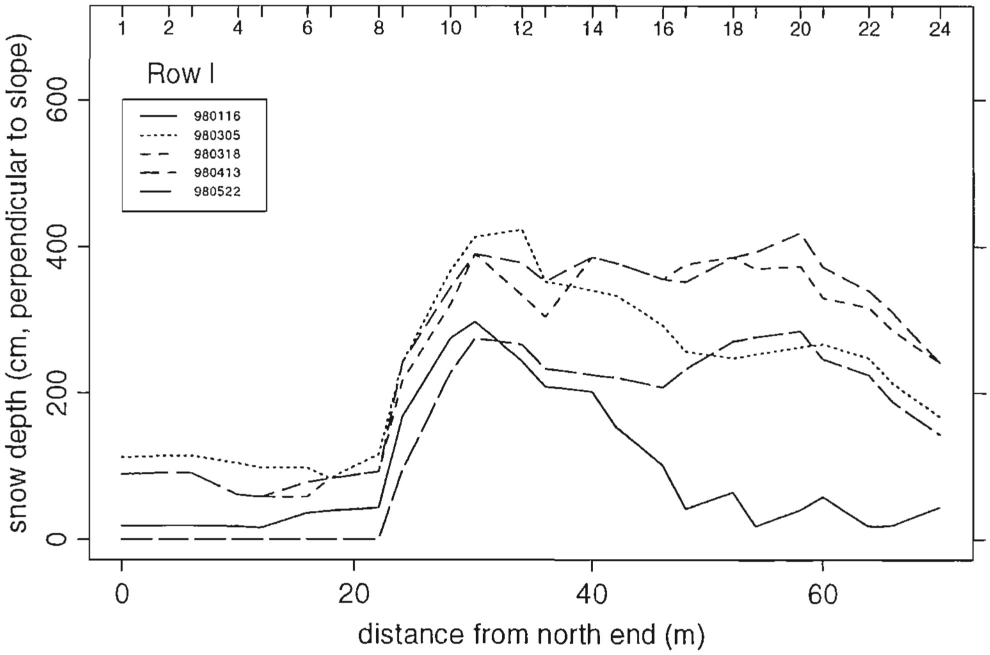

Figure 2a. Snow depth along row I.

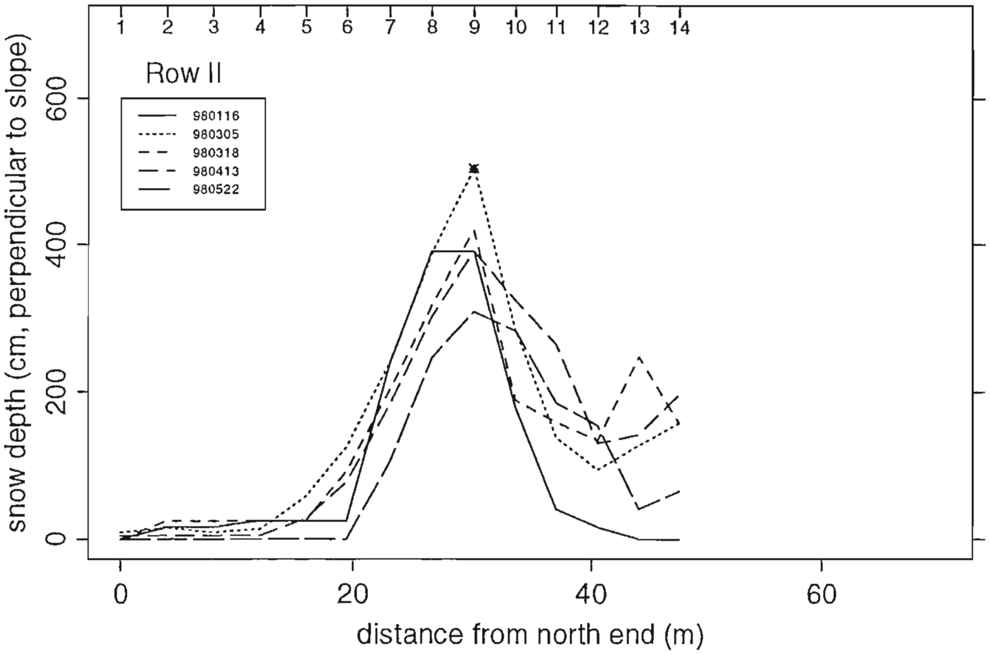

Figure 2b. Snow depth along row II.

of the northern part of the gully. It reached 0-0.5 m above the structures at one post in the Geobrugg nets in row II and at three posts of the J. Martin steel structures in row IV.

Maximum snow depths observed in 1997/98 are compared with snow depths from the previous winter in Fig. 3. The spatial distribution of the snow depth is similar in both winters and mainly determined by the shape of the gully and drifting snow in the prevailing northerly winds. The average difference in the maximum snow depths is about 1.3 m for posts where the snow depths exeeded 3 m during both winters. This difference in the snow depth between the two winters is highest in the EI nets in row III and lowest for the J. Martin steel structures in row IV.

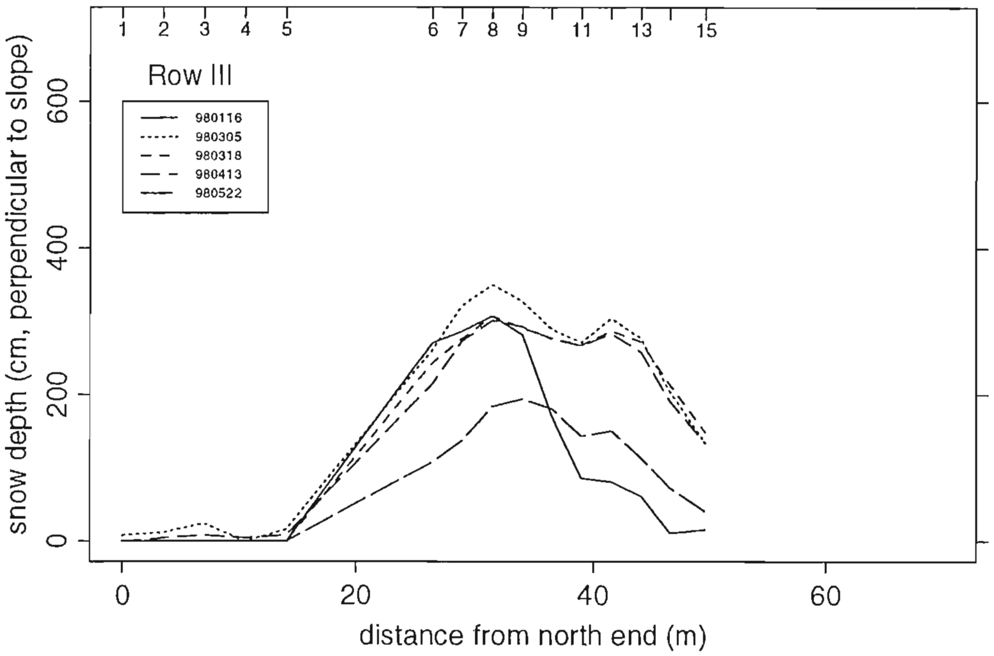

Figure 2c. Snow depth along row III.

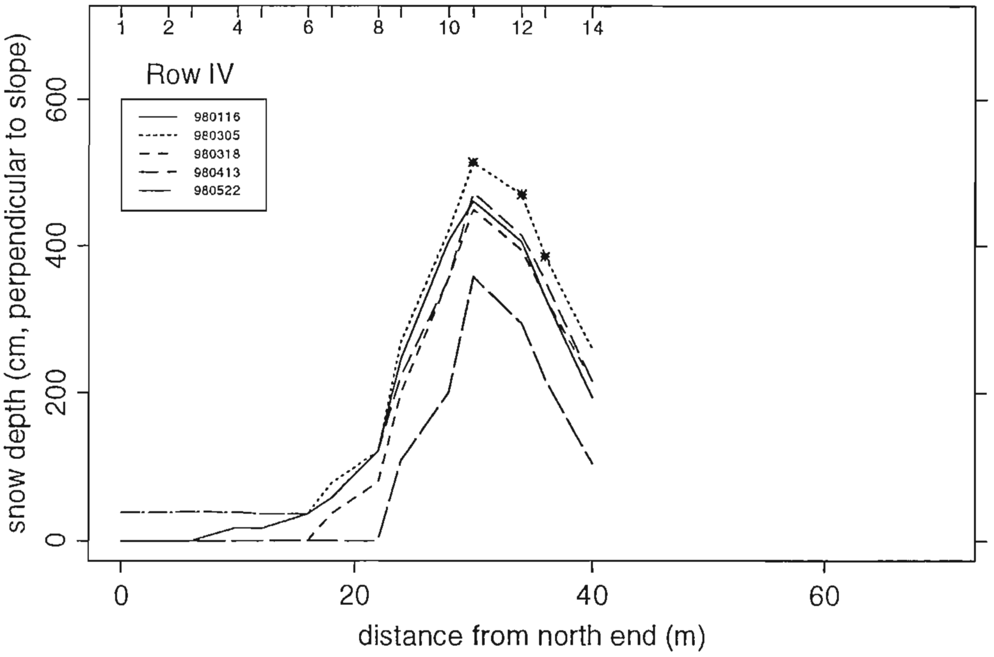

Figure 2d. Snow depth along row IV.

3. SNOW DENSITY

Loading of supporting structures is linearly related to snow density in the starting zone, which is belived to be higher in Iceland than in Alpine countries as discussed in the introduction. One of the goals of the pilot project is to quantify this expectation.

Snow profiles were measured on several days in pits between rows I and II in the test area (Fig. 4). The equivalent average density for loading computations (see eq. (1b) in Jóhannesson, Larsen and Hopf (1998)) was about 400 kg/m^3 during the middle of the winter (*cf.* Fig. 4, the first two pits). It increased to close to 500 kg/m^3 after the snow pack had become isothermal in the spring (*cf.* Fig. 4,

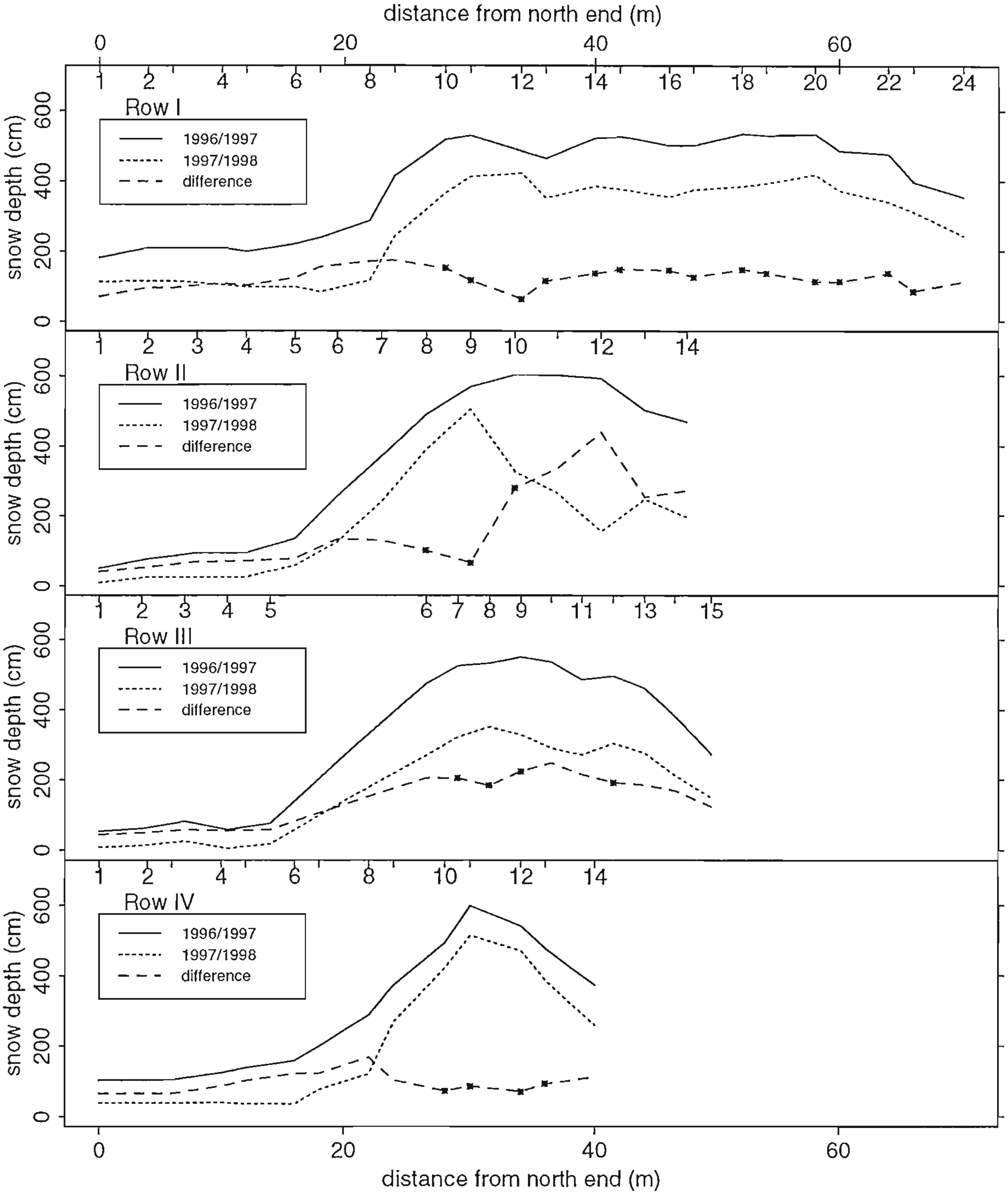

Figure 3. Maximum snow depth perpendicular to the slope for rows I, II, III and IV during the winters 1996/97 and 1997/98. The numbers at the top of each panel are sequential post numbers starting with 1 at the northern end of each row as in Figs. 2a-d. The symbols indicate snow depth differences at posts where the snow depth exeeded 3 m during both winters.

the last two pits), but this higher value was not reached until the snow depth had started to decrease. In spite of the lower density, the total loading on the structures, as computed by eqs. (2) and (3) in Jóhannesson, Larsen and Hopf (1998) (*cf.* the Swiss Guidelines (EISLF, 1998) and McClung and others (1984)), is higher for the pit on 05-03-1998 than for the last two pits on 13-04-1998 and 22-05-1998 in Fig. 4.

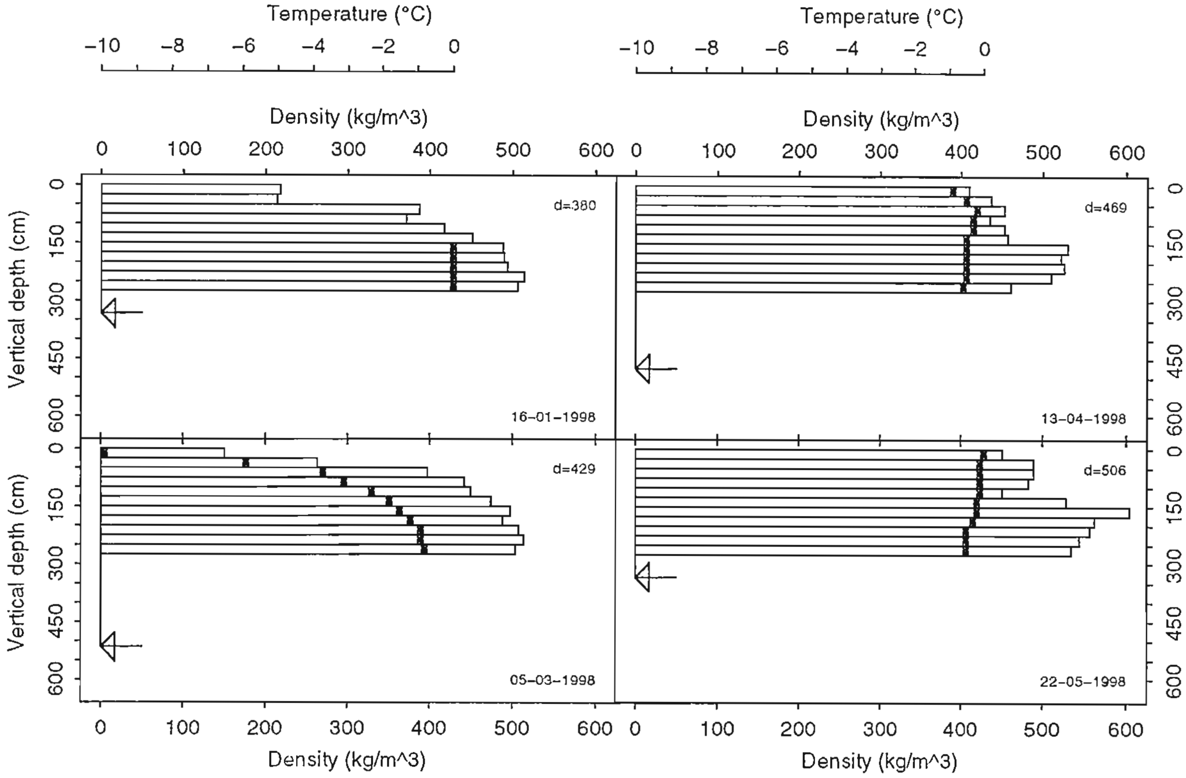

Figure 4. Density profiles from pits located between rows I and II. Temperature measurements are denoted with symbols. The profiles were all measured down to a vertical depth of approximately 3 m. The profiles were taken near the northern margin of the gully between rows I and II. The vertical snow height between posts 11 and 12 in row I is indicated with an arrow to the left in the figures in order to show the total snow depth near the northern side of the gully. The number in the upper right hand corner of the figures gives the equivalent average density of the whole snow layer (*cf.* eq. (1b) in Jóhannesson, Larsen and Hopf (1998)). The density below the bottom of the pit is assumed to be equal to the average density of the lowest 0.5 m of snow in the pit.

4. GLIDING

Gliding of the snow pack along the slope is one of the most important parameters determining the required strength of supporting structures. According to Swiss Guidelines (EISLF, 1990), loading of supporting structures is linearly related to a gliding parameter N, which varies from 1.2 to 3.2 under Alpine conditions. An appropriate estimate of gliding under Icelandic conditions is therefore critical for proper dimensioning of supporting structures in Iceland. Gliding is believed to be low under Icelandic conditions because of the moist climate and due to soil conditions which facilitate strong binding of the snow pack to the ground.

The gliding of the snow pack along the slope was measured at two locations within the test area and at one location north of the test area. The measurements were made with 20x30 cm glide shoes which were free to slide with the snow pack along the slope. The three measurements yielded less than 1 cm movement during the winter. Gliding measurements during the first winter of the experiment also showed very little gliding. Although it is not possible to draw general conclusions from measurements from only two winters, the observations are consistent with the expectation that gliding of the snow pack is comparatively low under Icelandic conditions.

5. TENSION AND PRESSURE MEASUREMENTS

Direct measurements of forces on the constructions are the most important measurements for determining dimensioning criteria for supporting structures.

Snow loading of the constructions in Siglufjörður was monitored by continuous tension recording instruments in the uphill anchors of the nets, continuous strain recording instruments in one of the posts of the nets, a continuous pressure measurement plate and maximum pressure plates in the stiff steel structures and by manual wire rope tension measurements (see Fig. 1). Two tension recording instruments (type Seamon load produced by Hugrún Ltd. in Reykjavík) were located in the uphill anchors between posts 8 and 9 in the Geobrugg nets in row II and between posts 8 and 9 in the EI nets in row III, and four Geokon strain gauges were mounted on post 9 in the Geobrugg nets. A 70x70 cm continuous pressure measurement plate and three 70x70 cm maximum pressure plates which were fixed to the J. Martin steel structures in row I between posts 11 and 12. Tension in the downhill wires of the Geobrugg and EI net lines in rows II and III was monitored by manual measurements.

5.1 Continuous tension measurements

Figure 8 shows the tension recorded by the continuous recording instruments in rows II and III. It is seen that the tension increases with increasing snow depth in the early part of the winter and reaches a maximum in March to April. The tension measured by the instrument in row III increases slower than for the instrument in row II. The reason for this difference is not clear. The onset of melting in the beginning of May leads to a sharp decrease in the tension. As during the winter 1996/97, there are no indications of an increase in the loading due to deformation or gliding introduced by melting.

The maximum tension during the winter is 157 kN and 124 kN in rows II and III, respectively. This may be compared with about 200 kN in row II during the winter 1996/97 when the maximum snow depth perpendicular to the slope reached 0.65-1 m higher near the location of the instrument in row II than during the winter 1997/98 (*cf.* Fig. 3). The maximum tension in row II is thus about 25% lower for the winter 1997/98 compared with the winter 1996/97. The maximum snow depth near the location of the instrument during the winter 1996/97 was about 5 m. The observed 25% reduction of the maximum tension is consistent with the linar relation between tension and snow depth squared expressed by eqs. (2) and (3) in Jóhannesson, Larsen and Hopf (1998) which predicts a reduction of 24-36% in this case.

The difference in the maximum tension between the instruments in rows II and III may be partly explained by the difference in post spacing between the two rows, *i.e.* 3.5 m in row II and 2.5 in row III. The observed difference is, however, smaller than expected from the theoretical snow pressure formulation quoted above, especially when the lower snow depth in row III is taken into account.

Recalibration of the recording instruments after the winter indicates that the calibration of the tension sensors changed by less than 1% of the measuring range of 400 kN during the winter. Problems related to a load induced hysteresis in the steel beem of the instrument, which occured in the winter 1996/97, did therefore not arise in the winter 1997/98. Improved calibration of the instruments, which was carried out in the fall of 1998, is believed to be accurate and stable for the whole measuring range of the instruments.

5.2 Manual tension measurements

The manual measurements of tension in the downhill wires were carried out by a Piab RTM 20-C rope tension meter which was calibrated for the types of wires which are used in the snow nets in Siglufjörður (see photograph 3 in the Appendix of Jóhannesson, Larsen and Hopf (1998)). The

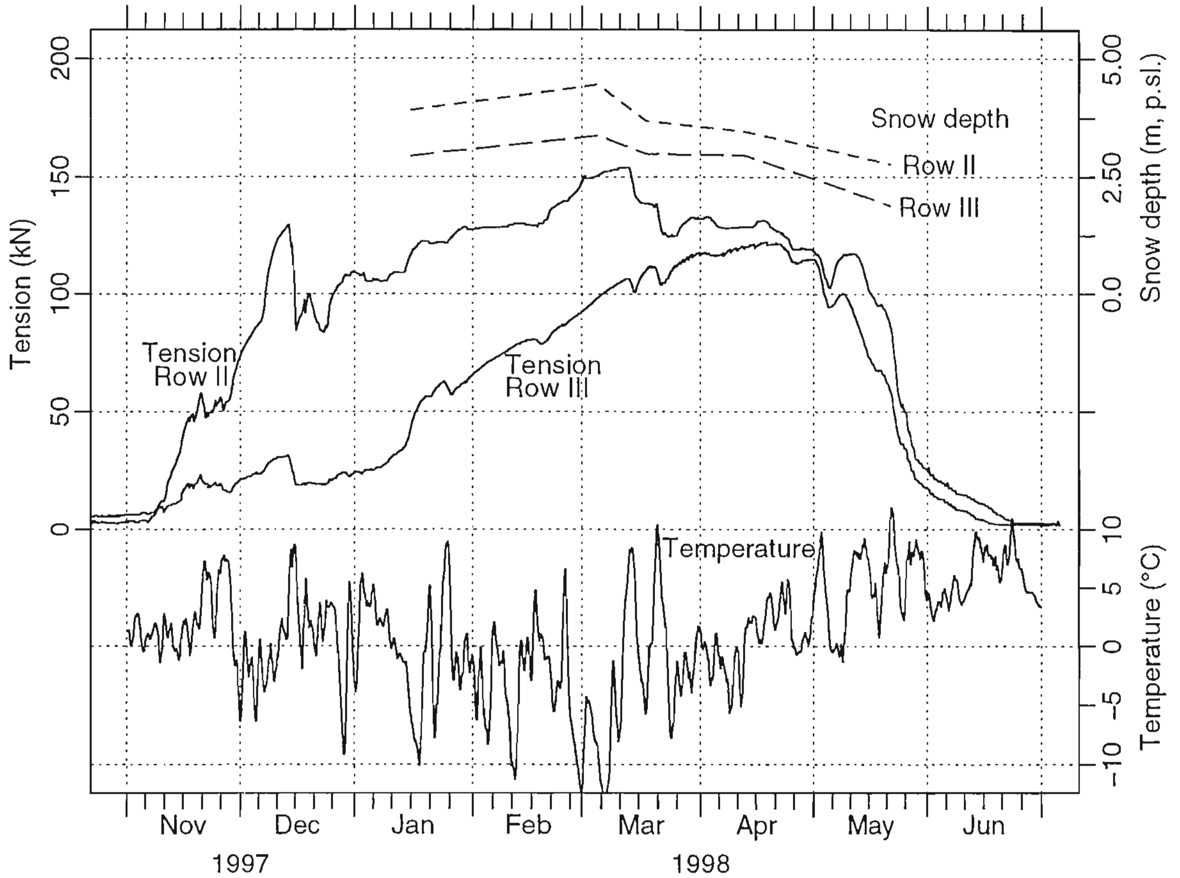

Figure 8. Tension in two uphill anchors in the Geobrugg and EI nets in Siglufjörður. The recording instruments are located between posts 8 and 9 in the Geobrugg nets in row II and between posts 8 and 9 in the EI nets in row III. Also shown are the snow depth perpendicular to the slope at the location of the recording instruments and temperature recorded at a meteorological station at sea level in Siglufjörður.

results are given in the following table.

Table 3: Tension in downhill wire ropes of the snow nets (kN).

Post	18 Mar	13 April	22 May
Geobrugg			
II-1	0	0	0
II-2	0	0	0
II-3	0	0	0
II-4	0	0	0
II-5	0	0	0
II-6	9.2	0.14	0

Post	18 Mar	13 April	22 May
II-7	24.0	17.6	2.4
II-8	50.2	42.3	24.5
II-9	53.8	114.1	40.6
II-10	66.9	83.9	47.9
II-11	6.3	0.72	4.5
II-12	16.8	27.8	23.2
II-13	11.5	11.0	0
II-14	14.6	0.31	0
EI			
III-1	0	0	0
III-2	0	0	0
III-3	0	0	0
III-4	0	0	0
III-5	0	0	0
III-6	26.0	28.0	5.0
III-7	40.3	38.4	12.7
III-8	23.7	24.8	19.8
III-9	21.7	64.3	21.1
III-10	35.5	44.4	31.1
III-11	25.6	29.6	22.4
III-12	29.3	31.3	26.4
III-13	18.8	18.1	9.4
III-14	21.1	18.0	3.5
III-15	4.2	0.19	0

The tension in the sections of the nets which are located north of the gully (*cf.* Fig. 1), where little snow accumulates, is negligible as was also found during the winter 1996/97. The highest values of the tension in the most heavily loaded downhill wire ropes of the Geobrugg nets is in the approximate range 50-115 kN, but 30-65 kN for the EI nets. Similar vales were observed in the winter 1996/97. The difference between the net lines corresponds roughtly to the different post spacing of the two net types, *i.e.* 3.5 m for the Geobrugg nets and 2.5 m for the EI nets in the gully.

5.3 Strain measurements in a post of the nets

Figure 9 shows the strain recorded by four wibrating wire sensors which were mounted about 1 m above the ground on post 9 in the Geobrugg nets in row II, and Figure 10 shows the compressive force and the moment computed from the strain records. The average strain in the post reached a relatively flat maximum of $-184\cdot10^{-6}$ in March and April. This corresponds to a load of 161 kN (using $E = 2.1\cdot10^{11}$ Pa, and post dimensions ϕ =193.7x7.1x4774 mm). The loading of the post corresponds well with the maximum tension of 157 kN in the uphill anchor and about 50 kN in the downhill wire rope of post 9 around the middle of March (*cf.* Table 3).

The four strain sensors were mounted with 90° spacing around the post. When the snow disappeared after the winter, they returned to the strain values recorded during the previous fall within $\pm15\cdot10^{-6}$, which is about 2% of the highest compressive strain recorded by sensor "W". The average strain in the post returned back to the previous value within $\pm3\text{-}4\cdot10^{-6}$, which is also about 2% of the maximum average compressive strain in the post. The internal consistency of the strain records may be assessed by comparing the average compressive strain recorded by the two pairs of sensors diametrically opposite to each other. The difference of the strain given by these pairwise averages

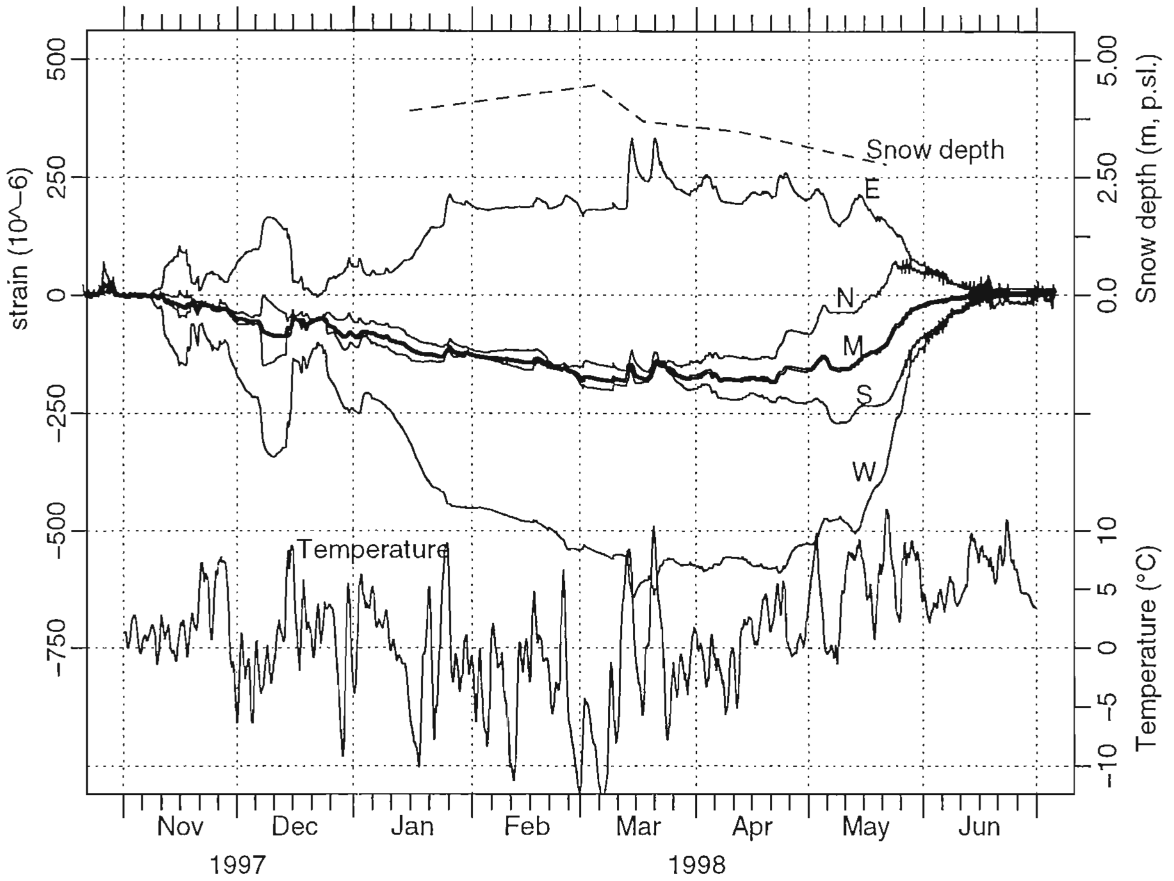

Figure 9. Strain recorded by four Geokon VK-4100 wibrating wire sensors mounted on post 9 in the Geobrugg nets in row II in Siglufjörður. The strain curves are labeled with "N", "S", "W" and "E" according to the direction of the corresponding sensor. The thick curve labeled "M" is the average strain in the post. Also shown are the snow depth perpendicular to the slope at the location of the instrument and temperature recorded at a meteorological station at sea level in Siglufjörður.

from the average of all four sensors had an RMS value of about $4 \cdot 10^{-6}$, which is about 2% of the maximum average compressive strain. The internal consistency of the four strain records is therefore good and it should be possible to use them to compute the moment in the post at the location of the sensors.

The moment in the post is given by $M = (e_{\max} E) I / (D/2)$, where $e_{\max} = \frac{1}{2} \sqrt{(e_W - e_E)^2 + (e_N - e_S)^2}$ is the maximum bending strain in the post, e_W, e_E, e_N and e_S is the measured strain on the West, East, North and South sides of the post, $E = 2.1 \cdot 10^{11}$ Pa is Youngs modulus for steel, $I = (\pi/64)(D^4 - d^4)$, and $D = 193.7$ mm and $d = 179.5$ mm are the outer and inner diameters of the post. The maximum bending strain is reached around the middle of March when $e_{\max}$ reached $487 \cdot 10^{-6}$ in a relatively sharp peak. The strain sensors are mounted 2.79 mm from the outer edge of the post which leads to a slight overestimate in the value of $e_{\max}$ at the surface of the post. The maximum value of $e_{\max}$ at the surface of the post is $474 \cdot 10^{-6}$ when this is taken into account. The maximum moment of the winter is then found to be 18.6 kNm (*cf.* Fig. 10). The maximum bending strain was about $400 \cdot 10^{-6}$ in the latter half of March and for most of April. The moment corresponding to

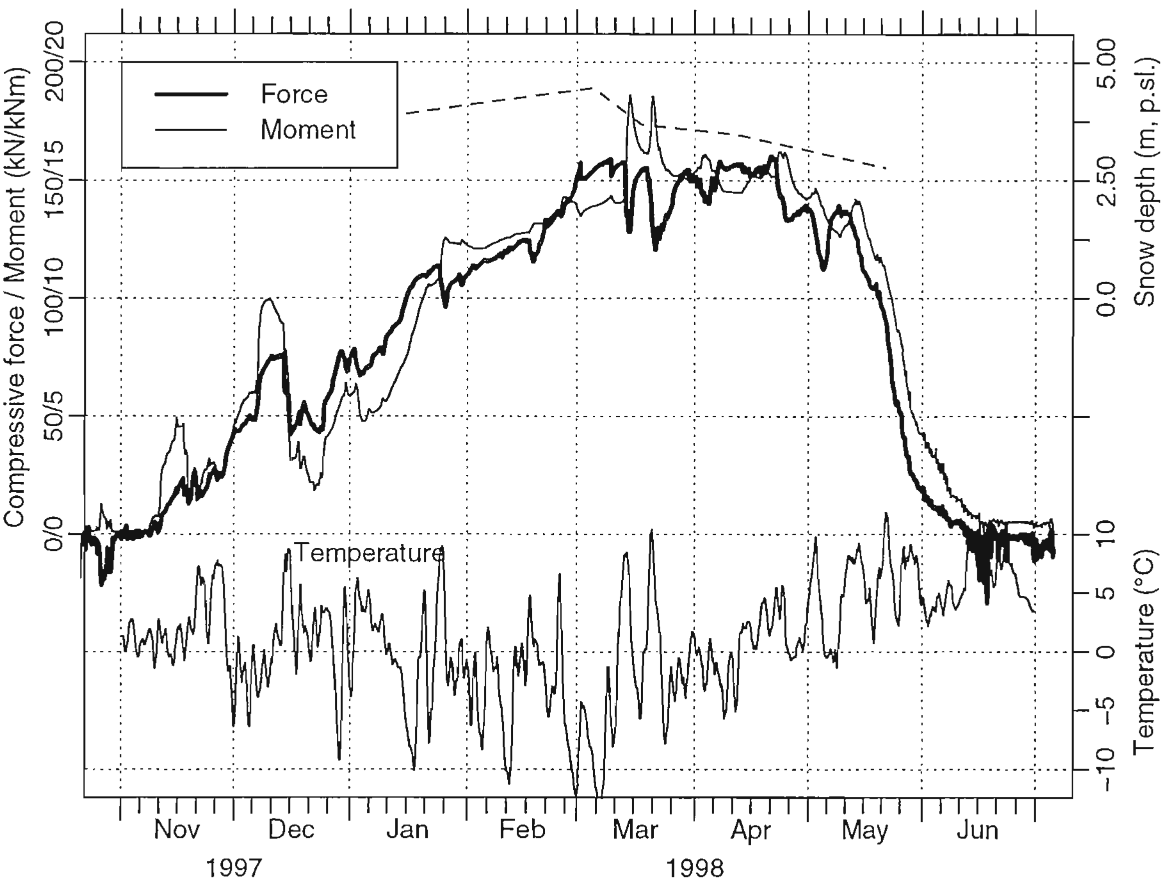

Figure 10. Compressive force (kN) and moment (kNm) in post 9 in the Geobrugg nets in row II in Siglufjörður. Also shown are the snow depth perpendicular to the slope at the location of the instrument and temperature recorded at a meteorological station at sea level in Siglufjörður. Wiggles in the force curve near the beginning and end of the record are due to differential heating of the post by the sun on clear days.

this strain, which was maintained for over six weeks, is 15.7 kNm (*cf.* Fig. 10).

The moment load specified by eq. (58) in the Swiss Guidelines (EISLF, 1990) gives a design moment load of only 5.7 kNm when allowance has been made for the high density of the Icelandic snow. This is less than one third of the measured maximum moment in Siglufjörður. Equation (58) in the Swiss Guidelines is based on the assumption that the snow pressure on the post is given by the depth averaged snow pressure on the construction applied over the width and length of the post (this is the assumption $\eta = 1$ in eq. (58) in the Guidelines). In practice, the effective width of the post may be expected to be substantially larger than this because the post will support more snow than corresponds to its width. This effect has been verified by field measurements in Norway where the loading of cylindrical masts has been found to be many times larger than would be expected from the width and length of the mast (Larsen, 1982; Larsen and Kristensen, 1998). The measured maximum moment load in Siglufjörður is lower than given by the design criteria proposed by Larsen and Kristensen (1998), which may be caused by the shielding effect of the net mesh. Measurements from more winters in Siglufjörður are required in order to obtain reliable estimates of design criteria for moment loads of net posts, but the measurements of the winter 1997/98 indicate that the criteria given by eq. (58) in the Swiss Guidelines are too low.

Design criteria for net posts according to the Swiss Guidelines are given by eq. (12) in sect. 3 064 5 of the SIA 161 standard. The contribution of the moment, which was measured in Siglufjörður, in eq. (12) of the standard is 2-3 times larger than the contribution of the measured compressive pressure forces along the post. This indicates that moment loads are an important part of the loads which posts of snow nets are exposed to. In spite of the high moment loads measured during the winter 1997/98, the total moment and pressure loads in the post still satisfy eq. (12) because the measured pressure in the post is lower than the design pressure used by the manufacturer of the nets.

5.4 Comparison of measurements in the nets with Swiss measurements

Table 4 compares the measured loads in the nets in Row II in Siglufjörður in 1997/98 with similar data from Oberalp in Switzerland from 1994/95 (Margreth, 1995). The maximum snow height in the Swiss nets in Oberalp was $H_k = 3.5$ m, which corresponds to $D_k = 2.5$ m. This is lower than the snow depth at the location of the instruments in Siglufjörður which reached a maximum of about $D_k = 4$ m in 1997/98.

Table 4: Maximum forces measured in Siglufjörður in 1997/98 and in Oberalp in Switzerland in 1994/95. The table also shows the design forces of Geobrugg nets with D_k=4 for N=2.5 and 3.2. The D_k = 4 m nets in the gully have N=3.2.

Location	Uphill anchor (kN)	Post (kN)	Downhill anchor (kN)
Siglufjörður, max	157	161	114
Siglufjörður, beg. Apr.	130	155	54-114
Oberalp, max	74	95	ca. 39
Geobrugg, design, D_k=4,N=2.5	332	255	81
Geobrugg, design, D_k=4,N=3.2	415	314	99

The maximum loads in the uphill anchor, the post and the downhill anchor in Siglufjörður were not reached at the same time (*cf.* Figs. 8, 9 and 10 and Table 3). Therefore, the table also shows the approximate loads in the beginning of April when the loads in the uphill anchor and in the post reached a relatively constant level near the maximum of the winter. The force distributions in the nets in Siglufjörður and Oberalp appear to be consistent with each other.

Table 4 also shows the design forces of the D_k = 4 m Geobrugg nets according to information from the manufacturer. The design forces of the D_k = 4 m EI nets in row III (not given in the table) are somewhat higher due to an errenous interpretation of the Swiss Guidelines. The measured loads are lower than the design forces, except for the tension in the downhill anchors in Siglufjörður. It is interesting to note that the measurements from both Siglufjörður and Oberalp indicate that the pressure in the post is higher than the tension in the uphill anchor by 20-30%, whereas the design pressure in the post is about 30% higher than the design tension in the uphill anchor. This indicates that the actual snow loading of the nets leads to a somewhat different distribution of forces than assumed in the Guidelines, with relatively higher loading of the net posts. In addition, it seems that moment loading of the net posts is substantially higher than assumed in the Guidelines as noted in the previous section. The measured tension in the downhill anchors also seems to be higher relative to the other forces than indicated by the design values.

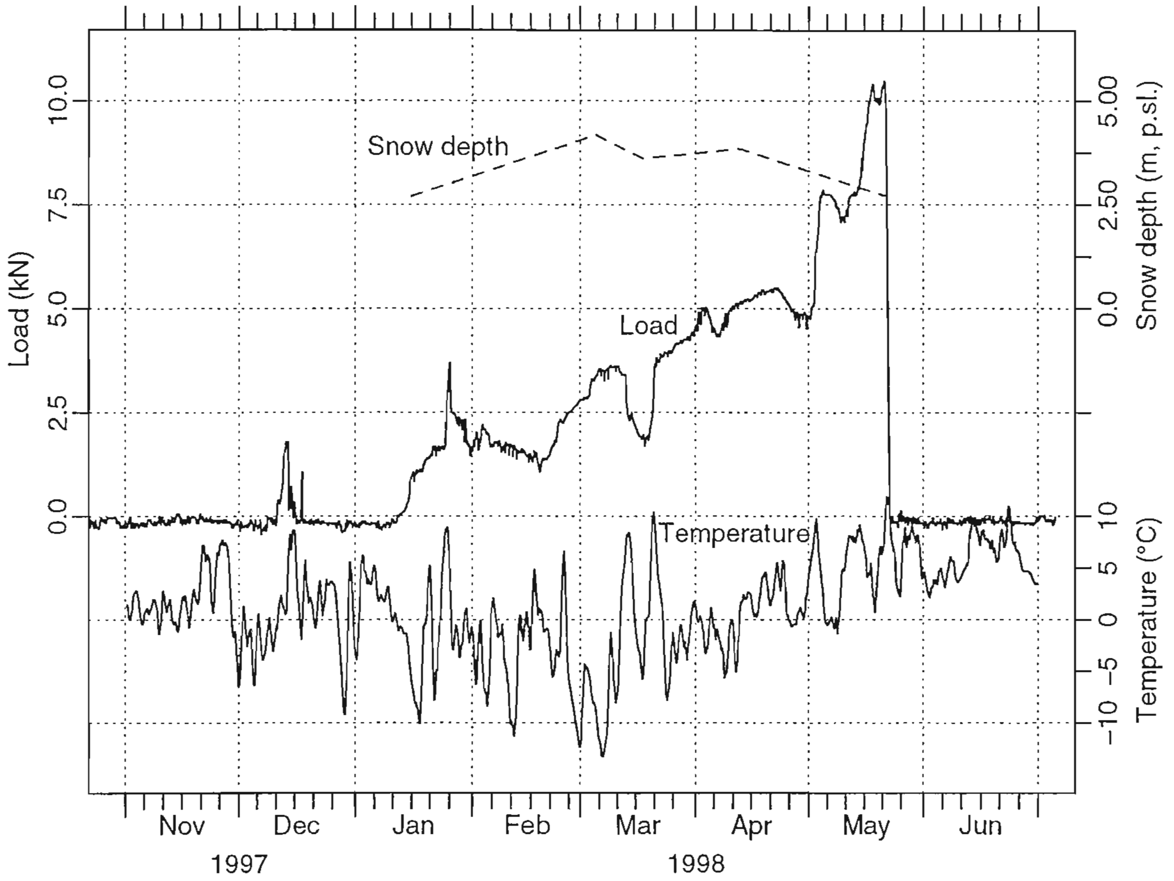

Figure 11. Load on a 70x70 cm plate 180 cm from the terrain between posts 11 and 12 in the J. Martin steel structures in row I in Siglufjörður. Also shown are the snow depth perpendicular to the slope at the location of the instrument and temperature recorded at a meteorological station at sea level in Siglufjörður.

5.5 Pressure measurements in the stiff constructions

Figure 11 shows the load recorded by the 70x70 cm continuous pressure recording instrument in the J. Martin steel structures in row I. The instrument is located about 180 cm from the slope (measured perpendicular to the slope) between maximum pressure plates I and II (see photograph 4 in the Appendix of Jóhannesson, Larsen and Hopf (1998) which shows the three maximum pressure plates). The time variation of the load on the plate is different from the variation of the tension in the uphill anchors of the nets shown in Fig. 8. The load on the plate increases steadily and reaches a maximum of 10.7 kN around the middle of May. Then it suddenly drops to near zero. The difference between the load shown in Fig. 11 and the tension shown in Fig. 8 may reflect the difference between the loading of a stiff steel construction and a net construction. The slow movement of the snow *through* the net mesh, which is observed to be on the order of 0.5 m in Siglufjörður during the winter, leads to a relaxation of the loading of the nets late of the winter. This effect does not lead to a relaxation of the stress on the stiff steel construction where the stress continues to increase due to internal deformation of the snow until late in the winter. The sudden relaxation of the load at the end of the winter may be caused by preferential melting of the snow near the steel construction. The load recorded by the continuous pressure recording instrument in row I is not consistent with the maximum load recorded by the maximum pressure plates as further described below.

The three maximum pressure plates are located between posts 11 and 12 of the steel bridges from J. Martin in row I. They were mounted at distances 230, 140 and 90 cm from the terrain (measured perpendicular to the slope). Each plate was fitted with 5 conical pins which made conical depressions in cylindrical aluminum surfaces with a diameter of 30 mm when the plate was subjected to pressure (see photograph 4 in the Appendix). The diameter of the conical depressions in the aluminum, d, in mm is a function of the applied load, f, in kg according the equation $d = 0.178 \cdot f^{0.5127}$, which was derived with a laboratory calibration (*cf.* Jóhannesson, Larsen and Hopf (1998)). The results of the measurements are given in the following table.

Table 5: Maximum loads measured in Row I.

Plate	Distance from slope (cm)	Load (kN)
I	230	19.9
II	140	34.8
III	90	29.3

The maximum snow thickness of the winter was approximately 4 m perpendicular to the slope at the location of the plates (*cf.* Fig. 2a). The maximum loads during the winter 1997/98 in Table 5 are lower than obtained during the previous winter of 1996/97, *i.e.* in the approximate range 20-35 kN compared with 30-50 kN for the previous winter. The maximum load during the winter 1997/98 is observed for plate II, but plate I recorded the highest load during 1996/97. This is consistent with the lower maximum snow depth during 1998/97 compared with 1997/96 at the location of the measurements, *i.e.* 4 m in 1998/97 and 5 m in 1998/97. Maximum snow pressure on supporting structure is believed to be proportional to the snow thickness (*cf.* Fig. 2 in McClung and others (1984), the Swiss Guidelines (EISLF, 1990) and eqs. (2) and (3) in Jóhannesson, Larsen and Hopf (1998)). The relative reduction of about 30-35% in the loading somewhat more than corresponds to the reduction in the snow depth.

The load recorded by the continuous pressure recording instrument shown in Fig. 11 is not consistent with the maximum load recorded by the maximum pressure plates decribed above. The maximum pressure plates I and II record 2-3 times higher pressure than the continuous pressure recording instrument. Each plate has an area of approximately 0.5 m^2. It may be expected to support snow pressure corresponding to a larger area due to bridgeing, perhaps extending a distance on the order of the dimensions of the plate in all directions. If it is assumed that each plate supports snow pressure corresponding to 2-3 times its area (the relative area of the steel surface of the beams in the stiff steel constructions is about 55%), the measured total load on each plate (in kN) given in Fig. 11 and Table 5 multiplied by a factor in the range 0.67-1 will be approximately equal to the snow pressure at the location of the plate (in kPa). These considerations make the load recorded by the continuous pressure recording instrument in row I roughly consistent with the tension in the uphill anchors in rows II and III, but the load recorded by the maximum pressure plates seems too high. The maximum pressure plates have the same geometry as the continuous pressure recording plate and it has been verified by calibration with loads of different duration that the diameter of the conical depression in the aluminum surface only depends on the maximum load and not on the duration of the load or on the load history. The reason for the inconsistency between the maximum pressure plates and continuous pressure recording plate is therefore not clear. Since the continuous pressure recording plate measures the instantaneous loading and since its accuracy of has been verified by repeated calibration, we will assume it gives the correct results. Further testing and calibration and data from the next winters are needed to resolve this problem.

6. CORROSION MEASUREMENTS

Test plates for measuring the rate of corrosion of steel and zinc were installed on the supporting structures in Siglufjörður in May 1997 and the first plates were taken down for inspection in July 1998. The rate of steel corrosion was found to be 16 μm pr. year and the rate of zinc corrosion was 0.4 μm pr. year. These rates are smaller than the first year corrosion rates measured in Reykjavík and Þorlákshöfn in experiments carried out in 1984-1988 (21-33 μm pr. year for steel and 1.2-1.7 μm pr. year for zinc, *cf.* Sigurðsson, Jóhannesson and Sigurjónsson, 1998). Thus, corrosion rates are lower at the relatively high altitude of the starting zone in Siglufjörður than near sea level in Reykjavík and Þorlákshöfn. Long term corrosion rates may from the experiments in Reykjavík and Þorlákshöfn be expected to be lower by a factor of approximately one half or more compared with the measured rates of the first year.

7. INSTALLATION OF NEW TYPES OF NETS

New types of nets with an improved corrosion protection were installed in both the Geobrugg and the EI net lines in the late summer of 1998. Two triangles were installed near the northern end of each line. One of the new triangles in each line is made of wire ropes with an aluminum/zinc corrosion protection, both for the perimeter ropes and the mesh wires. Another triangle has perimeter ropes with an aluminum/zinc corrosion protection and mesh wires of stainless steel. The perimeter wires in the new EI nets are lubricated, but not in the new Geobrugg wires. Laboratory tests indicate that this type of corrosion protection is a substantial improvement compared with the older design where wire ropes with a traditional hot dip galvanisation are used. The older design of galvanised nets has proved to be problematic under Icelandic conditions (*cf.* Sigurðsson, Jóhannesson and Sigurjónsson, 1998). The new nets will be monitored during the next years in order to evaluate this new corrosion protection technique.

One possible problem that may arise in the new nets with mixed types of wires is localised corrosion at the contact points of perimeter ropes with aluminum/zinc corrosion protection and mesh wires of stainless steel. Such contact points between hot dip calvanised wire ropes and stainless clips do not seem to have caused problems in the older design of nets from EI, where numerous small stainless steel clips are in contact with hot dip calvanised wire ropes. Since one may expect contact points between aluminum/zinc corrosion protection and stainless steel to be no worse with respect to localised corrosion than contact points between hot dip calvanisation and stainless steel, this may not be a significant problem in the new nets, but this must be verified by monitoring of the new nets.

8. CONCLUSIONS

The following conclusions for the design of supporting structures in Iceland may be drawn from the observations in the test area in Siglufjörður which are described in this report.

1. For extreme values of the snow height, $\tilde{\rho}$ =400-450 kg/m^3 seems to be an appropriate equivalent average snow density for the design of supporting structures in Iceland. This corresponds to the first case of loading according to the Swiss Guidelines. An appropriate density for the second case of loading is 500 kg/m^3 or more.
2. The effect of gliding on snow loading appears to by low.
3. Maximum loading of the structures occurs around the time of maximum snow depth. Densification, deformation or gliding induced by spring melting is not very significant for the dimensioning of supporting structures.

4. Moment loads on net posts appear to be substantially larger than specified in the Swiss Guidelines.

Although these results are preliminary since they are derived from measurements from only two winters, available additional observations from Norway and previous related observations from Iceland described in (Jóhannesson, Larsen and Hopf, 1998) give additional support to these conclusions.

There is an overall agreement between observed loads and theoretical predictions based on the Swiss Guidelines, when the high density of snow in Iceland is taken into account. This indicates that modified Swiss Guidelines with higher reference dimensioning density, and possibly with a higher specification of moment loading of net posts, will provide adequate requirements for supporting structures for Icelandic conditions. This implies that most requirements regarding the internal structure and relative strength of elements in the constructions, such as stronger end elements, relative forces in uphill and downhill anchors, *etc.*, will be unmodified. Apart from the higher density, the modifications would for example include an elimination of the height factor and an explicit determination of a low glide factor.

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