Veðurstofa Íslands
Report

Tómas Jóhannesson
Stefan Margreth

Adaptation of the Swiss Guidelines for supporting structures for Icelandic conditions

VÍ-G99013-ÚR07
Reykjavík
July 1999

CONTENTS

SUMMARY

Suitable design parameters for supporting structures under Icelandic conditions are being investigated in an experimental installation of steel bridges and snow nets at Siglufjörður in Northern Iceland, constructed in the autumn of 1996.

Observations from the test area have been used to adapt the Swiss Guidelines for Supporting Structures to Icelandic conditions. The observations and other relevant data from Iceland and Norway indicate that the most important difference between conditions in Iceland and those of Alpine countries is a higher snow density in Iceland. This is compensated for by adopting a relatively high gliding factor, which has essentially the same effect as a higher reference dimensioning density. In addition to the higher density, which is implemented through a relatively high gliding factor, the modifications to the Guidelines include an elimination of the height factor, an increase in the moment loading of net posts, improvements to the foundations of the structures, and an improved corrosion protection. Most of the requirements of the Guidelines 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.*, are not modified.

The results of the experiment in Siglufjörður after the first two winters will be reevaluated during the next years as more data become available. This may lead to some modifications in the recommendations which have been formulated on the basis of data now available. The consistency of the observations of the first two winters and of similar observations from Norway do, however, 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) 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 (snow bridges) and snow nets, were installed for experimental purposes in Hafnarfjall above the village Siglufjörður in northern Iceland in the fall of 1996.

Snow height in the test area, snow density, gliding of the snow pack and the loading of the structures, have been monitored for the past two winters (Jóhannesson, Larsen and Hopf, 1998; Jóhannesson, 1998). The observations indicate that an appropriate mid winter snow density for the design of supporting structures for Icelandic conditions is 400-450 kg/m^3, and that an appropriate density for the second case of loading about 500 kg/m^3. The corresponding values in the Swiss Guidelines (EISLF, 1990) are 270 and 350 kg/m^3, respectively. (The density corresponding to the second case of loading in the Swiss Guidelines is sometimes quoted as 400 kg/m^3. The value 350 kg/m^3 given above corresponds to eq. (49) on p. 50 of the Guidelines where the relative increase in the density/snow pressure with respect to the first case of loading is given as 1/0.77). The effect of gliding on snow loading appears to be small. In general, there are no indications of a variation in snow density or loading of the structures with elevation above sea level nor with the aspect of the slope for Icelandic conditions. There is an overall agreement between observed loads in Siglufjörður and theoretical predictions based on the Swiss Guidelines, when the high density of snow in Iceland is taken into account, except that moment loading of net posts is larger than assumed in the Guidelines (Jóhannesson, 1998).

The observations indicate that modified Swiss Guidelines with a 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. In order to limit the required modifications to the Swiss Guidelines, the effect of higher density of snow in Iceland is taken into account by adopting a relatively high gliding factor, which in practice has almost the same effect as a higher reference dimensioning density. This makes it possible to require stronger structures, and at the same time, to maintain the same strength classification as is used in the Guidelines. In addition to modifications due to the high snow density, strength requirements for supporting structures in Iceland should be independent of the height above sea level and the aspect of the slope. With regard to the design of supporting structures, the main results of the first two winters of the experiment in Siglufjörður 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 pressure caused by uphill winds, and micropile anchoring of posts should not be used in loose materials unless the connection between post and anchor provides stiffness under lateral loads (Sigurðsson, Jóhannesson and Sigurjónsson, 1998; Jóhannesson, Larsen and Hopf, 1998; Jóhannesson, 1998).

The following report describes the modifications of the Swiss Guidelines for Icelandic conditions which have been derived from the observations of the first two winters of the experiment in Siglufjörður. The requirements will be revised based on the observations of the winter 1998/1999 and the revised requirements published as formal requirements for supporting structures in Iceland by the Building Research Institute of Iceland (Rannsóknastofnun Byggingariðnaðarins).

2. REQUIREMENTS

The design of supporting structures for Icelandic conditions is made on the basis of the Swiss Guidelines for supporting structures (EISLF, 1990), with modifications and additional requirements as described below. Further explanations and concretions of the Guidelines are found in the publications EISLF (1963) and EISLF (1992), which are also adopted for Iceland unless otherwise stated below.

Superscripted numbers in the following subsections, which describe the modifications to the Guidelines and additional requirements that are adopted for Iceland, refer to a numbered list of comments in an Appendix at the end of the report. The comments contain references and additional information which is relevant to the corresponding modification or requirement.

2.1 Snow density, gliding factor and height factor

The high snow density in Iceland is taken into account by adopting a gliding factor N of 2.5 (or higher, see below) rather than 1.2 which would otherwise have been chosen based on the expected low gliding in Iceland.[1] With this modification of N, eqs. (48.1-48.5) and other equations of the Swiss Guidelines, which are based on an explicit choice of the density 270 kg/m^3, can be used as they stand in the Guidelines.

The value of the gliding factor is independent of the aspect of the slope, *i.e.* variations in the gliding factor according to the aspect of the slope, as specified in the table on p. 35 in the Guidelines, are not used in Iceland.

The height factor f_c is given the constant value 1.1 independent of the elevation above sea level, *i.e.* variations in the height factor according to elevation above sea level, as specified by the table on p. 34 in the Guidelines, are not used in Iceland.

As a general rule, the gliding factor N is given a value of 2.5 in Iceland. Higher values can be used as a safety precaution in difficult terrain where it is especially difficult to determine an appropriate extreme snow height, for example in gullies or shallow depressions in the slope.

2.2 Moments loads

Moment loads on net posts are specified by eq. (58) in section 58 of the Swiss Guidelines, with the modification that the effectiveness coefficient η is specified as $\eta = 3$ for Iceland rather than 1 as assumed on p. 59 of the Guidelines.[2]

Moment loads on posts of snow bridges are also considered according to eq. (58), but with $\eta = 1$, because the snow cover does not creep through stiff steel constructions to the same extent as through the mesh of snow nets. The main source of moment load on posts of snow bridges is the pulling action of the snow cover below the structures rather than snow pressure arising from creeping and gliding of the snow cover as a whole.[2]

2.3 Foundations

Ground plates are permitted as foundations, both for supports of snow bridges and for posts of snow nets.[3]

An even bed should be prepared for each ground plate in order to prevent uneven loading of the plate.

Ground plates of structures, for which the support is not approximately perpendicular to the slope should be dug down by at least 0.5 m in loose material as specified in section 60.2 on p. 62 in the Swiss Guidelines and the holes should be refilled after the installation of the structures. This applies to supports which deviate more than 15° from being perpendicular to the terrain. Such supports are common for snow bridges, but not for snow nets.

Ground plates of snow nets should be fixed to withstand lateral forces in the down slope direction arising from the lateral component of the snow pressure according to eq. (58) of the Swiss Guidelines with $\eta = 3$. In good soil conditions and where low snow gliding is expected, the lateral force on the plate arising from the compressive force in the post due to a deviation of the post from being perpendicular to the terrain, is assumed to be compensated by friction between the ground plate and the terrain. In loose soil conditions and where snow gliding is expected, the fixing of the ground plates should in addition be designed to withstand the lateral force on the plate arising from the compressive force in the post, assuming that the post deviates 5-10° from being perpendicular to the terrain. This fixing is typically achieved with wire ropes from the ground plates to the upper anchors. At certain locations in an uneven terrain, tensioned wire ropes from the ground plates to the upper anchors will be suspended above the ground and may be subjected to very high snow forces. At such locations, fixing of the ground plate with a concrete socle or an extra anchor should be considered instead of wire ropes.

If micropile/anchor foundations are used for snow net posts in loose soil, a concrete socle has to be used in order to provide lateral stiffness. Micropile/anchor foundations of posts without such concrete socles cannot be used in loose materials unless the connection between post and anchor provides stiffness under lateral loads.[4]

Supporting structures shall be dimensioned to withstand upslope and lateral wind pressures of $P = c_D \cdot 3$ kPa, on a plane perpendicular to the slope, when there is no snow in the structures.[5] The coefficient c_D is an appropriate form factor for the construction. This implies that ground plates of stiff steel constructions need to be anchored to the slope. Connections between supports or posts, on one hand, and micropiles or ground plates, on the other, must be designed for tensile loads corresponding to the moment caused by the wind pressure in addition to the compressive loads due to the snow pressure.

2.4 Corrosion protection of steel parts above ground

Steel parts above ground shall be hot dip galvanised according to the Swedish standard SS 3583[6], class B (SIS, 1988). Designation on drawings shall be "Fe/Zn class B SS 3583". Table A1 in the Appendix lists the requirements of the standard for steel thickness over 6 mm.

2.5 Corrosion protection of subsurface steel parts

Anchors and other subsurface steel parts (other than wire ropes) shall be produced with an additional steel thickness of 2 mm on each side in order to compensate for corrosion as specified in section 42.3 on p. 45 of the Swiss Guidelines. This applies to each side of flat parts and the radius of cylindrical parts. In addition,[7] anchors and other steel parts shall be hot dip galvanised according to the standard SS 3583, class B, (*i.e.* 115 μm average zinc thickness for steel thickness over 6 mm), with 200 μm maximum local thickness for anchors.[8] Designation on drawings shall be "Fe/Zn class B SS 3583". Permissible bond stress for indented wires is reduced by 30%, when galvanised, and for ribbed wires by 45%.[9]

2.6 Corrosion protection of wire ropes

Experience of traditional snow nets in Iceland demonstrates that they have a corrosion protection that is unsuitable for Icelandic conditions.[10] These nets are made from hot dip galvanised steel wire ropes, with wire diameters on the order of 1 mm for perimeter and downslope wire ropes and 0.3-0.8 mm for mesh wire ropes. Corrosion protection of wire ropes in snow nets in Iceland must, therefore, be substantially improved from snow nets currently produced for Alpine countries.

Adequate corrosion protection of wire ropes in snow nets may be achieved by using

1. Wire ropes made of stainless steel.
2. Coating materials other than zinc that provide improved corrosion protection.
3. Thicker wires and hot dip galvanisation with a thicker zink coating.

There are no additional requirements for stainless steel wire ropes except that the stainless steel should be of type 316.

Steel wires with a corrosion protection coating shall be lubricated with a lubricant designed to impede corrosion. This applies to both wires with traditional hot dip zinc coating and for wires with other types of coating, such as a Zn-Al coating. Wire ropes used as a rock anchor shall not be lubricated.

There is little practical experience on steel wire ropes with coating materials other than zinc in Iceland. The use of such wires in snow nets must, therefore, be considered experimental at the current point in time. Manufacturers are required to provide test results and other documented evidence that wire ropes in their snow nets may be expected to have a life time of at least 25 years under Icelandic conditions. General aspects of the corrosion conditions encountered in Iceland are described in Sigurðsson, Jóhannesson and Sigurjónsson (1998). Such evidence may for example be test results that give an indication of the relative improvement in the life time provided by the coating in question compared with traditional hot dip galvanisation as used in current types of snow nets. A relative improvement by a factor of more than 3 is considered adequate.

Considering the experimental status of the use of wire ropes with coating materials other than zinc in snow nets under Icelandic conditions, manufacturers are required to guarantee a 25 year life time of such wires in their snow nets. The term "life time" in this connection is taken to mean the time period over which corrosion eliminates the protective coating from more than 10% of the wire rope (estimated on a piece of rope with a length of 1 m). Several wire rope samples of about 1 m length each, which may easily be taken down for testing, shall be mounted in representative locations on all snow net installations in Iceland in order to facilitate monitoring of the corrosion conditions of the nets. One such sample for each wire rope type shall be analysed before the nets are installed. Samples mounted on the nets will be analysed 2, 5, 10 and 20 years after the installation of the nets.

Steel wire ropes with a traditional hot dip galvanisation shall have a strand construction with a diameter of individual wires as great as possible. Such wires are to be hot dip galvanised according to the standard DIN 1548, heavy galvanising ("dickverzinkung") (Beuth Verlag, 1988). Table A2 in the Appendix lists several wire rope types which are recommended in case wire ropes with a traditional hot dip galvanisation are used as a part of snow nets in Iceland.[11] Use of wire ropes of other types than listed in the table can only be made after consultation with the Building Research Institute of Iceland. The recommendations in table A2 are solely from the viewpoint of corrosion protection. Wire ropes made out of as thick wires as recommended in the table may be too stiff for it to be technically feasible to use such wire ropes in snow nets.

2.7 Wire ropes used as rock anchors

The parts of wire rope anchors, that are not covered by concrete in the drill hole, are usually protected by special protective shields in current snow nets from Switzerland. The need for such protection is pointed out in a letter dated 8 April 1992 from the Eidgenössisches Institut für Schnee- und Lawinenforschung to producers of wire rope anchors. This letter was sent after tests in 1991 indicated a loss of strength of about 25% in some 13 year old galvanised wire rope anchors. Such protective shields are, however, not required by the Swiss Guidelines from 1990. This special corrosion protection is needed in order to counteract increased corrosion which may arise from the close contact with the ground.

Manufacturers of rope anchors for Icelandic installations are encouraged to adopt such measures or other means of increasing the corrosion resistance of the part of the rope anchor which extends out of the concrete. Manufacturers are required to document the corrosion protection of their rope anchors in detail and compare it with the corrosion protection of other wire ropes in the snow nets.

2.8 Bolts, nuts, washers and shackles

All bolts, nuts, u-bolt clips, washers and shackles, shall be made from stainless steel, type 316, or be hot dip galvanised, according to the Swedish standard SS 3583, class B. The minimum average zinc thickness on threads shall be 53 μm with minimum local thickness 45 μm. Bolts, nuts and u-bolt clips from stainless steel are in practice inconvenient for use in supporting structures. Bolts, nuts and u-bolt clips will, therefore, typically be hot dip galvanised. Various types of clips which are used in the mesh of snow nets will on the other hand typically be made from stainless steel. Contact points between stainless wire ropes or stainless clips and wire ropes or posts of hot dip galvanised steel do not seem to constitute a problem in snow nets.[12]

Permanent tightening of nuts, for example for nuts on bolts that hold beams of steel bridges in their place, shall be ensured by washers, double nuts, or other appropriate means.[13] This is not necessary for nuts on u-bolt clips on wires which do not become loose in the same way as nuts on bolts which are a part of stiff steel constructions.

2.9 Other requirements

This section list several requirements from the Swiss Guidelines and related documents which are retained without modification for Icelandic conditions. They are given here in order to list them in one place since they are dispersed between different documents from EISLF.

1. A safety factor of 1.6 is adopted in all dimensioning of supporting structures (Swiss Guidelines, p. 43).[14]
2. The design of supporting structures is in general made for a slope of 45°, independent of the actual slope of the terrain where the structures will be installed. This is done for simplicity, and so that the use of an element will not be overly restricted to the particular part of the slope for which it was designed.
3. Supporting structures are produced for standardised values of the main design parameters as described in sections 2.2.2 and 2.4.2 in EISLF (1992). Section 2.2.2 in EISLF (1992) specifies values for ψ (slope, $\psi = 45°$), N (gliding factor), f_c (height factor), D_k (dimensioning snow depth perpendicular to the slope) and A (spacing between structures), some of which have already been fixed for Iceland by requirements in the preceding sections. The standardised values of D_k are 2.0/2.5/3.0/3.5/4.0/4.5/5.0 m. Section 2.4.2 states that single structures with a 2 m spacing must also be considered in the dimensioning and that structures must be strong enough or adjustable for use at the ends of a line, for example by allowing for additional posts and girders.
4. The design of supports of snow bridges must be performed for an overlength of 0.5 m more than needed on an even slope so that the structures can be adopted to terrain irregularities. Posts of snow nets must also be longer than needed on an even slope for the same reason. In the current versions of snow nets from Alpine countries, this is achieved by producing the posts with several holes near the top so that the fixing point of the nets on the post can be varied depending on the shape of the terrain. This current design of snow nets from Alpine countries is considered adequate for Icelandic conditions in this regard.
5. The value of $tg\phi$, which is used in the computation of the distance between lines in sections 21 and 22 of the Swiss Guidelines, is given a value of $tg\phi = 0.55$ in Iceland.

3. ACKNOWLEDGEMENTS

Pétur Sigurðsson, corrosion consultant, Þór Sigurjónsson from Línuhönnun Ltd, Josef Hopf, avalanche consultant from Austria, Jan Otto Larson from NGI in Norway, Bruno Haller from Geobrugg in Switzerland, Walter Schwarzmann from J. Martin in Austria and Jacques Bourriot from L'Entreprise Industrielle in France provided useful comments on an earlier versions of this report which is gratefully acknowledged.

Örlygur Kristfinnsson, IMO's snow observer in Siglufjörður, carried out much of the observations of snow height, snow density and tension in wire ropes in the test area of the pilot project in Siglufjörður on which the requirements in this report have been based.

The compilation of this report is financed by the Icelandic Avalanche Fund.

4. REFERENCES

Beuth Verlag GmbH. 1988. Zinc coating on round steel wires. DIN 1548.

CEB. 1992. Protection systems for reinforcement, CEB Bulletin d'information. Lausanne.

CEB. 1995. Coating protection for reinforcement. CEB State of the Art Report by Task Group VII/8, Thomas Telford Services Ltd.

Eidgenössisches Institut für Schnee- und Lawinenforschung. 1968. *Richtlinien für der Lawinenverbau im Anbruchgebiet.* (Swiss Guidelines for supporting structures, 1968 version).

Eidgenössisches Institut für Schnee- und Lawinenforschung. 1990. *Richtlinien für der Lawinenverbau im Anbruchgebiet.* (Swiss Guidelines for supporting structures). Bern, Bundesamt für Umwelt, Wald und Landschaft.

Eidgenössisches Institut für Schnee- und Lawinenforschung. 1963. Lawinenverbau im Anbruchgebiet. Kommentar zu den Richtlinien für den permanenten Stützverbau vom Februar 1961.

Eidgenössisches Institut für Schnee- und Lawinenforschung. 1992. Interne Richtlinie zur Regelung der Verfahren uns Zuständigkeiten bei der Prüfung von Werktypen und ihren Fundationen sowie von Ankermörtel im Lawinenstützverbau.

Frutiger, H. 1961. Korrosionsschutz von Stahlwerken im Lawinenverbau. Eine Zusammenstellung von Unterlagen und Problemen für die Tagung von 6. Februar 1961 in Zürich. Weissfluhjoch, Arbeitsgruppe für Lawinenverbau.

Jóhannesson, T. 1997. Stoðvirkjatilraun á Siglufi rði. Verk og kostnaðaráætlun fyrir árið 1997 og uppgjör ársins 1996. Icelandic Meteorological Offi ce, Report VÍ-G97002-ÚR01.

Jóhannesson, T., J. O. Larsen and J. Hopf. 1998. Pilot Project in Siglufjörður. Interpretation of observations from the winter 1996/97 and comparison with similar observations from other countries. Icelandic Meteorological Offi ce, Report VÍ-G98033-ÚR26.

Jóhannesson, T. 1998. Pilot Project in Siglufjörður. Observations from the winter 1997/98 Icelandic Meteorological Offi ce, Report VÍ-G98050-ÚR37.

Jónsson, G. S. and S. Einarsson. 1998. Greinargerð Hollustuverndar ríkisins um áhrif hugsanlegrar sínkmengunar frá upptakastoðvirkjum. Hollustuvernd ríkisins (Environmental and Food Agency of Iceland), Report GSJ/SE/HVR/16/12/98.

Larsen, J. O. 1982. Snøens sigetrykk mot konstruksjoner i bratt terreng. (Snow creep pressure on constructions on steep slopes). NGI, Report 75420/58110-1.

Larsen, J. O., D. M. McClung and S. B. Hansen. 1984. The temporal and spatial variation of snow pressure on mast structures. *Canadian Geotechnical Journal*, 22(2), 166-171.

Larsen, J. O. and K. Kristensen. 1998. Design criteria for cylindrical masts exposed to snow creep forces. *In* Hestnes, E. *ed. 25 years of snow avalanche research.* Oslo, Norw. Geot. Inst., Rep. nr. 203, 165-168.

Margreth, S. 1990. Schäden in Lawinenverbauungen durch den Orkan "Vivian" vom 27.2.1990. Weissfluhjoch, Eidgenössisches Institut für Schnee- und Lawinenforschung, Internal Report Nr. 662.

Margreth, S. 1995. Snow pressure measurements on snow net systems. ANENA symposium Chamonix, 30.05.1995-03.06.1995.

Margreth, S. 1996a. Schäden in Lawinenverbauungen im Winter 1994/95. Weissfluhjoch, Eidgenössisches Institut für Schnee- und Lawinenforschung, Internal Report Nr. 692.

Margreth, S. 1996b. Querbelastung auf Stützen von starren Werken. Merkblatt (2/96). Weissfluhjoch, Eidgenössisches Institut für Schnee- und Lawinenforschung.

McClung, D. M., J. O. Larsen and S. B. Hansen. 1984. Comparison of snow pressure measurements and theoretical predictions. *Canadian Geotechnical Journal*, 21(2), 250-258.

Norme Française. 1987. Revêtements métalliques. Galvanisation par immersion dans le zinc fondu (galvanisation à chaud). NF A 91-121.

Norme Française. 1992. Equipements de protection contre les avalanches. Filets paravalanches. NF P 95-304.

Norme Française. 1994. Produits sidérurgiques. Aciers pour galvanisation par immersion à chaud. NF A 35-503.

Sigurðsson, Þ., T. Jóhannesson and Þ. Sigurjónsson. 1998. Corrosion of steel and wire constructions under Icelandic meteorological conditions with special reference to steel snow bridges and avalanche nets. Report of observations of supporting structures in Auðbjargarstaðabrekka, Ólafsvík and Siglufjörður and a compilation of relevant information about corrosion protection of steel structures in Iceland. Icelandic Meteorological Office, Report VÍ-G98004-ÚR04.

SIS Förlag AB. 1988. Inorganic coatings - General hot dip galvanizing - Guiding principles and requirements. SS 3583.

APPENDIX: Background and notes

1 On the basis of observations in Siglufjörður and other data on extreme snow density in Iceland and Norway, appropriate dimensioning density for Icelandic conditions for the first and second case of loading as defined in the Swiss Guidelines, may be defined as ρ =420 and 550 kg/m^3, respectively. The corresponding densities in the Guidelines are 270 and 350 kg/m^3, respectively. The ratio between the densities for the first and second case of loading is about 0.77 in order to be consistent with eq. (49) of the Guidelines. Equation (27) of the Guidelines gives 78% higher snow loading for the density 420 kg/m^3 than for 270 kg/m^3, when changes in the creep factor K with density as specified on p. 37 of the Guidelines are taken into account. In order to take this higher density of snow in Iceland into account, the gliding factor N, therefore, needs to be increased by a factor of 1.78 in eq. (48.1) and also in all other equations, which are derived from eq. (27) in the Guidelines and based on an explicit choice of the density 270 kg/m^3.

In addition to the increased load due to the higher density in eq. (27), a higher density leads to an increased load due to the increased weight of the snow directly supported by the construction as described by eq. (48.4) and in section 55 of the Guidelines, which are based on an explicit choice of the densities 270 kg/m^3 (eq. (48.1)) and 300 kg/m^3 (sect. 55.4). An additional load increase also arises from the effect of the implicitly assumed value of the density in eq. (48.2). These effects are both smaller than the effect of the higher density through eq. (48.1) and are taken into account by increasing the gliding factor N by a factor of slightly more than 2 rather than by 1.78, *i.e.* from the value 1.2, which corresponds to a low gliding situation in Switzerland, to 2.5, which is adopted for a low gliding situation in Iceland.

2 The assumption $\eta = 1$ in eq. (58) of the Guidelines implies that the snow pressure on net posts is given by the depth averaged snow pressure on the construction applied over the width and length of the post. 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 depth averaged snow pressure acting over the area corresponding to the width and length of the mast (Larsen, 1982; Larsen and Kristensen, 1998). The measurements from Norway are not directly applicable to snow net posts because of the shielding effect of the net mesh which may be expected to reduce the moment loading of net posts compared with free standing masts.

Backcalculations of moment loading of damaged supports of snow bridges in Switzerland after the winter 1994/1995 have indicated higher loads than specified by the Guidelines (Margreth, 1996a). A higher value of η in eq. (58) of the Guidelines has therefore recently been proposed such that $\eta = 2$ for $N = 2.5$ and $\eta = 5$ for $N = 3.2$ (Margreth, 1996b). The forces indicated by the backcalculations for snow bridges arise from the pulling of snow cover below the bridges.

Lateral forces on snow net posts arise partly from the pulling of the snow cover below the nets in the same way as for snow bridges, as described above, and partily from snow pressure due to the snow cover above the nets when the snow glides through the net mesh. Strain measurements on a net post in Siglufjörður in the winter 1997/1998 yield a moment load which is about three times the moment load given by eq. (58) of the Swiss Guidelines (Jóhannesson, 1998), even when the high density of the snow in Iceland has been taken into account. Preliminary analysis of measurements from Siglufjörður from the winter 1998/1999 indicates a somewhat lower moment loading relative to the compressive loading of the net post. These observations indicate a similar ratio been observed loading and the predictions of eq. (58) of the Swiss Guidelines as has been found for supports of snow bridges in Switzerland as described above.

The choice $\eta = 3$ for Iceland is made in order to reach a similar ratio between the measured load and the dimensioning load for the moment as for other loads measured in Siglufjörður for which this ratio is approximately in the range 1-2. The Swiss backcalculations and the Icelandic measurements indicate that the same value of $\eta = 3$ is appropriate for both snow net posts and for supports of snow bridges.

Traditional snow nets of a French design, which were installed in Auðbjargarstaðabrekka, northern Iceland, and in Ólafsvík, western Iceland, in 1984 and 1985, have suffered structural damages due to heavy snow loads (Sigurðsson, Jóhannesson and Sigurjónsson, 1998). The nets have repeatedly been buried and heavily loaded. Some of the net posts have failed in the downslope direction below the middle of the post. This indicates that moment loading contributed to the failure, in combination with compression along the post. This type of failure may be related to the fact that the French standard NF P 95-304 for snow nets does not specify a lateral loading of net posts due to snow pressure.

Posts of snow bridges were damaged in Switzerland in the winter 1994/1995 due to lateral loads as mentioned above (Margreth, 1996a,b), and moment loading requirements have since been proposed for snow bridges on high gliding slopes (Margreth, 1996b). No moment loading is required on low gliding slopes, *i.e.* for $N < 2.5$ in this proposal. For Icelandic conditions, a moment load with $\eta = 1$ is specified for posts of snow bridges in spite of the low gliding expected under Icelandic conditions.

3 Ground plates have worked well as foundations for both snow bridges and snow nets in Siglufjörður under heavy loads, both for loose material and for solid bedrock.

4 As background for the requirement regarding micropiles in loose material, which is a departure from the Swiss Guidelines, it may be noted that some micropiles of net posts in Siglufjörður in loose material failed during the first winter of the experiment. This was repaired in the fall of 1997 by replacing the failed micropiles with ground plates. Although mistakes were made in the installation of the micropiles that failed, it is likely that the connection of net posts with micropiles needs a substantial lateral stiffness in order to withstand the lateral load due to uneven loading of the nets and to unavoidable differences between the direction of the post and the micropile. Concrete socles are usually required for micropile/anchor foundations of snow nets in loose material because the earth material does not provide sufficient lateral stiffness. The connection between micropile/anchor foundations and upper structures of steel bridges is usually stiff enough so that no additional concrete socles are necessary.

5 The wind pressure in kPa is computed according to the formula $P = c_D(g/16)v^2$, where c_D is a form factor, g is the acceleration of gravity and v is wind speed. We adopt $v = 70$ m/s for the wind speed based on extreme gusts which have been measured on exceptionally windy locations on mountains in Iceland.

As background for the requirement regarding loading due to wind pressure, which is not made in the Swiss Guidelines, it may be noted that some of the snow bridges in Siglufjörður were damaged in a storm shortly after the installation of the structures in the fall of 1996 (Jóhannesson, Larsen and Hopf, 1998). Wind damages of supporting structures occurred at several locations in Switzerland in a storm on February 27, 1990 (Margreth, 1990), and have also occurred on several other occasions (Margreth, personal communication).

6 Steel parts above ground are not hot dip galvanised according to the Swiss Guidelines. Earlier versions of the Guidelines (EISLF, 1968, section 44.7) specified a 0.5 mm tolerance on each side of steel parts due to corrosion if the steel parts are not hot dip galvanised. This requirement has been abandoned in the current version of the Guidelines (EISLF, 1990). Measurements have shown that corrosion of steel parts in supporting structures in Austria has not reduced the steel thickness over a time period of about 50 years by more than the expected thickness variations in

the manufacturing of the parts (Frutiger, 1961). Observations of girders and posts from supporting structures in Switzerland indicate that these steel parts are in good shape after about 30 years (Margreth, personal communication, the information is from a report from the Swiss Federal Institute for Materials Testing and Research from 1983).

Corrosion of black steel may be expected to be substantially higher in the wet maritime Icelandic climate than in Alpine countries, in part due to airborne salt carried by winds from the ocean (Sigurðsson, Jóhannesson and Sigurjónsson, 1998). First year corrosion rates of test plates in the test area in Siglufjörður have been measured to be 16 μm pr. year, which is 50-75% of first year corrosion rates measure near sea level in southwestern Iceland. Long term corrosion rates may be expected to be lower by a factor of approximately one half or more compared with the measured rates of the first year. Over a time period of 50-100 years, corrosion may thus be expected to reduce the thickness of steel parts by on the order of 0.8-1.6 mm. This is a sufficiently high rate of corrosion to justify the galvanisation of all steel parts above ground in supporting structures in Iceland (Sigurðsson, Jóhannesson and Sigurjónsson, 1998).

The Swedish standard SS 3583 has three different coating classes, A, B and C, as given in the following table for steel thickness over 6 mm.

Table A1: Swedish standard SS 3583 for hot dip galvanisation of steel with thickness over 6 mm.

Class	Minimum local zinc thickness (μm)	Average zinc thickness (μm)
A	85	95
B	100	115
C	190	215

In later years, coating according to class B has usually been required in Iceland.

Steel parts of French supporting structures are hot dip galvanised according to the French standards NF A 91-121 and NF A 35-503 which specify a coating thickness of 70 μm for high quality steel. It should not be a problem to increase this thickness to the 100/115 μm required here.

Zinc pollution of ground water from hot dip galvanised supporting structures has been mentioned as a possible argument against requiring hot dip galvanisation of snow bridges. The Environmental and Food Agency of Iceland has investigated this potential problem and found that zinc pollution from hot dip galvanised supporting structures will not lead to a violation of the quality standards for ground water quality in Iceland (Jónsson and Einarsson, 1998).

7 Corrosion of subsurface steel parts depends very much on local ground conditions. Under unfavourable conditions, corrosion of black subsurface steel parts in Iceland has been inferred to exceed 200 μm pr. year over decades (Pétur Sigurðsson, personal communication).

8 According to (CEB, 1992), the time required for developing a full bond between steel and concrete is usually longer for galvanised bars, but the bond always reaches the level prescribed by standards.

9 This reduction in the permissible bond stress is taken from the German standard CEB (1995).

10 Snow nets installed in Ólafsvík, western Iceland, in 1985 were severely damaged from corrosion after 12 years. There are clearly visible signs of corrosion in snow nets in Auðbjargarstaðabrekka, northern Iceland, which were installed in 1984. Signs of corrosion became visible

on wires in the experimental installation of snow nets in Siglufjörður in less than one year (Sigurðsson, Jóhannesson and Sigurjónsson, 1998).

11 The following table lists several wire rope types which may be expected to have an adequate corrosion protection for conditions in Iceland.

Table A2: Recommended steel wire ropes with a traditional hot dip galvanisation.

Rope diameter mm	Type	Diameter of wires	Zinc coating (g/m^2)	Zinc coating (μm)
8-10	1x19	1.6-2.0	240	34
15-16	1x37	2.1-2.3	250	36
18-22	7x19	1.2-1.5	210	30

The recommendations in the table are derived from standards and work practices that are currently in use in Iceland for the construction of electrical power lines and for other constructions in the Icelandic highland as further described by Sigurðsson, Jóhannesson and Sigurjónsson (1998).

12 Such contact points between hot dip galvanised wire ropes and stainless clips do not seem to have caused problems in the traditional type of snow nets from the French manufacturer EI, which were installed in Iceland in 1984 and 1985. These nets include numerous small stainless steel clips in contact with hot dip galvanised wire ropes. One may expect contact points between Al-Zn corrosion protection and stainless steel to be no worse with respect to localised corrosion than contact points between hot dip galvanisation and stainless steel (Pétur Sigurðsson, personal communication).

13 As background for the requirement regarding tightening of nuts with washers, double nuts or other means, which is not made in the Swiss Guidelines, it may be noted that many nuts in the snow bridges in Siglufjörður became loose during the first months after the installation of the structures in the fall of 1996. This presumably happened due to vibrations induced by wind forces. Several nuts became completely loose and were found on the ground below the structures. The nuts were retightened as a part of repairs of the structures after wind damages that happened in the fall of 1996 (see point 5 above) and a second nut was added on each bolt in order to prevent the nuts from becoming loose again.

14 A new building code adopted after 1990 in Switzerland specifies a safety factor of 1.65 (Margreth, personal communication). This change from the previous value of 1.6 is too small to justify a special requirement for supporting structures in Iceland.