Veðurstofa Íslands
Report

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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

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CONTENTS

SUMMARY

Suitable corrosion protection for supporting structures in Iceland has been evaluated by an analysis of existing steel bridges and snow nets and a comparison of their corrosion protection with standards and work practices that are currently in use in Iceland.

It is recommended that steel bridges and solid steel parts of snow nets, including the subsurface parts of anchors and micropiles, are hot dip galvanised according to the standard SS-3583, class B. Experience from electrical power lines in Iceland indicates that the life time of steel constructions, hot dip galvanised according to this standard, is at least 50 years. For steel bridges, this leads to a cost increase on the order of 10% compared with black steel structures which are traditionally used in Alpine countries. Increasing the thickness of steel parts in order to compensate for the expected thinning due to corrosion is not an economic alternative compared to hot dip galvanising.

The corrosion protection of current snow nets, which are made of hot dip galvanised steel wire ropes, needs to be substantially improved for Icelandic conditions. It is estimated that snow nets with the current design have a life time of only 10-20 years in many locations in Iceland. Twelve year old snow nets in Ólafsvík, western Iceland, are severely damaged from corrosion and there are visible signs of corrosion on wires in a less than one year old experimental installation of snow nets in Siglufjörður, northern Iceland. Possible improvements of the corrosion protection of snow nets are currently under investigation by some manufacturers.

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. About 200 m of supporting structures, both stiff steel constructions and snow nets, have been installed for experimental purposes in Hafnarfjall above the village Siglufjörður in northern Iceland. The project is financed by the Icelandic Avalanche Fund.

A part of the pilot project is a study of suitable corrosion protection for supporting structures and an evaluation of the current design of the structures with regard to corrosion. For this purpose, the structures in Siglufjörður together with older snow nets in Ólafsvík, western Iceland, and Auðbjargarstaðabrekka, north-eastern Iceland, have been analysed and their corrosion protection compared with standards and work practices that are currently in use in Iceland. The results of this analysis are compiled in this report. In addition, corrosion protection standards and current work practices for reducing corrosion are described together with general background information about corrosion under Icelandic conditions. The report is intended to be useful for producers of supporting structures who are planning product development for Icelandic conditions and it will be the basis for corrosion protection recommendations for supporting structures which will be adopted by Icelandic authorities in the future.

2. BACKGROUND

2.1 Maritime wet climate

The corrosion of metals depends on several factors, *i.e.* the wetting time, the chemistry of the precipitation and the temperature. Corrosion conditions in the atmosphere in Iceland are different from most other neighbouring countries.

- Iceland is surrounded by the sea and it is located in the middle of the main path of low pressure areas passing across the North Atlantic Ocean. This leads to a rainy and windy temperate climate.
- The average relative humidity in Iceland is typically around and in many cases higher than 80% (Einarsson, 1976). This causes metal surfaces to be covered by a wet film essentially all the time.
- As a consequence of strong and frequent winds and the closeness of the ocean, the concentration of airborne salt particles in the atmosphere is much higher in Iceland than in most neighbouring countries (see further below).
- The average yearly temperature in lowland areas in Iceland varies from 3-4 °C in northern parts of the country to 4-5 °C in the western, southern and eastern parts, with higher values in the range 5-6 °C at a few locations (Einarsson, 1976). Average temperatures in January are typically in the range -2 to 0 °C and in July in the range 9-12 °C. Starting zones of avalanches that threaten inhabited areas in Iceland are most often in the altitude range 300-700 m a.s.l. The rate of decrease of the temperature with altitude may be assumed to be about 0.6 °C per 100 m.

Corrosion handbooks provide guidelines about corrosion arising from the combination of different metals in constructions, *e.g.* the ASM Handbook, volume 13 (ASM, 1987). Such guidelines do not always apply in Iceland due to the abundance of salt particles in the air caused by winds from the ocean, the high salt content of precipitation and the long wetting time. As an example, the use of stainless steel fasteners for steel and aluminium is recommended in Europe but has caused serious problems in Iceland.

2.2 Chemical composition of precipitation

The chemical composition of precipitation in Iceland differs from location to location. This is mainly due to differences in the amount of airborne salt from the ocean, which is at a maximum along the south and south-western coast of the country. This part of the country also experiences the longest wetting times. In a corrosion test performed in Þorlákshöfn on the southern shore of the Reykjanes peninsula in south-western Iceland in 1984-1988, the salt content in the precipitation at the test location was about 50% higher than in Reykjavík and about 90% higher than at Írafoss south of Þingvellir which is only about 30 km north-east of Þorlákshöfn (Rb, 1986; Pétur Sigurðsson, unpublished information).

The following table list the results of chemical analyses of precipitation at the meteorological stations in Reykjavík and Írafoss south of Þingvellir for the time period 1992-96 (IMO, Jóhanna M. Thorlacius, unpublished measurements). Precipitation and humidity are given in the table in addition to the chemical concentrations for Reykjavík, but humidity measurements were not available for Írafoss. These results confirm earlier measurements from Reykjavík and Írafoss from the years 1984-85 (*cf.* Rb, 1986).

Table 1: Average chemical composition of precipitation at Reykjavík and Írafoss 1992-1996[1].

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Reykjavík													
Precip. (mm)	63	88	85	46	51	49	47	53	64	51	107	97	799
Humidity (%)	77	77	77	71	76	78	79	82	81	79	78	77	78
Acidity. (pH)	6.0	6.1	6.1	6.3	6.1	5.9	5.7	5.8	5.9	6.0	6.1	6.2	6.0
Na (mg/l)	20.5	9.2	11.1	6.8	3.0	2.3	1.4	1.2	4.0	13.2	12.4	6.7	8.3
Cl (mg/l)	36.9	16.3	19.9	11.7	5.0	3.7	2.2	2.0	6.8	23.4	21.8	12.0	14.7
SO_4 (mg/l)	6.41	3.13	3.90	3.47	3.34	2.75	2.81	2.54	3.01	5.61	4.17	2.56	3.64
Írafoss													
Precip. (mm)	186	160	185	106	114	143	111	159	171	149	171	204	1861
Acidity. (pH)	5.5	5.7	5.4	5.7	5.4	5.4	5.6	5.4	5.4	5.2	5.6	5.9	5.5
Na (mg/l)	6.4	5.4	5.4	1.9	1.8	0.8	0.6	0.5	1.5	4.2	6.0	2.9	3.3
Cl (mg/l)	11.5	9.8	9.6	3.5	3.2	1.4	1.6	1.0	2.5	7.1	10.2	5.3	6.0
SO_4 (mg/l)	1.98	1.90	1.68	2.36	1.15	0.59	1.43	0.36	0.71	1.48	1.67	0.98	1.34

The cloride content of groundwater in Iceland is believed to be mainly of marine origin (Sigurðsson and Einarsson, 1988). The cloride content of groundwater in Iceland is measured to be about 10 ppm in coastal areas around the country with the highest concentrations along the south-western coast reaching up to 50 ppm on the outer part of the Reykjanes peninsula (*cf.* Sigurðsson and Einarsson, 1988, Fig. 5). The cloride concentration decreases to a minimum below 2 ppm in the central highland. The ground water is enriched in cloride by 30-40% compared to the precipitation in coastal areas due to evapotranspiration. The measured concentration of cloride in groundwater around the country is therefore in general agreement with the results of the chemical analyses for Reykjavík and Írafoss listed in Table 1.

Accumulation of salt on insulators of high voltage power lines in Iceland has been monitored by "Rafmagnsveitur ríkisins" (Árni Jón Elíasson, personal communication) at Írafoss south of Þingvellir approximately 25 km from the ocean, at Hrauneyjafoss, which is approximately 80 km from the

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[1] The averages of the chemical compositions in the table are weighted with the precipitation. Data from January 1992 from Reykjavík were not available. The derived values for January are therefore based on the period 1993-1996 only.

ocean on the southern central highland, and at Svartárkot, which is approximately 75 km from the ocean on the northern central highland. The salt accumulation is measured both regularly on fixed days of the week and also (on different locations) after particularly severe winds that carry salt from the ocean. Typical salt concentrations are about 0.03 g/m^2 with higher values between 0.1 and 0.5 g/m^2 often observed after heavy winds from the ocean. The salt concentrations at Hrauneyjafoss and Svartárkot are lower than at Írafoss due to their location further away from the shore. These measurements demonstrate the importance of wind transported salt from the ocean.

2.3 Industrial pollution

In spite of the sparse population of Iceland there is some industrial pollution that can give rise to corrosion. The aluminium smelter ÍSAL at Straumsvík on the south-western coast gives away SO_2 which corrodes metals. SO_2 is specially known as a corrosive agent for zinc. The capacity of the ÍSAL plant has recently been increased by 60% and a new aluminum plant is under construction at Grundartangi in western Iceland.

Geothermal steam increases the corrosion of metals, especially zinc, in several areas in Iceland.

2.4 Corrosion standards

As a consequence of the long wetting time, the abundance of wind born salt particles and the high salt content of the precipitation, Icelandic institutions and organisation have adopted rather strict work practices for corrosion protection of steel and wire rope constructions which are intended to last for a long time. Standards for corrosion protection have been adapted from foreign standards, mainly of Swedish, Danish and German origin as further described below, but formal Icelandic requirements or standards have not been issued by official institutions. Rather, it has been the responsibility of each institution or organisation to decide on an appropriate corrosion protection for its constructions.

3. OBSERVATIONS OF STEEL CORROSION IN ICELAND

The only corrosion test of steel and zinc that has been performed in Iceland was carried out in Reykjavík and Þorlákshöfn during the period 1984 to 1988 (Rb, 1986). The results are shown in Figures 1 and 2 (accumulated corrosion from the start of the experiment) and in Table 2 (incremental corrosion for each of the three years).

3.1 Direct measurements

Table 2: Rate of corrosion of steel and zinc in Reykjavík and Þorlákshöfn, 1984-1988.

	1st year	2nd year	3rd year
Steel			
Reykjavík	21 μm	12 μm	13 μm
Þorlákshöfn	33 μm	26 μm	22 μm
Zinc			
Reykjavík	1.2 μm	0.6 μm	0.8 μm
Þorlákshöfn	1.7 μm	1.0 μm	0.8 μm

As expected, the corrosion rate decreases with time. This is due to the formation of a corrosion layer on the surface which prevents corrosion agents from reaching the metal surface. A further decrease in the corrosion rate of steel may be expected after longer time has elapsed (*cf.* the ISO/DIS 9224 standard), but the experiments in Reykjavík and Þorlákshöfn were not continued long enough for this to be observed. A further decrease is, however, not expected for zinc according to the same standard.

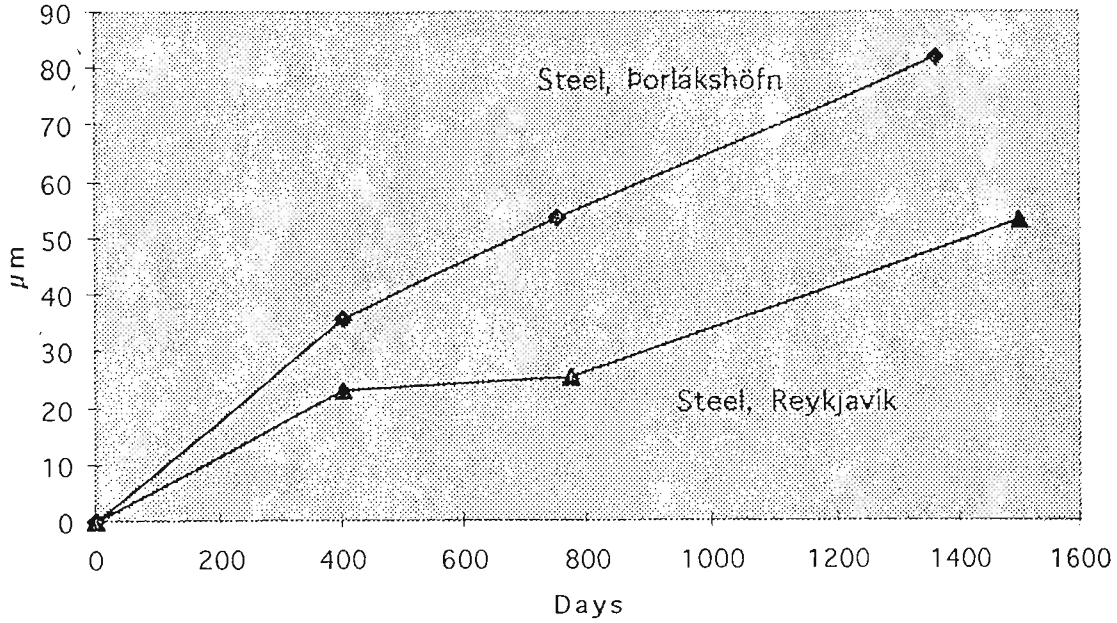

Figure 1. Steel corrosion in Reykjavík and Þorlákshöfn, 1984-1988.

The rate of corrosion of a protective zinc layer on wire ropes depends on the thickness of the wires (Slunder and Boyd, 1986; Mears, 1933). Thus, the rate is measured to be about 4 times higher on wires with a diameter of 0.5 mm than on wires with a diameter 12.5 mm, for which the corrosion rate is almost the same as for a flat zinc surface.

In addition to the experiments in Reykjavík and Þorlákshöfn, several inspections have been carried out on hot dip galvanised steel ropes and steel structures in electrical power lines. Severe corrosion problems have been observed in galvanised guy wires in an electrical power line in an especially windy location near the ocean in western Iceland after 10-12 years. The wires had a zinc thickness of 26-29 μm according to specifications. Severe problems have also been observed in galvanised snow nets in Ólafsvík in western Iceland, with specified zinc thickness of about 4 μm, after less than 10-12 years, and in galvanised rock fall nets near the ocean in Vestfirðir with a specified zinc thickness of about 4 μm after less than 6-7 years. Zinc measurements of 13 year old wires from Auðbjargarstaðabrekka and less than one year old wires from Siglufjörður, which are of the same type as the above wires in Ólafsvík and Vestfirðir, yield a zinc thickness of about 7 μm. The initial zinc thickness of the wires from Ólafsvík and Vestfirðir may therefore have been higher than the 4 μm which are specified in the standard quoted by the manufacturer.

The onset of corrosion has already been observed in parts of hot dip galvanised wires in snow nets in Siglufjörður less than one year after the installation of the structures (see photograph 7 at the end of the report). The initial zinc thickness of these wires was not measured, but according to specifications from the manufacturer it should have been be 8-9 μm. This indicates that significantly higher rates of zinc corrosion, than quoted above, can occur at individual locations within the constructions, or that there are local differences in the initial thickness of zinc on the wires beyond the specifications of the manufacturers.

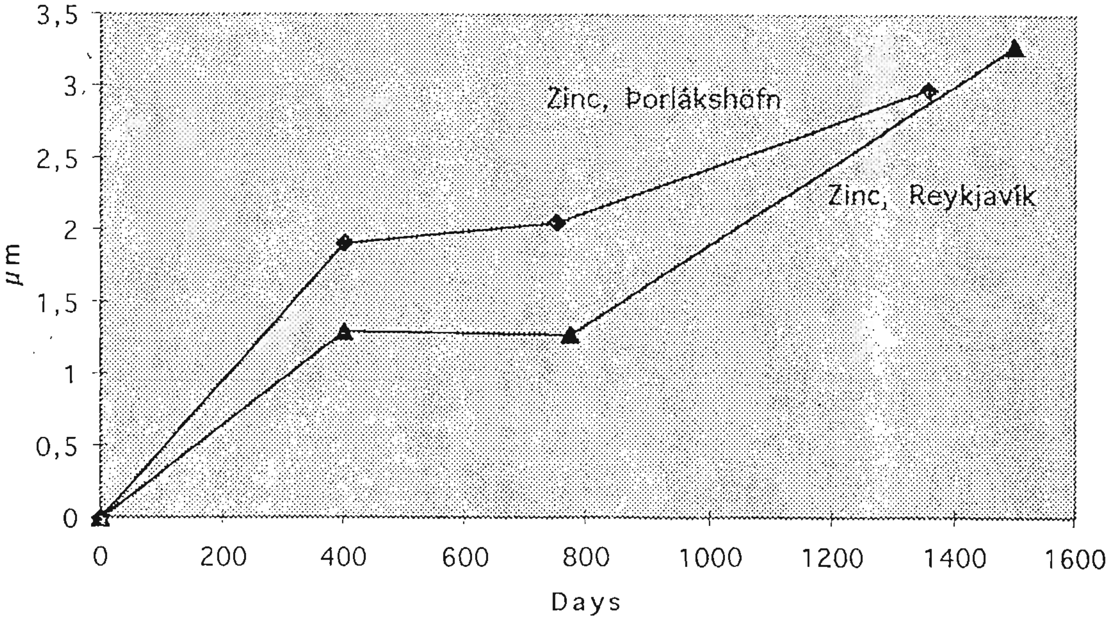

Figure 2. Zinc corrosion in Reykjavík and Þorlákshöfn, 1984-1988.

3.2 Steel structures in electrical power lines

All steel parts in electrical power lines in Iceland are hot dip galvanised. They are in general not painted on top of the galvanisation, except for repairing damaged galvanisation. The oldest distribution lines are for the most part built in 1957-1960. No measurements of the initial zinc thickness are available, but according to the tender documents, zinc thickness of 90 μm and 65 μm was required for steel thickness above and below 4.76 mm, respectively. With the exception of Sogslína II, significant corrosion has not been observed in these lines for the almost four decades since their construction. Current requirements for power lines in Iceland are based on the Swedish standard SS-3583, class B, which specifies an average zinc thickness of 115 μm for steel thickness over 6 mm (see below). The experience from the electrical power lines indicates that the life time of steel constructions, hot dip galvanised according to current standards, is at least 50 years.

3.3 Painted steel structures in bridges and light poles

Most steel bridges built before 1990-1995 were only sandblasted and painted. Some of these bridges have been repainted, but others have not been repainted, especially bridges located away from the ocean, and have lasted for many decades without serious corrosion problems. Experience with sandblasted and painted steel constructions in Iceland indicates that, as a general rule, the need for repainting becomes urgent after 10-20 years, *i.e.* the corrosion protection provided by the painting is no longer effective after this time period. The corrosion problem that arises, after the protection of the paint is over, depends on the individual location. One may assume that in most cases, except in especially sheltered inland locations, the rate of corrosion of steel surfaces after the painting has disappeared will be similar as observed in the corrosion experiments in Reykjavík and Þorlákshöfn described above.

Steel parts in some of the most recent bridges in Iceland have been both hot dip galvanised and painted unless the parts are too large for hot dip galvanisation. Light poles for the road Reykjanesbraut between Reykjavík and Keflavík, which were installed in 1996, were also both hot dip galvanised and painted. Such structures are so recent that no direct experience about their durability is available.

3.4 Galvanised steel wires

In general, the experience in Iceland with hot dip galvanised guys made of 7 or 19 wires is good, when the diameter of individual wires is in the range of 2.44 mm to 4.80 mm.

Guys in transmission lines, mostly built in 1970-1984, are in good condition, with few exceptions. Rope made of 6x36 Warrington seale, with diameter of outer wires 1.20 mm had to be replaced after 10 to 12 years, but only on towers located in an especially windy location near the sea.

Guys in distribution lines, mostly built in 1957-1960, with 7x3.08 mm wires, are still in use. In many cases the guys have been replaced at tower sites located near the sea, and also at sites far from the sea where the handling of wires has been incorrect, especially with far too sharp bends or even where the wires have been tied as done with nylon ropes, instead of using u-bolt clips or other appropriate fastening methods. These almost 40 years old wire ropes, not placed near the sea, have in many cases a brownish look, *i.e.* some rust has formed, but the strength of the wire is only slightly decreased.

U-bolt clips, used for fastening the guys in the distribution lines, are usually zinc plated, but not hot dip galvanised as they should be, and become rusty in 1-3 years. In some cases this can start rusting of the guy wires.

4. STANDARDS AND WORK PRACTICES ADOPTED IN ICELAND

4.1 Galvanisation of steel beams

The common work practice in Iceland is to hot dip galvanise all steel beams for outdoor use, in particular all steel parts in electrical power lines are hot dip galvanised.

The most used galvanisation standard in Iceland is the Swedish standard SS-3583, but the standards ISO 1460 and the German standard DIN 55928, part 5, are also sometimes used. The German standard requires only about 90 μm average zinc thickness. The Swedish standard has three different coating classes, A, B and C, as given in the following table for steel thicknesses over 6 mm.

Table 3: 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.

As described in the previous section, experience indicates that steel parts hot dip galvanised according to this standard have a life time of over 50 years in most areas in Iceland.

4.2 Painting of steel beams

Sandblasting and painting of steel constructions as the only corrosion protection is in general not recommended under Icelandic conditions when hot dip galvanisation is possible.

A very small proportion of hot dip galvanised steel parts in bridges and light poles have been both hot dip galvanised and painted as mentioned above. The most likely reason for the limited use of this protection method is the cost increase, in spite of the fact that the life time of steel structures will increase by more than double if they are painted after galvanising. The life time of a steel structure that is both hot dip galvanised and painted can be estimated as $K * (G+P)$ where G is the life time of galvanised steel and P is the life time of painted steel. K is a factor that is believed to be in the range 1.5-2 depending on the location of the structure. If, for example, the life time of the zinc coating of galvanised steel is 30 years and the life time of a paint coating of bare steel is 20 years then the life time of the duplex system may be estimated as $K * (30+20) = 75\text{-}100$ years.

4.3 Galvanisation and structure of steel wires

Except for use in ships and cranes, the main use of steel wire ropes or cables in Iceland is in guys for transmission line towers. The structure of the ropes is, with very few exceptions, ordinary cross lay stranded of round hot dip galvanised steel wires.

In most cases, the wire and cables do comply in all respects with the requirements of the German Standards DIN 2078 and 3051, and the zinc coating with DIN 1548, heavy galvanising ("dickverzinkung").

The main part of the distribution lines in Iceland is built in the years 1957-1960. Guy-ropes in these lines are in most cases made of 7x3.08 mm wires, with zinc amount 260 g/m^2 (37 μm), and in some cases 7x2.44 mm, with zinc 250 g/m^2 (36 μm), with steel grade 1370 MPa or less.

Most of the transmission lines, 66-220 kV, are built in the period 1970-1984. The range of wires in these lines is 7x(2.44 to 3.90) mm and 19x(2.70 to 4.80) mm, with zinc 250-290 g/m^2 (36-41 μm). Steel grade is 1370 and 1570 MPa.

The only exception from this is the 220 kV Brennimelslína I, built in 1977, where the guys are made of 6x36 Warrington seale + IWRC[1], diameter 22 and 24 mm, with diameter of outer wires 1.20 and 1.40 mm, and a specified zinc thickness of 26-29 μm. These wires needed to be replaced after 10-12 years at some locations as mentioned above.

4.4 Corrosion protection of anchors

Anchor rods are made of round bars, 18-36 mm in diameter. Steel quality St 52-3N according to DIN 17100. The rods are hot dip galvanised, with minimum zinc thickness 100-115 μm (700-800 g/m^2) on a flat surface and 44-53 μm on threaded parts. The lower values correspond to a local minimum, but the higher values to an average. In loose soil, the anchor rods are fastened by anchor plates, made of precast concrete. From the year 1980, anchoring to rock has been made with rock bolts. The rock bolts are made of ribbed round bars (same as used for reinforced concrete structures), with yield strength 400 MPa until 1996, but 500 MPa now. In most cases the guy rope, the anchor rod and the rock bolt all lie on the same line, that is have the same direction.

Rock bolts in distribution lines are 16 and 20 mm x (1500-2000 mm). Rock bolts in transmission lines are 20 mm x (1500-2000 mm), 25 mm x 2000 mm, 32 mm x (1700-4000mm) and 4x20mm x (4500 and 6000 mm). Rock bolts are always hot dip galvanised, with minimum zinc thickness 100-115 μm. The rock bolts are fastened by cement grout, where the diameter of bore hole is 32 mm for 16-25 mm bolts, 63 or 75 mm for the 32 mm bolt and 75 mm for the 4x20 mm bolt.

4.5 Bolts, nuts, washers and shackles

For outdoor use these are in most cases hot dip galvanised in electrical power lines, but sometimes made of stainless steel. To secure fastening of the nut, a spring lock washer is used on bolts with steel grade less than 8.8 acc. to DIN 267, but with defined prestress (torque) of bolts with higher steel grade. Two nuts, or nut and split pin are used, in cases where it is not possible to tighten

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[1] IWRC = Independent Wire Rope Core.

the nut sufficiently. Zinc thickness is the same as for anchor rods.

5. POLLUTION FROM GALVANISATION OF SUPPORTING STRUCTURES

The question of possible zinc pollution arising from galvanisation of supporting structures has come up in discussions with producers of such structures. One may estimate the order of magnitude of this pollution by observing that the total area of galvanised steel surfaces in a starting zone where supporting structures have been installed is about 30% of the total area of the zone, both for stiff steel constructions and for snow nets. If it is assumed that the corrosion of zinc proceeds at the rate indicated in Table 2, *i.e.* a rate on the order of 1 μm per year, then one may estimate the inflow of zinc to the ground to be about 2 g/m^2/year.

Typical values of precipitation in the starting zones in question are 1000-2000 mm/year. The concentration of zinc in the ground water flowing from such a starting zone may therefore be estimated to be on the order of 1-2 ppm if no dilution by inflow of ground water from adjacent areas is present. In reality, supporting structures will be constructed in localised areas within larger mountain slopes and a dilution by a factor in the approximate range 4-20 may be expected before the water flows into neighbouring areas below the slope of the mountain (based on preliminary ideas about possible layout of supporting structures on a large scale on the slopes above Neskaupstaður and Siglufjörður). One may therefore estimate zinc pollution of ground water arising from supporting structures in starting zones to be on the order of 0.05-0.5 ppm. Standards from the European Union (80/778/EEC) specify the guide level 0.1 mg/l (mg/l is the same as ppm in this case) for the concentration of zinc in water for human consumption. No explicit maximum allowable limit is, however, defined. Higher levels up to 5 g/l are specified for the concentration of drinking water after some storage time in pipes in water distribution systems. The Recommended Dayly Allowance of zinc in Iceland is 7 mg for women and 9 mg for men and research has shown that the average zinc consumption of Icelanders reaches this recommended amount. The Recommended Dayly Allowance in the U.S.A. is 15 mg for both sexes. Assuming a water consumption of about 2 l, the addition in human zinc intake, caused by a 0.05-0.5 ppm zinc concentration in drinking water, is therefore not very high relative to zinc intake from other sources. Zinc pollution has, furthermore, not prevented large scale installation of hot dip galvanised snow nets in Switzerland, Italy and France. Nevertheless, the fact that the estimated zinc pollution from a starting zone with galvanised supporting structures may be as high or higher than the guide level of the EU, indicates that this matter should be studied further before large projects involving galvanised supporting structures are initiated.

6. LIFE TIME OF SUPPORTING STRUCTURES

An "appropriate" life time for supporting structures is a question of balancing the value of a higher initial construction cost due to corrosion protection with the resulting economic gain due to lower maintenance costs. Since a higher yearly maintenance cost may be compensated by a lower initial construction cost, it is not possible to derive a single estimate of an appropriate life time for supporting structures. A possible way to approach this question is to add to the initial construction cost the present value of the required maintenance costs over a fixed interval. An important aspect of the maintenance of supporting structures is that they are typically installed in locations which are difficult to access. Maintenance therefore tends to be relatively costly and larger initial costs in order to prevent later maintenance are likely to be more economical than for constructions in more easily accessible locations.

In the following discussion we will for simplicity omit yearly maintenance, for example due to damages by rock fall and small debris flows, and focus on large scale replacements of the main construction when its strength has been significantly reduced by corrosion. For snow nets, it will be assumed that inner nets and ropes will need to be replaced after a certain period whose length depends on the quality of the corrosion protection of the wires, whereas posts and anchoring could be used for a much longer period. The cost arising from the total replacement of all nets and ropes in the construction may be estimated to be about 50% of the original project cost (sum of original cost of material and installation). The present value of repeated replacements of this kind may be estimated as

$$R = rC\sum_{n=1}^{k}(1+i)^{-(l_w n)} = rC(1-(1+i)^{-N})/(1-(1+i)^{-l_w})/(1+i)^{l_w} \quad ,$$

where $r = 50\%$ is the replacement cost relative to the construction cost, C is the construction cost, l_w is the life time of the wires, k is the number of life times in the time span which is adopted for the summation, *i.e.* $N = l_w k = 50$ years, and $i = 0.06$ is the interest rate for the present value computations. The values adopted for r, N and i lead to a present value of the replacement cost equal to 29%, 14% and 3% of the original construction cost for life times of one third, one half and equal to the adopted time span of 50 years. Therefore, snow nets that require replacement of all nets and ropes every 10-20 years should be assumed to be on the order of 25%.more expensive than the initial project cost when compared to more durable constructions that do not need such maintenance.

Similarly, increasing the life time of stiff black steel constructions from say 25 years to over 50 years by hot dip galvanisation or by adding an extra layer of approximately 0.5 mm to the thickness of the posts and beams may be assumed to increase the present value of the construction by approximately 10%.

The above considerations indicate that there is significant economic gain associated with increasing the life time of supporting structures beyond 25 years, perhaps to 50 years, and conversely that there is very significant economic loss associated with the use of structures with shorter life times than 25 years.

7. SUMMARY OF OBSERVATIONS OF EXISTING SUPPORTING STRUCTURES IN ICELAND

7.1 General

Supporting structures have been built at three locations in Iceland, *i.e.* in Auðbjargarstaðabrekka, north-eastern Iceland, in Ólafsvík, western Iceland, and in Siglufjörður, northern Iceland. The lengths and types of the structures are given in the following table.

Table 4: Supporting structures in Iceland.

Location	Type	Producer	Length (m)	Number of posts	Height (D_k, m)	Installed
Auðbjargarstaðabrekka	nets	EI	33	10	3	1984
Ólafsvík	nets	EI	184	54	3	1985
Siglufjörður	bridges	J. Martin	110	38	3-5	1996
Siglufjörður	nets	Geobrugg	50	14	3-4	1996
Siglufjörður	nets	EI	41.5	15	3-4	1996

The structures in each location were examined by the corrosion work group and the structure and condition of wires and other components of the constructions were catalogued. Zinc thickness on flat surfaces on a number of galvanised steel parts was measured in the field. Zinc thickness of several samples from wire ropes of different types was measured in the laboratory. Current and previous damages of foundations and of the supporting constructions were described. The observations were recorded on special forms or check lists and they are summarised in the following sections. An example of the check lists is shown in Appendix A.

7.2 Snow nets in Auðbjargarstaðabrekka

The nets in Auðbjargarstaðabrekka are the first supporting structures which were built in Iceland (photograph 1). They were installed by the Icelandic Road Administration in order to reduce the frequency of avalanches on the road along the coast between the fjords Skjálfandi and Öxarfjörður.

Soon after the installation in 1984, it turned out that the height of the nets in Auðbjargarstaðabrekka was in most parts lower than the local snow depth on the slope. For this reason, the nets have repeatedly been buried and avalanches have been released from the slope above the nets.

Heavy loads in winters when the nets were buried, and impact by avalanches from above, have caused repeated damages of the nets (*cf.* photograph 1). A total of 7 out of the 10 posts have failed near the top, at the location of the downslope wire loop or the perimeter wires, and the middle or lower parts of 2 posts are bent due to high compressional loadings. One groundplate has, furthermore, been broken due to high pressures. There are no visible damages of the uphill or downhill wire rope anchors, except that the upper part of one of the uphill wire anchors has been forced into loose material near the top of the bore hole. Some of the posts were originally not installed with the correct orientation with respect to the slope. In spite of this, none of the groundplates below the posts have been visibly moved due to the heavy loads, with the exception of the groundplate that has broken.

Some corrosion is visible in wire ropes of the mesh in a part of the nets (about 20-30% of the two northernmost nets is rusted). The wire ropes of the mesh have a diameter of 5.25 mm with 0.35 mm wires. Almost no rusting was observed in the perimeter wire ropes or in the downhill cables which have diameters between 15 and 16 mm with about 1 mm wires. Most u-bolt clips for fastening cables to anchors are rusted. Many connection cylinders that connect the perimeter wire ropes are also rusted and have in some cases lead to localised corrosion of the neighbouring wires. Zinc thickness measurements from Auðbjargarstaðabrekka are tabulated in a separate section below.

The corrosion condition of nets in Auðbjargarstaðabrekka after 13 years is not bad although some corrosion is visible in the net mesh and u-bold clips. The supporting construction is, however, badly damaged and needs substantial repairs if nets are to be maintained on the slope in the future.

7.3 Snow nets in Ólafsvík

The nets in Ólafsvík were installed by the town of Ólafsvík in order to reduce the snow avalanche danger in a local health center which is located close to the mountain to the south of the main part of the town (photograph 2).

Various mistakes were made in the installation of the nets and a part of them collapsed soon after the installation due to failures of the foundations. As in Auðbjargarstaðabrekka, it was discovered soon after the installation in 1985 that the height of the nets was in many winters lower than the local snow depth. The nets have thus been buried several times. An avalanche was released in 1995 from an area below the nets to the east and from the area where the nets had collapsed. The collapsed nets were repaired in the autumn of 1997.

A large proportion of the wires in the mesh of the nets in Ólafsvík is heavily rusted (photograph 4), in some cases to the extent that the wires are stiff from the accumulated rust and break easily when they are bent back and forth a few times. Some mesh wires were so corroded that they could be pulled apart by hand. These wire ropes are of the same type as the mesh wires in Auðbjargarstaðabrekka, *i.e* they have a diameter of 5.25 mm with 0.35 mm wires. Samples of the wire ropes were tested for breaking strength by the Icelandic Building Research Institute. A sample with little visible corrosion had a breaking strength of 14.5 kN, a second sample which had substantial visible corrosion and had become rather stiff had a breaking strength of 10.9 kN and a heavily corroded wire rope with some broken threads had a breaking strength of only 9.3 kN. According to information from the manufacturer of the nets, the original breaking strength of this type of wire ropes is between 15.5 and 17.25 kN.

Most of the perimeter wire ropes and the downhill cables in Ólafsvík, which have diameters between 15 and 16 mm with 0.6-1 mm wires, were not visibly damaged by corrosion, but parts of the ropes were nevertheless heavily rusted. Wires along the ground between the upper anchors and the groundplates were in general highly corroded. Wire ropes in the anchors were, however, in good condition. Most u-bolt clips for fastening cables to anchors and connection cylinders in the perimeter wire ropes were rusted as was also the case for the nets in Auðbjargarstaðabrekka.

The corrosion condition of nets in Ólafsvík after 12 years is very bad and both mesh wires and some of the perimeter wires are in urgent need of replacement. Parts of the supporting construction is also badly damaged. The repair work in the fall of 1997 has improved the condition of the nets, but there is clearly a need for further repair work in the near future.

7.4 Supporting structures in Siglufjörður

The supporting structures in Siglufjörður were installed in October 1996 by the Icelandic Meteorological Office and the Icelandic Avalanche Fund for experimental purposes (photograph 3). They are stronger than the nets in Auðbjargarstaðabrekka and Ólafsvík because they are designed for higher values of the snow density which are believed to be appropriate for Icelandic conditions.

A part of the snow bridges from J. Martin in Siglufjörður was damaged in strong winds shortly after the installation of the structures in the fall of 1996. This was repaired by drilling anchors through the groundplates of all the posts that are mounted on groundplates. Mistakes were made in the installation of 5 posts, which are founded on micropiles in loose material, in the Geobrugg net line, and these posts failed during the first winter. This was repaired in the fall of 1997 by replacing the micropiles of these posts with groundplates.

A part of the supporting structures in Siglufjörður is located in a gully where there is a large accumulation of drifting snow. The structures in the gully were buried in the winter 1996/1997, but this did not lead to failures of the structures, with the exception of the damages to the micropiles in the Geobrugg net line as mentioned above. Snow loading of the constructions in Siglufjörður has been monitored by instruments since their installation. The measurements indicate that the loading of the structures can be interpreted by the same formulas as used for the design of supporting structures in Alpine countries if allowance is made for the higher density of snow in Iceland. There seems to be little loading due to gliding of the snow cover along the slope, which in part compensates for the higher loading due to the high snow density.

Test plates for measuring the rate of corrosion of steel and zinc were installed on the supporting structures in Siglufjörður, but the first results from these plates are not yet available.

Most of the stiff constructions from J. Martin are hot dip galvanised according to the standard SS-3583, class B, but two units in the lowest line are made of black steel for comparison (photograph 5). Nuts and bolts are zinc plated but not hot dip galvanised and many of them are visibly corroded after the first winter (photograph 6). The main difference with regard to corrosion protection between the steel bridges in Siglufjörður and steel structures designed according to current practice in Iceland is that the anchors and parts of the foundations are not hot dip galvanised and that nuts, bolts and other smaller steel parts are only zinc planted. Changing this to conform with the Icelandic work practice would result in a minor cost increase compared to the structures which were installed in Siglufjörður. The main structure of steel bridges are usually not hot dip galvanised in Alpine countries. Requiring hot dip galvanisation for such structures in Iceland, as was done in Siglufjörður, leads to a cost increase on the order of 10% compared to traditional Alpine structures.

Wires in the net meshes and the "maschengitter" of the snow nets from Geobrugg in Siglufjörður are already starting to rust after the first winter (photograph 7). In addition, a number of the galvanised steel clips, which are used to fasten the wires in the mesh to each other, are rusted after the first winter. Rust can also be seen in a few spots on perimeter wire ropes and on downhill cables. Zinc thickness measurements of samples from downhill wire ropes, with a diameter of 16 mm and wire diameter of about 1.1 mm, indicate a zinc thickness of only 5-7 μm. This is quite thin for this thickness of wires and not in agreement with the specifications of the manufacturer. Zinc thickness measurements from Siglufjörður are tabulated in the next section.

Rust was observed on the innermost or the middle strand of some of the 16 mm downhill wire ropes in the EI nets in Siglufjörður, but not on the outermost strands. Parts of the wires are covered by a white or gray dust. According to corrosion experts here in Iceland this dust is called "white rust" and it is interpreted as an indicator of a beginning corrosion (*cf.* Slunder and Boyd, 1986, p. 15). According to information from the French manufacturer of the nets (and also according information from Geobrugg in Switzerland), this dust is formed by a harmless chemical reaction on the surface of the fresh galvanisation and does not indicate the initial phases of corrosion. This difference of opinion is not very relevant, however, since observations from Auðbjargarstaðabrekka and Ólafsvík indicate that the type of wires which is used in these nets will become highly corroded during a period on the order of 10 years. Zinc thickness measurements of samples from downhill wire ropes, with a diameter of 16 mm and wire diameter of about 1.0 mm, indicate a zinc thickness of only 5.6-7 μm. As for the Geobrugg wire ropes described in the previous paragraph, this is quite thin for this thickness of wires and not in agreement with the specifications of the manufacturer. Some of the triangular net meshes in the EI nets in Siglufjörður were pulled down along the perimeter wire ropes by the snow and needed to be fastened by u-bolt clips in the summer of 1997 (photograph 8). The fixing of the nets to the perimeter wires of the EI nets therefore needs to be improved.

Wire ropes in the snow nets from Geobrugg and EI in Siglufjörður and also the older nets from EI in Auðbjargarstaðabrekka and Ólafsvík, differ in construction from wires which are traditionally used in Iceland, for example in guys in transmission line towers. The wire ropes of the nets in Siglufjörður have both much thinner wires for the same diameter of the rope and they also have a thinner zinc coating for comparable wire diameters. The hot dip galvanisation of the steel parts in the supporting constructions of the snow nets is, however, similar as traditionally used in Iceland, as was specified in the initial invitation to tender. As further discussed below, the current snow nets need a fundamental improvement in the corrosion protection of the wire ropes if a substantial maintenance cost due to repeated replacements of the wires is to be avoided.

7.5 Results of zinc measurements

Zinc thickness on flat surfaces on a number of hot dip galvanised and zinc plated steel parts of the supporting structures in Auðbjargarstaðabrekka and Siglufjörður was measured in the field by a portable zinc thickness meter. The results of the measurements are given in the following table.

Table 5: Zinc thickness measurements on steel surfaces of supporting structures.

Location	Minimum thickness (μm)	Average thickness (μm)	Number of measurements	Note
Auðbjargarstaðabrekka				
Posts	58	109	30	
Siglufjörður, steel bridges				
Beams	177	240	22	
Girders	171	218	7	
Supports	212	238	9	
Connection	129	168	11	between girder and support
U-bars	117	186	10	
Bolts	13.5	16	6	
Siglufjörður, nets				
Geobrugg posts	281	372	18	
EI posts	85	104	26	

The zinc thickness on the steel bridges and on the Geobrugg posts is well above the required average thickness of 115 μm according to SS-3583, class B (except for bolts and small steel parts). The zinc thickness on the EI posts is somewhat below the requirements of the standard.

Zinc thickness was measured on several samples of wires from Auðbjargarstaðabrekka and Siglufjörður. The measurements, which were made according to the standard SS-ISO 1460, are given in the following table. It should be noted that the wires from Auðbjargarstaðabrekka are 13 years old and the wires from Siglufjörður are slightly less than one year old. The measurements do, therefore, not directly correspond to the initial zinc thickness on the wires.

Table 6: Zinc thickness measurements of wire samples.

Diameter mm	Type	Core	Diameter of wires	Zinc coating (μm)	Number of measurements	Note
Auðbjargarstaðabrekka, EI						
5.5	6x19	Fiber	0.3	7.6	10	
9.0	6x19	Fiber	0.55	8.1	5	
15.0	7x19	IWRC[1]	0.95	23.2	5	
Siglufjörður, Geobrugg						
7.4-7.8	7x7	IWRC	0.8	19.0	3	initial measurement
				15.2	3	repeated measurement
16.0	7x19	IWRC	1.1	7.0	5	initial measurement
				5.0	5	repeated measurement
20	6x36 WS		1.05	23.0	3	
Siglufjörður, EI						
5.0	6x19	Fiber	0.3	7.0	10	
≈9.0	6x19	Fiber	0.75	14.7	5	
15.0	7x19	IWRC	0.9	11.6	4	outer strands
			1.0	14.1	3	center strand
16.0	7x19	IWRC	1.0	7.0	5	outer strands, initial
				8.2	5	outer strands, repeated
				5.6	4	center strand, initial
				5.2	3	center strand, repeated

According to specifications from the manufactures[2], the zinc thickness on the wires should vary from about 4 μm for ropes with wire diameters below 0.5 mm to about 14 μm for ropes with wire diameters of about 1.2 mm. For wire diameters of 1-1.1 mm, the specified zinc thickness is about 11 μm. The measurements in the above table indicate substantial deviations from the specifications. There are 16 mm wire ropes made of approximately 1 mm wires with a very low zinc thickness of 5-8 μm in both the EI and the Geobrugg nets. The average of the measurements of the 16 mm ropes is about half of the specified zinc thickness. On the other hand, a rather high zinc thickness of 15-20 μm is measured on samples with thinner wires from the mesh ropes in the Geobrugg nets, which are nevertheless visibly rusted in several locations after the first winter. The measured zinc thickness on the mesh wire ropes in the EI nets is also higher than specified. Although the measurements from the 16 mm ropes from Siglufjörður are from about 1 year old wire ropes, it does not appear likely that the low values are caused by corrosion during this single year. As noted in the table, the high measurements from the Geobrugg mesh ropes and the low measurements from the 16 mm ropes where confirmed by repeated measurements of these rather unexpected values.

One may in general expect local variations in the zinc thickness on wires, but it should of course not in any location be lower than the specifications. The high values measured on the samples from the Geobrugg mesh wires may be caused by a locally thicker than average zinc coating in the particular location of the wire where the sample was taken. These measurements may, therefore, not be representative for the whole mesh. The low zinc thickness measurements on the 16 mm ropes

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[1] IWRC = Independent Wire Rope Core.

[2] The standard ISO-2232:1990(F), Table 5, quality B, for the wire ropes from EI and a table of wire properties from the manufacturer for the wire ropes from Geobrugg.

indicate either a too thin zinc coating on the respective wires as a whole or localised parts with about half of the specified zinc thickness (unless we are prepared to accept a corrosion of about 5 μm during a time period of less than one year for these particular wires, which appears unlikely when we consider the other zinc measurements in Table 6). In either case, the measurements indicate that the quality of the zinc coating of the wires in both the Geobrugg and the EI nets needs to be investigated and improvéd in order to meet the specifications of the manufacturers.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Steel structures

It is recommended that all steel parts of solid steel structures, including the subsurface parts of anchors and micropiles, are hot dip galvanised according to the standard SS-3583, class B, which is described above, with an average zinc thickness of 115 μm for parts thicker than 6 mm.

Alternatively, one may consider increasing the thickness of the black steel beams and other steel parts in order to compensate for the expected corrosion. If a corrosion rate of 10 μm per year over an interval of 50 years is chosen for the purpose of discussion, this possibility leads to a thickness increase of about 1 mm. The increased material cost arising from this alternative is comparable with the cost of galvanisation and there will also be some additional costs arising from higher transportation costs and higher installation costs due to heavier constructions. Therefore, the use of thicker steel does not seem to be an economic alternative to hot dip galvanisation.

Another aspect of the question of galvanised versus black steel structures is the question of the visibility of the structures on the slope and the associated environmental impact. The brownish black structures will be less visible in the summertime and blend more naturally into the landscape than galvanised structures at that time of year. Black structures will, on the other hand, be much more visible than galvanised structures against the background of white snow in the wintertime.

8.2 Steel wires

It is recommended to use strand construction with a diameter of individual wires as great as possible. Sharp bending of such strands can be avoided by use of big diameter thimbles. This means that wire construction would differ from existing snow supporting structures in the following manner:

Table 7: Existing and recommended steel wires in snow nets.

Diameter mm	Type	Core	Diameter of outer wires	Diameter of core wires	Zinc coating	
					(g/m^2)	(μm)
Existing						
5-6	6x19	Fiber	0.3-0.4		20-30	4
8	7x7	IWRC	0.88	0.96	60	8.6
8-10	6x19	Fiber	0.6-0.7		50	7.1
15-16	6x19	Fiber/IWRC	1.0		75	11
16	7x19	IWRC	1.04	1.15	70	10
18-22	6x36WS	IWRC	1.0-1.25	1.16-1.4	80-100	11-14
Recommended						
5-6	1x19		1.0-1.2		180	$26^{1,2}$
8-10	1x19		1.6-2.0		240	34^{2}
15-16	1x37		2.1-2.3		250	36^{2}
18-22	7x19		1.2-1.5		210	$30^{2,3}$

Zinc thickness in the upper part of the table is taken from the standard ISO-2232:1990(F), Table 5, quality B, for wire ropes from EI and from a table of wire properties from the manufacturer for wire ropes from Geobrugg. As noted above, measurements from Auðbjargarstaðabrekka and Siglufjörður indicate that the zinc thickness on the mesh wire ropes is higher than the required by the specifications in the table, and that zinc thickness on some 16 mm wire ropes is lower than the specifications.

The recommended zinc thickness in the lower part of the table is according to the standard DIN 1548, heavy galvanising ("dickverzinkung").

The superscripted numbers in the last column of the lower part of the table refer to the following comments.

1. Steel wire ropes in nets, diameter 5-6 mm, should probably be made of stainless steel, but special care must be taken for all fittings and contact with other wires. This has to be discussed and investigated further.
2. The strands should be lubricated. Experience has proved that a well lubricated rope can stand two to five times more bending than a non-lubricated one. Lubrication reduces internal friction and impedes corrosion[1].
3. Rope used as a rock anchor, should not be lubricated.

The above recommendations are solely from the viewpoint of corrosion protection. Wire ropes made out of as thick wires as recommended above may be too stiff for it to be technically feasible to use such wire ropes in snow nets. This question must be further addressed by the individual manufacturers. The main point of the above recommendations is that, perhaps with the exception of the 5-6 mm wire ropes, one may expect a life time of more than say 25 years for wires as recommended in the table based on the experience from Iceland. If substantially less corrosion resistant wires are used, one must expect maintenance problems after only 10-15 years.

Alternatively, one may consider using better corrosion protection for wires than ordinary hot dip galvanisation, possibly in combination with stainless steel wires in parts of the nets. This possibility is currently under investigation by some manufacturers of snow nets.

All steel parts of snow net constructions, including u-bolt clips, nuts, washers and shackles, should be hot dip galvanised, according to the standard SS 3583, class B, so that rust forming in guy fittings can not start the rusting process in the guy wires.

8.3 Anchoring

For rock bolts (foundation bolts) made of ribbed bars the use of hot dip galvanising as corrosion protection is recommended. 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. Furthermore, it is stated in (CEB, 1992), that if the bars, after galvanisation, are quenched in a bath of water-chromate, the bond will reach higher values than those of not galvanised bars under similar conditions.

According to (CEB, 1995), the average coating thickness shall be 84 μm according to an Australian standard for bars 5 mm or greater, and 85 μm according to German standards. According to the German standard the maximum allowed local thickness of zinc is 200 μm. Here it is recommended to use the standard SS 3583, class B (*i.e.* 115 μm average zinc thickness for steel thickness over 6 mm) for rock bolts made of ribbed bars, with 200 μm maximum local thickness. Permissible

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[1] According to information from Geobrugg in Switzerland, the effect of lubrication to reduce corrosion needs to be well investigated before it is decided to use lubricated wires in snow nets. Some lubricants are observed to be corrosive to wires according to Geobrugg.

bond stress for indented wires is reduced by 30%, if galvanised, and for ribbed wires about 45% according to German standards (CEB, 1995).

8.4 Comparison of snow bridges and avalanche nets

Assuming that problems such as foundation failures or rock fall do not shorten the life time, snow bridges, hot-dip galvanised, with average zinc thickness 115 μm, will last for at least 50 years, if similarities are drawn from the experience of steel towers in Iceland. Avalanche nets with present design can last for about 10-20 years under Icelandic conditions. Improved nets can, with a better choice of steel wires and wire fittings as described above, last for 20-30 years. The life time of such improved nets can, nevertheless, be expected to be substantially shorter than for snow bridges, *i.e.* about 25 versus 50 years.

In the absence of rock fall, one may therefore assume maintenance costs to be much greater for the current nets than for bridges. One may roughly take this into account by computing the sum of the initial cost and the present value of future replacements costs as described above in the section about life time of supporting structures. This increases the cost of snow nets of the present design by about 25% and by about 10% for an improved design of nets with an approximate life time of 25 years. The initial material and installation cost is similar for snow bridges and nets for the experiment in Siglufjörður (Jóhannesson, 1996) and according to information from some Alpine countries, but general statements about this cost difference in the future cannot be made since prices will be determined by bids for each project. Snow nets do, on the other hand, have the advantage that they have a smaller visual impact than snow bridges. Therefore, higher maintenance costs of snow nets can possibly in certain places be balanced by environmental aspects.

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APPENDIX A: CHECK LIST FOR OBSERVATIONS

VEÐURSTOFA ÍSLANDS

Upptakastoðvirki - Ástandskönnun

Dagsetn 5.6.1997
Nafn Árni Jónsson VÍ
Þór Sigurjónsson Lh

Staður Ólafsvík - ofan heilsugæslustöðvar

Byggingarár 1985

Stoðir	Gerð	Kringlótt stálrör (vantar þvermál)
	Er halli réttur ?	Yfirleitt í lagi í efri röð, en afleitur í neðri röð.
	Eru þær bognar ?	Nei, nema skv. næstu línu.
	Staðbundin kiknun ?	Já, á nokkrum stoðum, þar sem vægiarmur milli staga er stór.
	Rifið út úr götum ?	Já, á nokkrum stoðum
	Tæring - sjónmat	Nei
	" - sinkþykkt	
	" - stefnuhæð ?	
	Splitti - tærð ?	Já, almennt mikið tærð.
	" - vantar eða brotin?	Örfá brotin.
	Annað	Stoðirnar líta almennt vel út, nema þar sem grundun hefur gefið sig
Undirstöður		
	Gerð	Fjórar U-skúffur (vantar stærð).
	Þrýst niður ?	Víða þrýst ofan í jarðveg.
	Þrýst upp brekku ?	Já, nokkrar, sem höfðu einnig þrýst niður.
	Vír á jörðu	9 mm með fiberkjarna
	" " " - fjöldi þátta og þvermál	6 x 19 x 0,6 mm
	" " " - slaki	Já, víða slaknað, þar sem grundun hefur gefið sig.
	" " " - tæring	Víðast hvar haugryðgaður.
	" " " - lásar	M12 víralásar.
	Annað	Vír ýmist á eða í jörðu.
Stög		
	Þvermál og kjarni	Sjá jaðarvír
	Fjöldi og þvermál þátta	"
	Tæring	"
	Lásar	"
	Annað	"
Jaðarvír neta		
	Þvermál og kjarni	Ca. 16 mm vír með fiberkjarna.
	Fjöldi og þvermál þátta	> 6 x 19 x 0,8 mm ysl, en 0,5 - 0,6 mm og sverari innar.
	Tæring	Allt frá engri upp í haugryðgað.
	Lásar	Presshólkar úr stáli, haugryðgaðir.
	Annað	Sums staðar er vír farinn að ryðga út frá presshólkum.
Net		
	Þvermál og kjarni	5,25 mm vír með fiberkjarna.
	Fjöldi og þvermál þátta	6 x 19 x 0,35 mm
	Tæring	Allt frá engri og upp í haugryðgað.
	Lásar	Sinkhúðaðir skrúfaðir víralásar á vírendum orðnir tærðir
	Annað	en möskvalásar úr ryðfríu stáli líta vel út. Tæring á lásum varla það mikil að skerði burð.
Bergfestur		
	Gerð	21 mm vír, 7 x 19 x 1,4 mm þættir, án fiberkjarna.
	Stefna	Of brött, þ.e. ekki nálægt stefnu krafts (eða +/- 15 deg.)
	Ástand	Vír ótærður, en berg gefið sig víða vegna rangrar kraftstefnu. Í þykkum
	Annað	jarðvegi er lárétt færsla við yfirborð allt upp í 0,5 til 1,0 m.
Annað		
	Bergfestur víða of nálægt stoðum, þannig að þegar snjór leggst í virkið, þá verður kraftur í stagi og stoð stærri en ella. Neðri girðing fallin á 8 staura kafla.	

APPENDIX B: PHOTOGRAPHS OF SUPPORTING STRUCTURES

Photograph 1. Snow nets from EI in Auðbjargarstaðabrekka, northern Iceland.

Photograph 2. Snow nets from EI in Ólafsvík, western Iceland.

Photograph 3. Supporting structures from J. Martin, Geobrugg and EI in Hafnarfjall in Siglufjörður, northern Iceland.

Photograph 4. A rusty part of the EI nets in Ólafsvík.

Photograph 5. A part of the stiff steel structures from J. Martin in Siglufjörður showing both black and galvanised bridges.

Photograph 6. Rusty nuts and bolts in the steel bridges from J. Martin in Siglufjörður.

Photograph 7. Rusty clips and wires from the Geobrugg nets in Siglufjörður.

Photograph 8. A part of the EI nets in Siglufjörður showing a net which has been pulled down along the perimeter wire ropes.