A NEW CHALLENGE TO ARCTIC CABLE INSTALLATIONS—FRAZIL ICE

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Abstract: With the expected warming of the Arctic, and the rush to take advantage of the lessoned ice conditions, several cable systems have been planned to utilize this new shorter trans Asia-Europe route. However, installing cables in the Arctic still have a myriad of engineering challenges presented by the Arctic's unique environmental attributes. Issues such as destructive deep scour by pack ice keels and ice bergs, strudel scour, short installation window, adverse weather, shoreline erosion, have been widely recognized, studied, and generally engineering contingencies have been developed. Yet another, very unique phenomena called frazil ice was recently encountered on a newly installed cable system in Southwest Alaska. Frazil ice potentially poses new engineering challenges for submarine cable installations in the Arctic environment. It is ice that forms in the water column rather than the well-known, buoyant, crystalline structure of frozen water that forms on the surface. The implications for submarine cables are that when enough ice forms on the cable, the cable becomes buoyant, and floats to the surface. Once the cable has been lifted off the bottom, there is high risk that the cable will break or fault when coming into contact with moving surface ice, or become damaged when moved by ocean currents. Solutions to this problem include burying or armoring the cable (by using a very heavily armored cable or the application of iron split pipe protection), installing plastic split pipe protection (such as Uraduct®—frazil ice does not adhere well to plastics) and physically anchoring (pinning) the cable to the bottom. To date, more study needs to be completed on which method provides the best and most affordable solution.

1. INTRODUCTION

In 2012 GCI successfully launched the TERRA SW communications network which now replaces satellite services with a hybrid high speed fiber optic terrestrial/submarine cable backbone and broadband microwave service to rural Southwest Alaska (Figure 1). The backbone for this unique system consists of over 650 km of submarine and terrestrial fiber optic cable installed in challenging undersea conditions, rugged terrain, mountain passes, and tundra, all in very remote locations.

The environmental conditions and remoteness presented formidable engineering and installation challenges in offering adequate protection, security, and redundancy, while at the same time being cost conscience in meeting budget limitations required to make the project a reality. With the successful ahead of schedule go live in January 2012; it appeared that the bulk of these engineering and installation challenges had been successfully overcome.

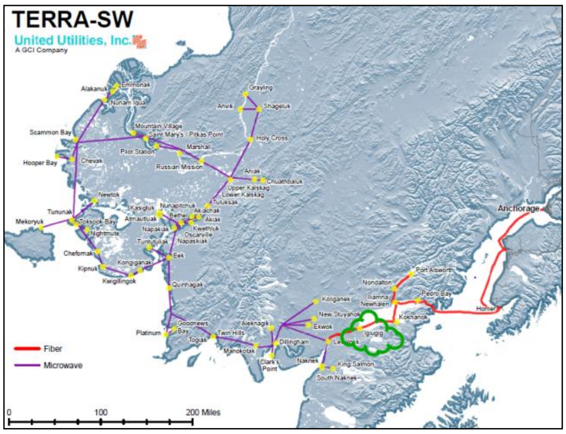

Figure 1. TERRA SW System, showing location of Igiugig frazil ice (green cloud).

So it came as some surprise when a phone call was received from the Igiugig village in late December 2011 stating that the cable was floating. How can this be? Submarine cable does not float. After reviewing a few photos emailed from the site it was clear that something very unique was occurring at the cable landing, on the bank of the Kvichak River (Figure 2). To our disbelief, there appeared to be an ice covered object floating in the open section of the river. Astonishingly, the cable installed on the river bottom became encrusted in ice and floated to the surface.

Figure 2. Cable encrusted in thick coating of ice floating on surface.

A site visit was arranged, but by the time we arrived at the remote site, the floating ice encrusted object had disappeared. Closer examination of the photos taken, interviews with the on-site witnesses, and deployment of an underwater under the ice camera to view the condition of the submarine cable, confirmed that the cable had been coated in ice and floated to the surface for a distance estimated to be 100 meters from what was visually observed on the surface. The underwater camera showed that cable and its near shore split pipe armour protection had been lifted from the river bottom, and moved several meters downstream (Figure 3).

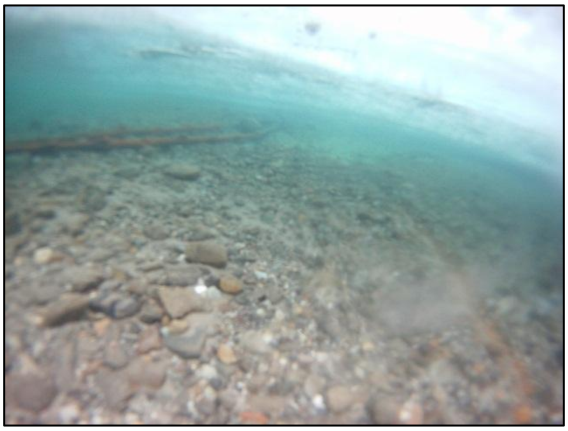

Figure 3. The right of the picture shows the indentation and rust mark from the original installed position of the cable and armor protection, and to the left is the armored cable after being floated downstream by the ice.

It is generally understood that ice does not form on the bottom, but rather on the surface due to the crystalline structure of the ice having a lower density than liquid water. This is a unique property of water which except in extreme cases, prevents our oceans and lakes from freezing solid in cold weather, and is thus one of the precursors for life as we know it [1] [2]. However, document research concluded that under the right conditions, ice can sometimes form in the water column, known as the unique phenomena of "frazil ice."

2. WHAT IS FRAZIL ICE

The formation of frazil ice occurs in turbulent super cooled water 0.01 to 0.1 degrees below the freezing point [3] [4] [5]. Frazil ice occurs in rivers and oceans in cold regions where ice forms. In the ocean, it is synonymous with the term "grease ice", which is the official World Meteorological Organization (WMO) description. This terminology was actually derived from the old whaling description given the greasy appearance taken by the sea when frazil ice forms [3] [6]. Several conditions have to exist for frazil ice to occur, these are:

- The water must be super cooled
- A turbulent state must exist
- Seeding from heterogeneous nucleation must occur--this is the introduction of ice crystals either as snow, frost crystals, or frozen water droplets [7] [4] [8] [6] [9]

With these three conditions present, the super cooled water allows for the formation of ice crystals. The turbulent state allows for the formed crystals to free flow throughout the water column. When the stimulus of heterogeneous nucleation is added, this creates a rapid multiplication of the ice crystals through what is called "collision breeding" [10]. Due to the surface properties of the molecules, once "collision breeding" occurs, the crystals rapidly aggregate together and can adhere to foreign material in the water [3] [11]. Thus, frazil ice may adhere to and propagate on the river/ocean bottom, rocks, or just about any underwater body that is also cooled to the same temperature. When frazil ice adheres to underwater structures, it is termed, "anchor ice" [11] [1] [3]. Anchor ice has been observed coating large rocks and boulders to the extent, they are floated off the bottom and transported considerable distances [11]. Frazil ice occurrences have been a nuisance to hydroelectric projects in Canada, Sweden, Russia and Iceland, to Arctic offshore gas explorations off Alaska's North Slope, [4] [3] [12] and now to submarine cable.

3. CONDITIONS AT IGIUGIG CABLE LANDING

Igiugig, Alaska is at the source of the Kvichak River, which is the primary outflow point for Lake Iliamna (Figure 4). Lake Iliamna is the largest lake in Alaska, the eighth largest lake in the United States covering 2,600 km^2 (roughly the size of the state of Rhode Island), and encompasses a water volume of 115 km^3 [13].

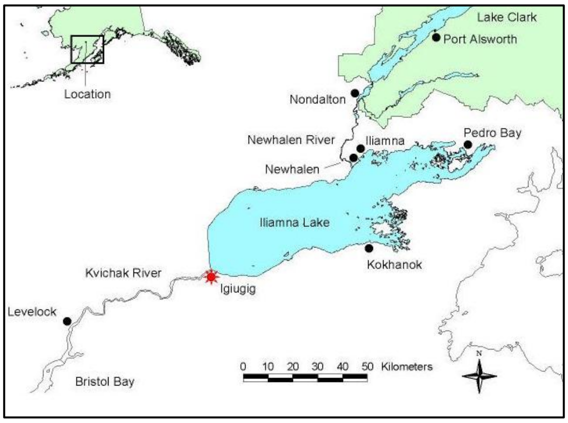

Figure 4. Igiugig Village on the Kvichak River, the primary outflow for Lake Iliamna

The Kvichak River is relatively narrow, roughly only 150 meters wide, thus providing a tremendous constriction for the outflow of this sizeable body of water. The resultant currents are very strong, estimated to be up to or exceeding 12 knots during the late summer/early fall peak flow. The current usually slows to around 5 knots during the winter when the lake is frozen. In fact, the name Igiugig, originated from the native Yupik language, meaning "a throat that swallows water" [14]. This extremely swift current produces the turbulent conditions ideal for the formation of frazil ice. In addition, the high current in the main channel precludes the formation of surface ice, thus keeping an open lead in the river—a prime condition for super-cooling of the water. **[8] [3] [7]** The air temperature leading up to this event was in the realm of -30° C for close to two weeks, and during the day there was the presence of ice fog—a prime source for heterogeneous nucleation. Thus, the "perfect storm" of events had been assembled, creating ideal conditions for frazil ice formation (Figure 5). All three conditions had been met for the formation of frazil ice, and resulting anchor ice **[7] [4] [8] [6]**.

Figure 5. Open lead seen over main river channel and the occurrence of ice fog, two predecessors for the formation of frazil ice.

Anchor ice is very transient in nature and can appear very suddenly after the passage of days with no frazil ice formation. It can also disappear just as suddenly when one of the conditions no longer exists [3]**.** Fortunately for the Igiugig cable, the "fraziled" cable did not make fast to the surface ice, which could have resulted in catastrophic cable damage during the surface ice break-up. But rather, the event lasted for approximately three (3) days, whence one or more of the conditions ceased; most likely the warming temperature warmed slightly to -24° C, and there was a reduction in ice fog, hence reducing the source of heterogeneous nucleation. The frazil ice mysteriously disappeared just a quickly and mysteriously as it had appeared, only resulting in the cable (with armor protection) being moved several meters downstream with no optical degradation of the fiber characteristics.

4. CONCLUSION/IMPLICATIONS

Because frazil and anchor ice can occur in fresh water rivers and lakes as well as in the ocean in polar regions, [9] [15] [9] [8] [5] [11] [10] [12] [16] [3] [1] [7] [6] [4], it is a potential detriment to submarine cables installed in these environments. This newly recognized hazard requires prudent planning and engineering to minimize the potential risk of catastrophic cable failure should the accumulation of anchor ice occur on a submarine cable.

There are two avenues to reduce the risks of frazil ice. One is to select sites which are less likely to have the three conditions necessary for the formation of frazil ice [3] [4] [12]. The second is to engineer methods or protective measures to prevent or guard against frazil ice [4] [17] [18] [12].

In oceans, frazil ice occurs particularly in near-shore regions where the predominant winds blow the ice away from shore creating a large expanse of sea water at its freezing point exposed to super cold air. It also occurs commonly near the discharge of river mouths where a layer of fresh melt water at its freezing point lies over a layer of seawater at its freezing point (a colder temperature) [3]. Both of these locations however, would present ideal cable landing opportunities, as a shore clear of ice would be less likely to see the effects of another arctic cable hazard—ice scour and gouging from the keels of pressure ridges which form when the ice is blown in-shore. River mouths commonly tend to be close to the natural population centers due to the transportation and food sources they provide, thus making them convenient locations for cable landings. However, at river mouths another arctic hazard may occur: strudel scour--another arctic hazard to be avoided, double ruling out this convenient landing point (strudel scour is the fresh water river outflow flowing over the ocean ice, and when it encounters a hole in the ice, flows downward in a whirlpool creating bottom scoring observed to be as severe as 10 meters deep). Permitting requirements, land ownership and site acquisition can also limit the location of potential landing sites, eliminating the option of selectivity.

While it is necessary to be aware of the site conditions required for the formation of ice hazards, frazil ice, in particular, will be unavoidable. Thus, engineering methods and/or protective measures to prevent and reduce the risks of frazil ice formation on the cable will be the more common and practical alternative. Since anchor ice has only been observed forming in depths up to 33m [3] [5] [16] [15], the protective measures need only be implemented to this critical depth. The most obvious solution is to bury or directional bore the cable in the sea bed beyond 33m water depth. On the shallow arctic shelves, such as the North Slope of Alaska, it will require a considerable distance to reach the 33m water depth, and add significant installation costs to the project. However, on the North Slope, burial to past this water depth will be necessary anyway for protection from ice scour and gouging.

For locations where cable burial may not be feasible, some possible remedial actions include:

- Installation of cable armouring (split pipe) along the area of concern. This would have the effect of adding weight to the cable such that the anchor ice, when formed, would not have sufficient buoyancy to move or harm the cable.
- It has been demonstrated in hydroelectric applications that frazil ice does not adhere very well to plastics such as UHWMPE [19] [20]. Thus, a UHWMPE duct could be installed, such as the Uraduct® product. Installing a submarine cable with PE (polyethylene) jacket vs. the standard yarn serving may also be beneficial, and an easy cost efficient solution.
- Another remedy which has been used in hydroelectric applications is heating [4] [21] [18] [17]. On a submarine cable, this could be accomplished with a heat tape, or possibly even inducing a current down the armor wires.
- Pinning the cable to the sea floor, with a U-bolt type apparatus is another possible solution. This would serve to prevent the cable from floating due the accumulation of anchor ice.

At Igiugig, the swift current makes any type of diver assisted retro-installation very difficult and dangerous. There is a very short window immediately following ice breakup, and just prior to the lake level snow melt rise that the river is somewhat diver friendly. But it still entails working in up to a 5 knot current. Given these conditions, our initial remedy was to install additional armor protection along the cable, into the main channel of the river. We predict that the added weight will overcome the buoyancy of future anchor ice accumulation. At the time of this writing, weather conditions at Igiugig have not been as cold as the winter of 2011/2012, and thus no anchor ice formation on the submarine cable has been reported. Time will tell if this is a satisfactory solution for the uniquely severe conditions at Igiugig.

Because this is a newly discovered submarine cable hazard, further study and research is warranted. Cost effective measures under controlled conditions need to be proven offering satisfactory protection measures verse the costly and possibly deliberating trial and error methods in the field, with in-service cables.

5. ACKNOWLEDGMENTS

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Figure 6. Bruce Rein collecting data, January 2012.

6. ABOUT THE AUTHOR

Greg Wilt is Director of OSP Long Haul and Submarine Fiber at GCI, Anchorage, AK, and prior has served various positions for AT&T Submarine Systems. Greg is currently engaged with cost and feasibility analysis of Arctic cable installations around Alaska (Figure 7).

Figure 7. Author on Kvichak River.

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