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WINTER CONCRETING FULL-SCALE FIELD TRIAL OF ROCK TOWER FOUNDATIONS

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Abstract

Winter concreting can be an attractive option for construction in remote areas where concerns about wildlife and soil integrity are prioritized. In order to minimize disturbance of wildlife and to be able to access remote sites with minimal damage to the soil, partial winter construction of a power line is being considered in northern Norway. Ice formation has to be prevented during the early stages of concreting of mast foundations in order to ensure design properties, long transportation ways have to be considered, and quick setting and achievement of the ultimate design strength are desired. Conventional materials in conjunction with artificial heating are considered to provide a potential solution. In the current field trial we investigated the feasibility of grouting anchor bolts (rock anchors) at ground temperatures below freezing using a vertically-installed hydronic heating system to warm up the rock prior to grouting. Also, hydronic heating of the footing during winter concreting has been tested. We found that the method is able to maintain temperatures well above freezing.

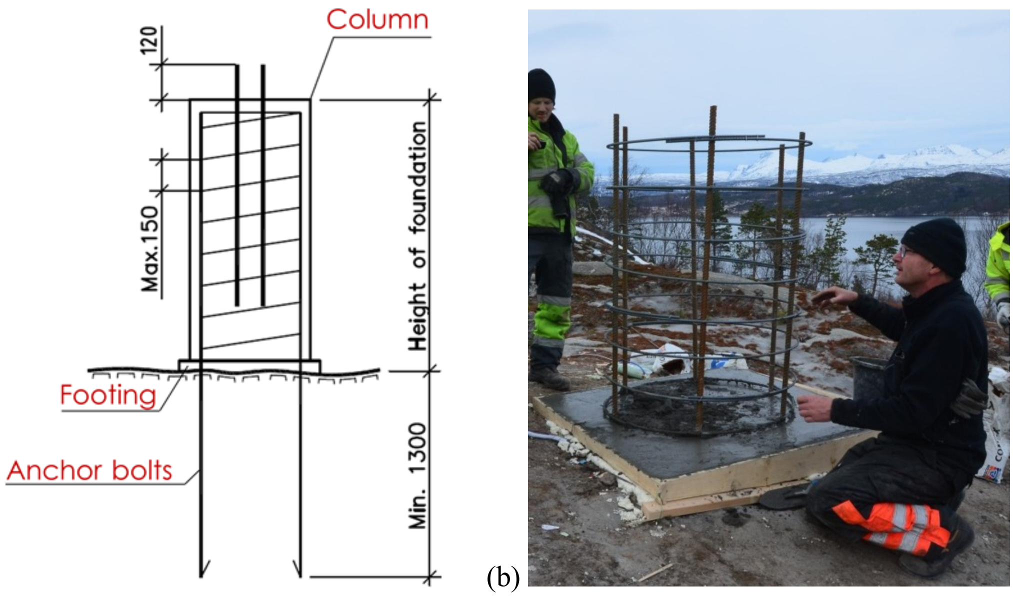
Keywords: Concrete, winter casting, hydronic heating

1 Introduction

Winter concreting can be an attractive option for construction in remote areas where concerns about wildlife and soil integrity are prioritized. In order to minimize disturbance of wildlife and to be able to access remote sites with minimal damage to the soil, partial winter construction of a power line is being considered in northern Norway. Ice formation has to be prevented during the early stages of concreting of mast foundations in order to ensure design properties, quick and safe setting and achievement of the ultimate design strength. Challenges include: wind and snow drift, air temperatures below 5 °C, bedrock temperatures between 0 and –10 °C, long transport ways for concrete, helicopter transport of concrete from the road, small volumes of grouting and concrete, access and equipment limitations in challenging terrain. In this study, conventional materials in conjunction with artificial heating are considered to provide a potential solution.

Concrete properties depend on the environmental conditions during preparation, casting, and curing. Casting in warm conditions (e.g., exceeding 30 °C) can be more detrimental to compressive strength than casting in cold conditions (e.g., around 5 °C; Ortiz et al., 2005). However, environmental temperatures below 0 °C have never been shown to be beneficial. To the contrary, laboratory tests have shown that concreting in very cold environments adversely affects the 28-day properties of the concrete even in the presence of antifreeze additives (e.g., Çullu and Arslan, 2013; Nassif and Petrou, 2013). However, from a practical point of view it has been recognized that concrete can be placed during cold weather if properly protected (ACI306R-10). This study aims to investigate one practical solution to winter concreting, i.e. grouting of anchor bolts up to 1.5 m below the rock surface.

We present results of a case study in which anchor bolts and footing of a foundation were cast in cold conditions (**Fig. 1(a)**). The ground was heated with a hydronic system prior to grouting, and during casting of the footing of the foundation the fresh concrete was heated to secure near optimal conditions for curing of the concrete.

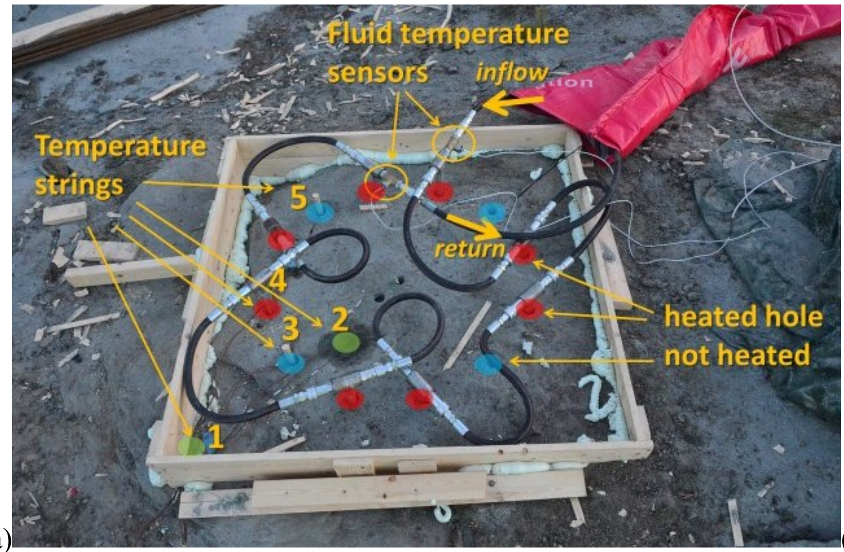


(a) (b)

Fig. 1 (a) Sketch of mast foundation design considered, defining anchor bolts, footing and column (adapted from construction design documents). Distances are given in mm. (b) Photograph showing grouted anchor bolts protruding through the freshly cast footing of the control foundation.

2 Full scale test set-up

Full-scale tests were performed on a rock surface at Djupvik (17.533° E, 68.4535° N), near Narvik, Norway, 40 m above sea level, from February to March 2014. The site is in close proximity to an outdoor laboratory designed to investigate frost in ground (Sveen and Sørensen, 2013). Two foundations were cast within 15 m of each other, where one foundation served as a control. A total of 60 and 18 thermocouples were deployed in the rock and footings respectively to record temperatures every 5 minutes. Temperatures were recorded by a Campbell Scientific CR1000 data logger that also measured air temperature and wind speed at the site. Data were downloaded hourly, processed and displayed on a web page. The test site was overseen by a camera recording images every 15 minutes. The control foundation **(Fig. 1 (b))** was identical to the heated foundation except that only 6 instead of 12 rock anchors were grouted. Rock temperature profiles were recorded at two places between the foundations. Hydronic heating was performed with a HeatWork MY35 Mini Heater, capable of delivering up to 35kW heating power and suitable for transport in challenging areas, including by helicopter.

(a)


(b)


Fig. 2 (a) Heating concept: 12 holes were to be grouted, 8 holes were heated (red circles). The filled circles mark heated (red, e.g. #4) and not heated (blue, e.g. #3, #5) holes for anchor bolts, and the reference temperature strings (green, #1, #2). The hydronic heating fluid is pumped through the rods in series (inflow and return are indicated). (b) Hydronic heating rod.

12 holes for anchor bolts were placed in a circle of 0.85 m diameter **(Fig. 2(a)).** The holes were nominally 1.5 m deep. In addition, two reference strings were placed in the rock inside the circle and at the corner of the footing, respectively **(Fig. 2 (a)).** During heating, temperature profiles were recorded by the reference strings (#1 and #2 in **Fig. 2 (a)**, and strings in the not-heated holes (#3 and #5). Temperature strings of holes #3 and #5 were transferred to the rebar anchor bolts before grouting **(Fig. 3a)**. In addition, a temperature string had been attached to the anchor bolt in heated hole #4. Measurements during heating were used to confirm successful heat transfer into the rock.

Heating of the rock was accomplished with custom-designed hydronic heating rods **(Fig. b)**. The diameter of the rods was approximately 10 mm less than the diameter of the holes. Heating rods were placed in the ground **(Fig. 2a)**, the foundation site had been covered with HeatWork Winter Insulation Blanket #2273, and a water–glycol mixture of 100 °C was circulated through the heating rods at a rate of 17 L/min. As can be seen in **Fig. 2a**, the connecting hoses between the heating rods covered the rock surface, thereby providing an additional heat flow top-down into the rock.

The ground was heated for 40 hours, from 3 Mar 2014 at 17:25 until 5 Mar at 10:10 (**Table 1**).

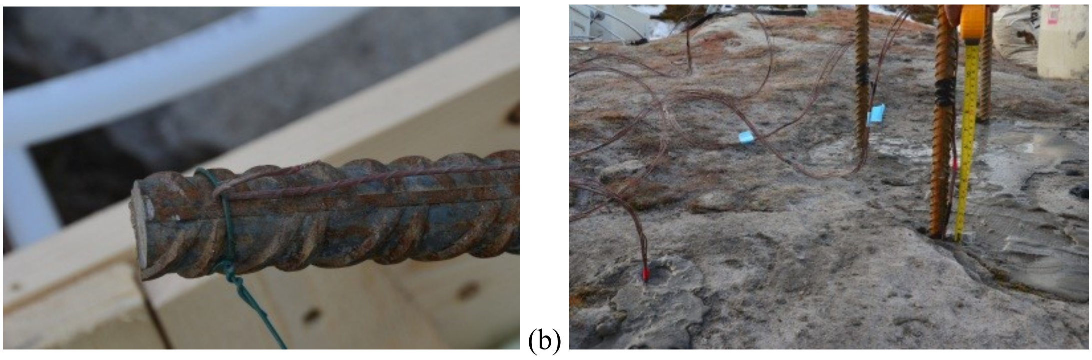

(a) (b)

Fig. 3 a) Thermocouple mounted to anchor bolt, (b) instrumented anchor bolts (rebars) during grouting.

Table 1 Key events during 2014 field tests. Time zone UTC+1.

Start	End	Period	Activity
25 Feb, 15:50	21 May, 20:00	85 days	Environmental monitoring
3 Mar, 17:25	5 Mar, 10:10	40 hours	Heating of ground, 100 °C
5 Mar, 10:10	5 Mar, 11:10	1 hour	Move rock sensors and install sensors for footing
5 Mar, 11:10	5 Mar, 11:20	0.1 hour	Grouting of anchor bolts, heated foundation
5 Mar, 13:20	5 Mar, 13:50	0.5 hours	Casting of heated footing (20 °C)
5 Mar, 13:50	5 Mar, 14:30	0.5 hours	Casting of not-heated footing (20 °C)
5 Mar, 13:50	9 Mar, 17:35	100 hours	Heating of heated footing, 30 °C
6 Mar, 9:00	6 Mar, 11:25	2.5 hours	Interruption of heating

Once the ground had been heated, the rock anchors were grouted (**Fig. 3(b)**). 2 to 2.5 hours after grouting the anchors, the footing was cast and covered with insulation (**Table 1, Fig. 4(b)).** A heat pipe had been cast into the footing close to the outer perimeter **(Fig. 4(a)).** The footing was heated with a fluid temperature of 30 °C during the first 100 hours, i.e., from 5 Mar 2014 at 13:50 until 9 Mar 2014, 17:35 (**Table 1**).

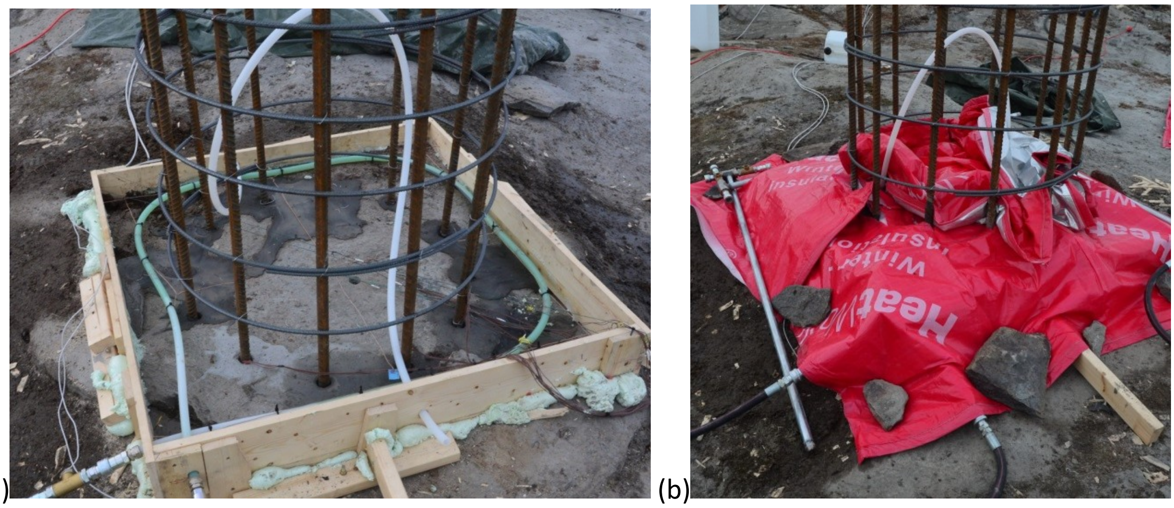

(a) (b)

Fig. 4 (a) PERT Heat loop in the footing prior to casting, and (b) insulated footing during curing.

3. Results and Discussion

3.1 Weather condition during tests

Fig 5. Shows the recorded weather data record during the tests with (a) air temperature, (b) wind speed, (c) wind direction. Also the rock temperatures (d) at reference site 1 at 0.8 and 1.5 m depth are shown. The graphs are divided by 4 vertical lines that separates two phases. Pase I (3 to 5 Mar) when the ground was heated, and phase II (5 to 9 Mar) when the concrete in the footing was cast and setting. At the start of ground heating on 3 Mar (phase I), rock temperatures were –2 °C throughout the upper 1.5 m, providing an environment hostile to conventional grouting **(Fig. 5(d)).** Air temperatures (around 0 °C) did not matter during this phase as the heating system at 100 °C shielded the foundation site from atmosphere. Unfortunately, air temperatures rose to between 0 and 10 °C at the beginning of the casting of the footing on 5 Mar (phase II).

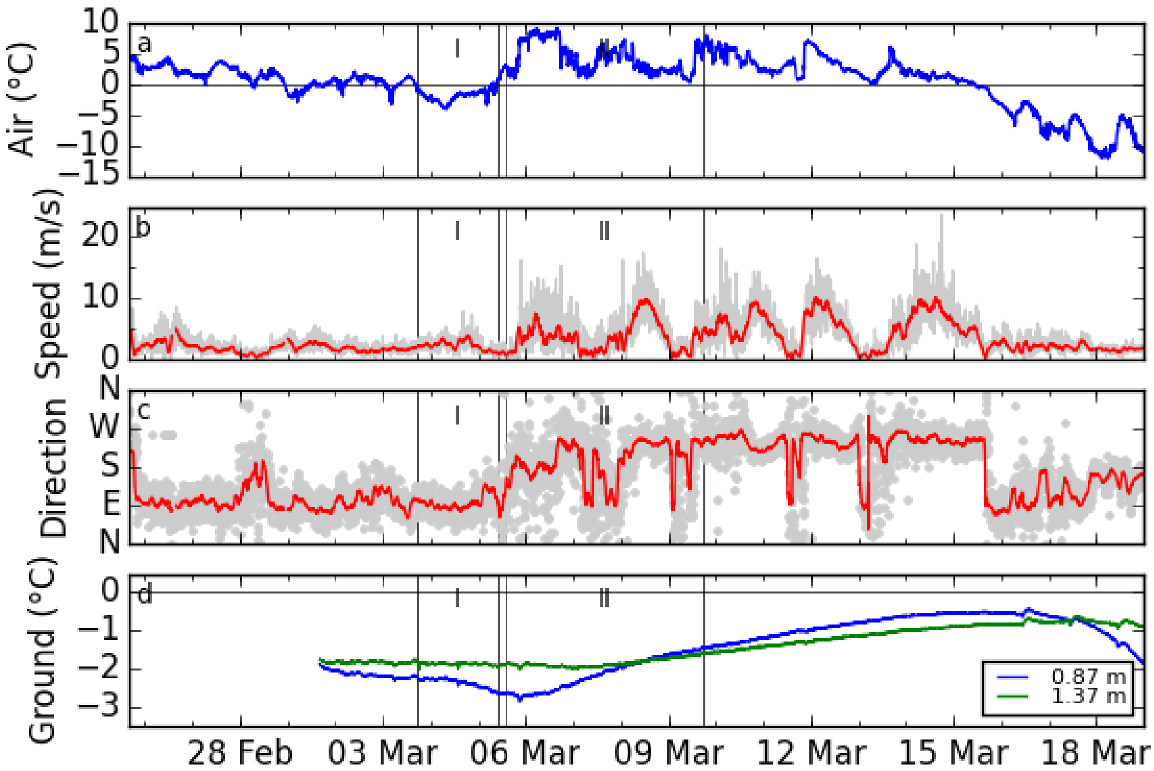


Fig. 5. Weather record during the tests with (a) air temperature, (b) wind speed, (c) wind direction, and (d) rock temperatures at reference site 1 at 0.8 and 1.5 m depth, respectively (not affected by test construction). The line in (b) and (c) is the 2-hour running average. Ground and footing had been heated during phase I (3 to 5 Mar) and II (5 to 9 Mar), respectively (see also Table 1).

While the conditions still qualify as cold weather concreting by ACI306R-10 definitions, it was warmer than hoped for. A period of colder weather started a few days later with air temperatures below –10 °C.

3.2. Heating of bedrock and grouting of rock bolts

Fig 6 shows the temperature development in holde #5 (a) and hole # 2 (b). Rock temperatures increased rapidly during warming (phase I, **Fig. 6a and b**). The temperature development in an anchor hole that had not been heated (string 5, **Fig. 6a**) was similar to the reference hole (string 2, **Fig. b**). The temperature increase was largest near the upper surface due to a combination of both vertical and horizontal heat transfer. At 0.8 and 1.5 m depth, temperature increase was due to horizontal heat transfer from the heating rods. The temperatures were lowest at the bottom due to vertical heat loss into the ground. Even though the lowest sensor of reference string 2 was 0.3 m below the depth of the heating rods, significant increase to temperatures above freezing had been registered there too (**Fig. 6b**). After heating for 40 hours, ground temperatures ranged from above 30 to 35 °C near the surface to between 5 and 10 °C at 1.5 m.

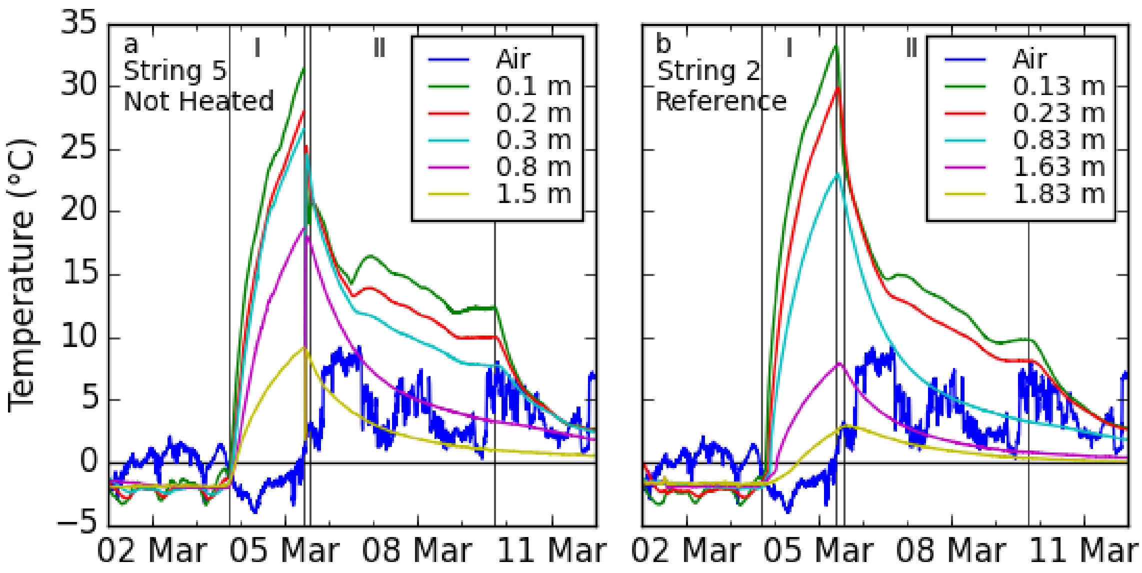


Fig. 6. (a) Temperatures in hole #5 (not heated) during the heating process (3 to 5 Mar), subsequent cooling while the anchors were grouted (5 Mar), and curing of the heated footing (from 5 Mar onward). (b) Same figure for reference hole #2. Note different meaning of line color between the figures. Vertical lines delineate heating phase I and curing phase II as in Fig. 5.

Near-surface temperatures (i.e. above 0.2 m) decreased quickly to 25 °C during the three hours since the end of heating (i.e. between phases I and II in **Fig. 6 (b).** Casting of the footing and heating of the footing to 30 °C during phase II delayed the rate of temperature decrease in the ground (change of slope of the upper two sensors in **Fig. 6 (b)** at the beginning of phase II). The not-so-smooth development of ground temperatures above 0.8 m were due to wind and temperature changes of the air, transferred through both the foot and the anchor bolts. After the end of surface heating at the end of phase II, ground temperatures decreased more rapidly but remained above 0 °C for several days.

3.3. Concreting of foundation footing

One of the objectives with the tests was to document the systems possibility to give good curing conditions for the foundations footing. Unfortunately, the temperature conditions during the tests was not very cold so the foundation footings were cast during with air temperatures well above 0 °C. Even though the air temperature was relatively high, it was decided that it would be interesting to study how the stored bedrock heat energy and the installed PERT heat loop would affect the curing conditions of the foundation footing. It would also be of special interest to see how the curing conditions of the unheated foundation would develop since the frozen bedrock and the 0 to 10 °C air temperatures would be typical for early spring conditions.

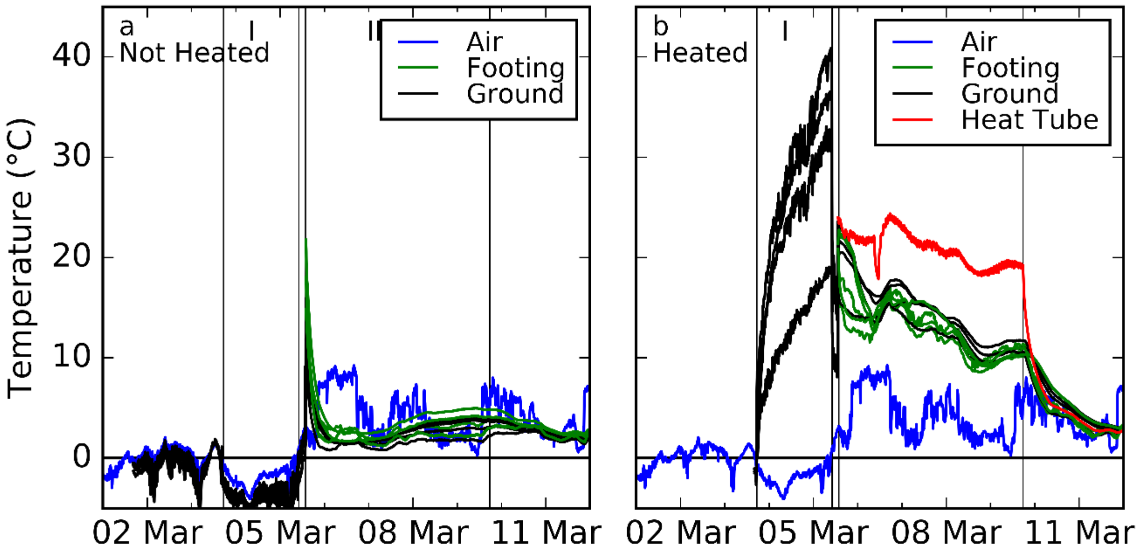


Fig. 7. (a) Curing temperatures in unheated reference foundation. b) Curing temperatures in heated foundation.

Fig 7 a) shows the temperature measured in the foundation that was cast without additional heating. The figure shows that even if the concrete temperature was 24 °C at the time of casting, and the air temperature was close to 10 °C, the concrete temperature rapidly dropped to 2 °C, barely avoiding immediate freezing. After casting the footing was covered with insulation and as a result a slight temperature rise (probably due to hydration heat) can be seen. The temperature then dropped gradually and actuall froze when the air temperature dropped below 0 °C after March 11th (not shown in **Fig 7**).

Fig. b) shows the temperature measured in the foundation that was heated by the pre-heated bedrock and circulating 30°C in the PERT heat loop. As can be seen the temperature dropped slowly for all sensors, but remained remarkably homogeneous for the whole area securing near to ideal curing conditions even in for sensors placed at very unfavourable positions, and even as close as 2 cm from the heat pipe (red line).

4 Conclusion

In the current field trial we investigated the feasibility of grouting anchor bolts (rock anchors) at ground temperatures below freezing using a vertically-installed hydronic heating system to warm up the rock prior to grouting. Also, hydronic heating of the footing during winter concreting had been tested. The tests demonstrated that the method is able to maintain temperatures well above freezing securing safe installation of rock anchor bolts and casting of small foundations on frozen bedrock.

6 Acknowledgements

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