AVEC Construction and Operating Experience

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Toksook Bay, Alaska

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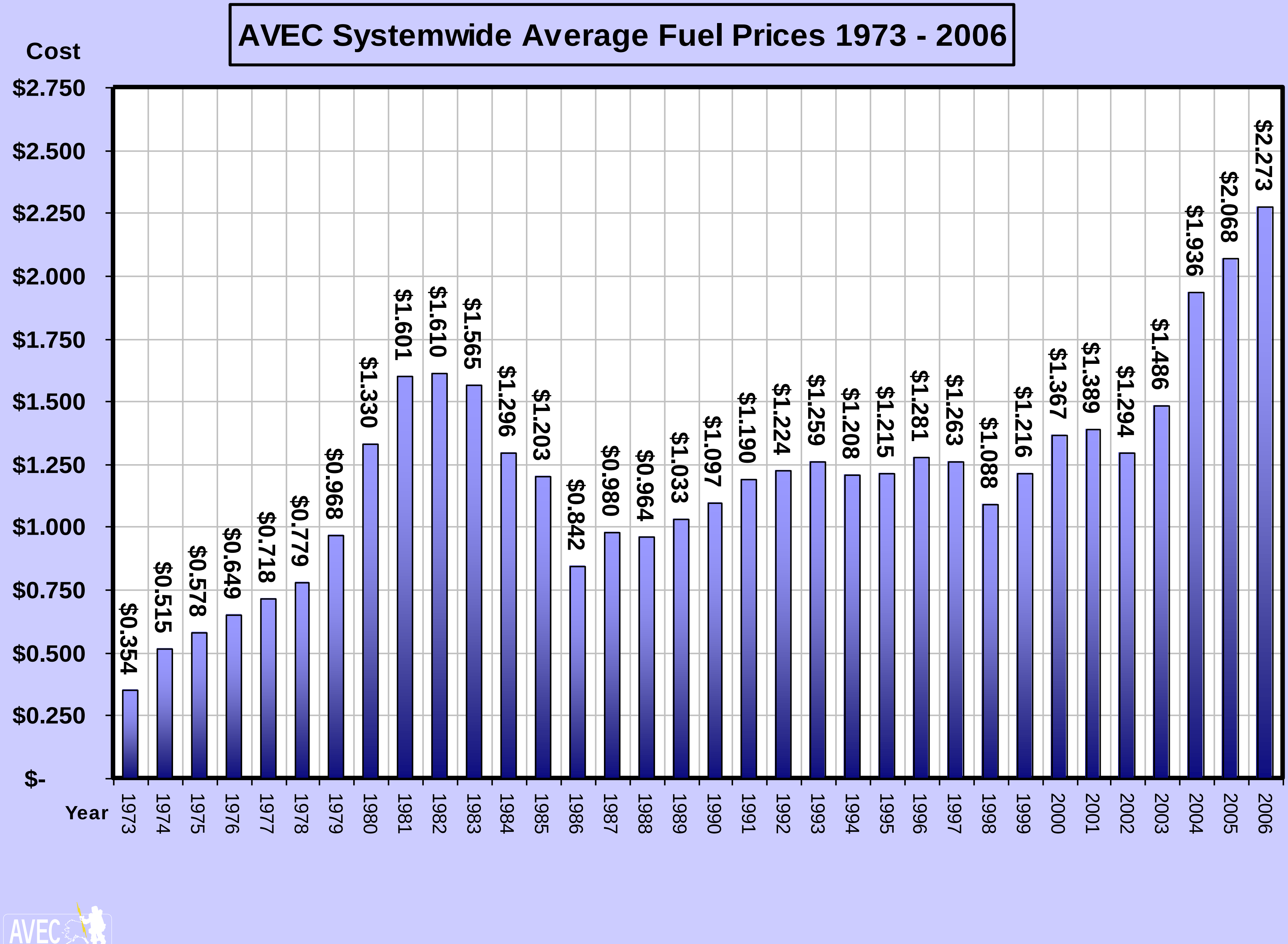
This project received financial support from the Alaska Village Electric Cooperative, Denali Commission, Coastal Villages Region Fund, U.S. Department of Energy, and the Alaska Energy Authority.

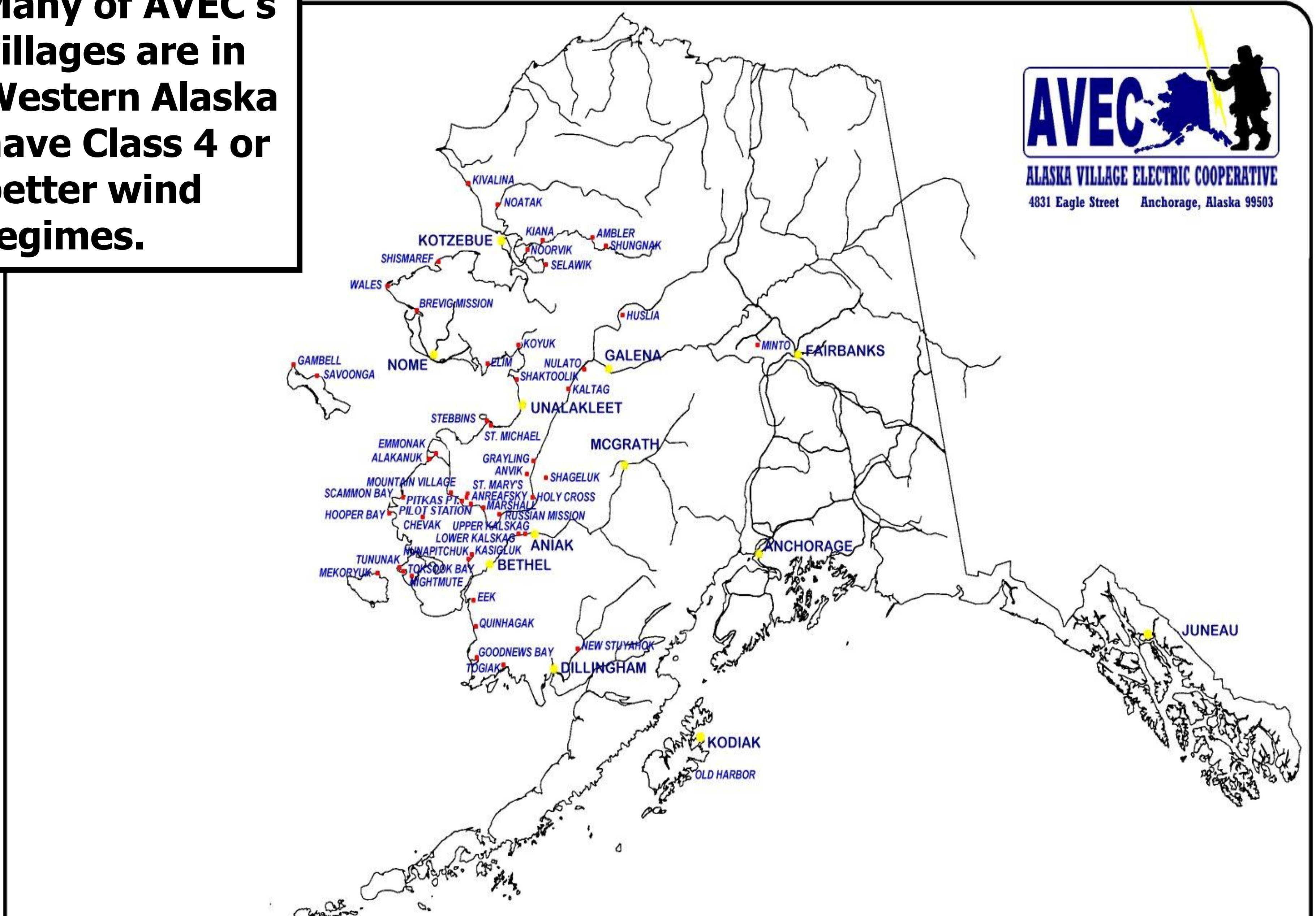
Background Information

- 27 of AVEC's 53 villages are in wind regimes of class 4 or better.
- Given the characteristics of an NW/100, this means that one machine should be able to produce about 220,000 kWh per year.
- Given a diesel efficiency of 14 kWh/gallon generated by our new diesel sets, this means that one 100-kW wind turbine might displace about 15,746 gallons per year of diesel fuel use for power generation. A mini-wind farm of three units would displace about 47,238 gallons per year.



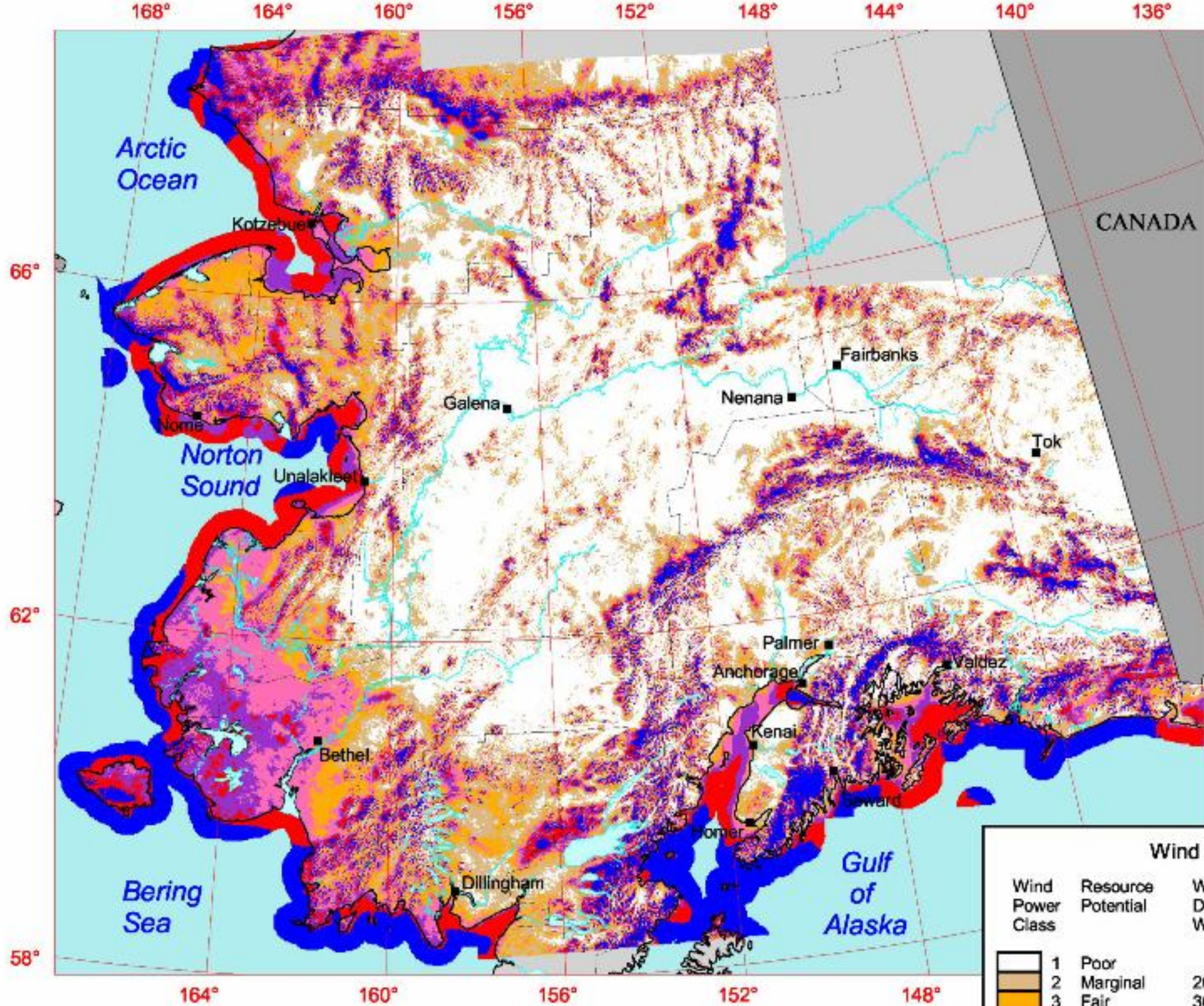
AVEC Systemwide Average Fuel Prices 1973 - 2006
Cost
$2.750
$2.500
$2.250
$2.000
$1.750
$1.500
$1.250
$1.000
$0.750
$0.500
$0.250
$-
Year
1973 $0.354
1974 $0.515
1975 $0.578
1976 $0.649
1977 $0.718
1978 $0.779
1979 $0.968
1980 $1.330
1981 $1.601
1982 $1.610
1983 $1.565
1984 $1.296
1985 $1.203
1986 $0.842
1987 $0.980
1988 $0.964
1989 $1.033
1990 $1.097
1991 $1.190
1992 $1.224
1993 $1.259
1994 $1.208
1995 $1.215
1996 $1.281
1997 $1.263
1998 $1.088
1999 $1.216
2000 $1.367
2001 $1.389
2002 $1.294
2003 $1.486
2004 $1.936
2005 $2.068
2006 $2.273

Many of AVEC's villages are in Western Alaska have Class 4 or better wind regimes.



MAP OF ALASKA VILLAGE ELECTRIC COOPERATIVE VILLAGES

Alaska Mainland Regions 50 m Wind Power



The annual wind power estimates for this map were produced by AWS Truewind using their Mesomap system and historical weather data. It has been validated with available surface data by NREL and wind energy meteorological consultants.

Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m ^{2}	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
1	Poor	0 - 200	0.0 - 5.3	0.0 - 11.9
2	Marginal	200 - 300	5.3 - 6.1	11.9 - 13.7
3	Fair	300 - 400	6.1 - 6.7	13.7 - 15.0
4	Good	400 - 500	6.7 - 7.3	15.0 - 16.4
5	Excellent	500 - 600	7.3 - 7.7	16.4 - 17.2
6	Outstanding	600 - 800	7.7 - 8.5	17.2 - 19.0
7	Superb	> 800	> 8.5	> 19.0

[a] Wind speeds are based on a Weibull k of 1.8. Weibull k values in Alaska vary from 1.4 to 2.0.

100 0 100 200 300 400 Kilometers
50 0 50 100 150 200 250 Miles

NREL

U.S. Department of Energy
National Renewable Energy Laboratory

18-JAN-2006 4.1.1

Consider that in 2006 AVEC:

- Purchased 5.2 million gallons of diesel fuel
- Actively used nearly 550 fuel tanks for storage
- Took on fuel in 170 separate deliveries (including 44 by air)
- Has only one village – Minto – that can be supplied by a fuel truck
- Continued to experience electric load growth driven by new water and sewer systems, airports, schools and housing in the villages
  - This load growth increases fuel use and fuel storage needs

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Therefore, successful integration of wind generation could mean the following to AVEC:

- A hedge against increasing fuel costs
- A hedge against the increasing costs of marine deliveries
- Extension of on-hand fuel supplies which may translate to favorable delivery scheduling by marine transporters
- A reduction of the need to build expensive, additional storage on hard-to-acquire or difficult-to-construct sites.

To do such efforts cost effectively, we need to do good planning and coordinate efforts with other construction projects underway in the village.

- The recent bulk fuel tank farm and power plant priorities of the Denali Commission provide some opportunity to coordinate logistics and use specialty equipment such as pile drivers or cranes that may be on-site.

Access for specialty equipment required to place foundations and erect turbines is a challenge.

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Poor roads, water and sewer lines, boardwalks and existing overhead power and phone lines present obstacles and challenges.
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Above ground water and sewer lines are often crossed with timber bridges that will only support an ATV or snowmachine.
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Boardwalks can be easily damaged by heavy equipment or melting permafrost.
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Foundations in permafrost are a challenge

- They must not settle, tilt or be uplifted
- Pile foundations (six to eight piles) may extend 1/3 to 2/3 the height of the tower into the ground

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- Due to the significant capital expense of installing deep foundations in permafrost conditions, the turbine owner wants to make sure that the investment will consistently produce power over the – year life of the equipment.

- Warming trends are affecting the expanse and depth of permafrost.

- For example, the next slide shows that the mean annual temperature in Bethel has increased from less than 28° F to over 31° F in the 55 years from 1950 to 2005

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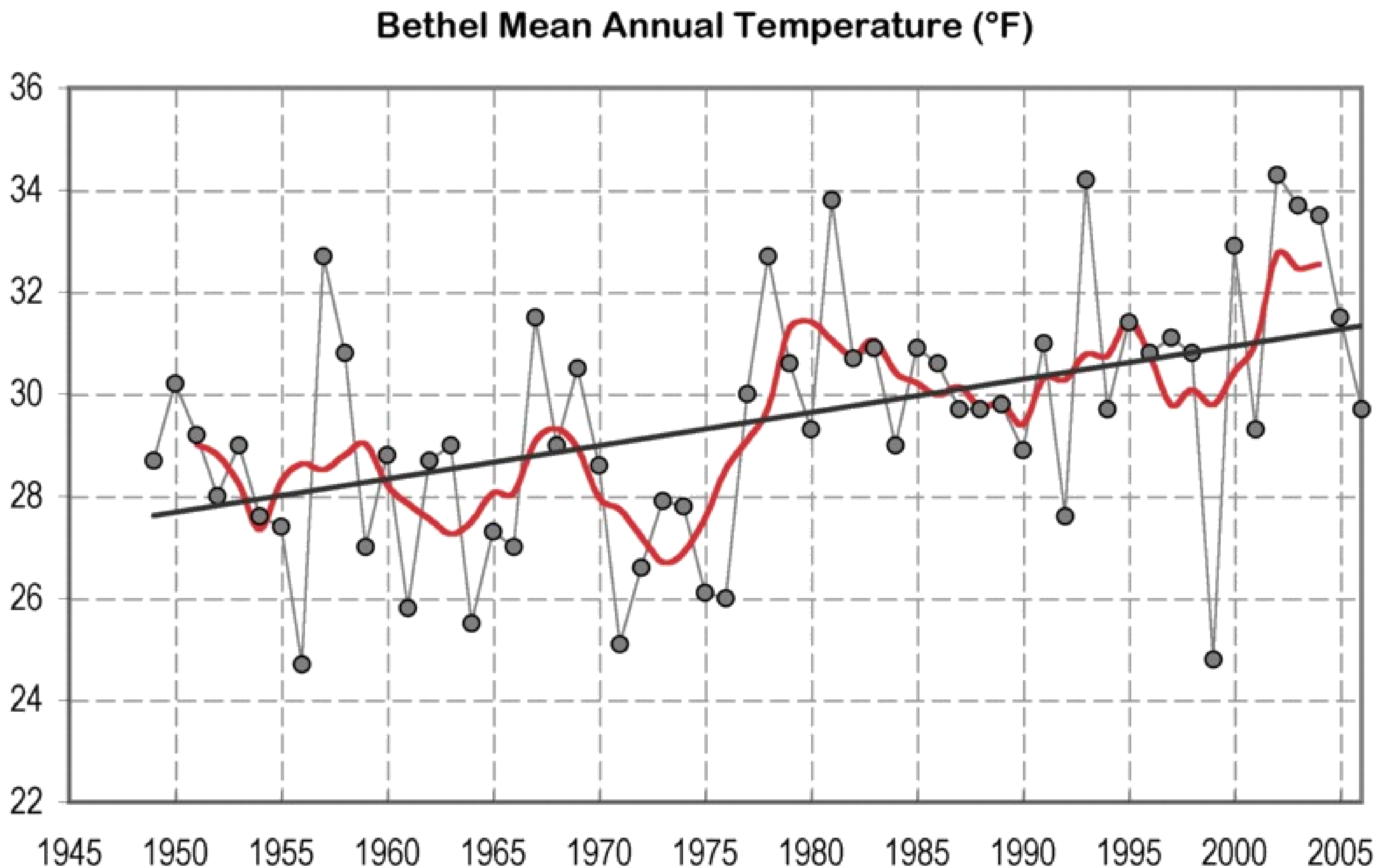

University of Alaska Geophysical Institute Climate Trends

- Increasing mean temperatures may contribute to diminished snow cover, increased surface water, and other conditions that may lead to thawing in the underlying permafrost.
- One manifestation of warming permafrost is the disappearance of lakes, which is thought to be caused when the permafrost under the lake thaws through its entire thickness and allows the lake to drain into the material below. (Science Magazine; June 03, 2005)
  - The following slide illustrates the process.

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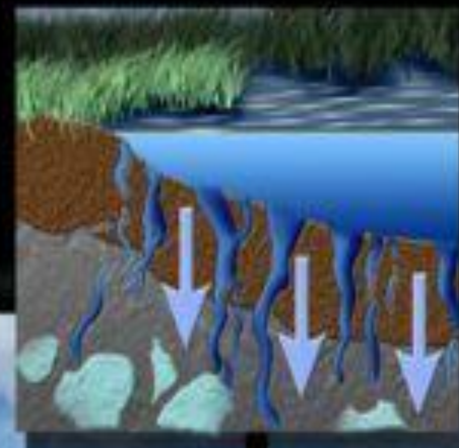
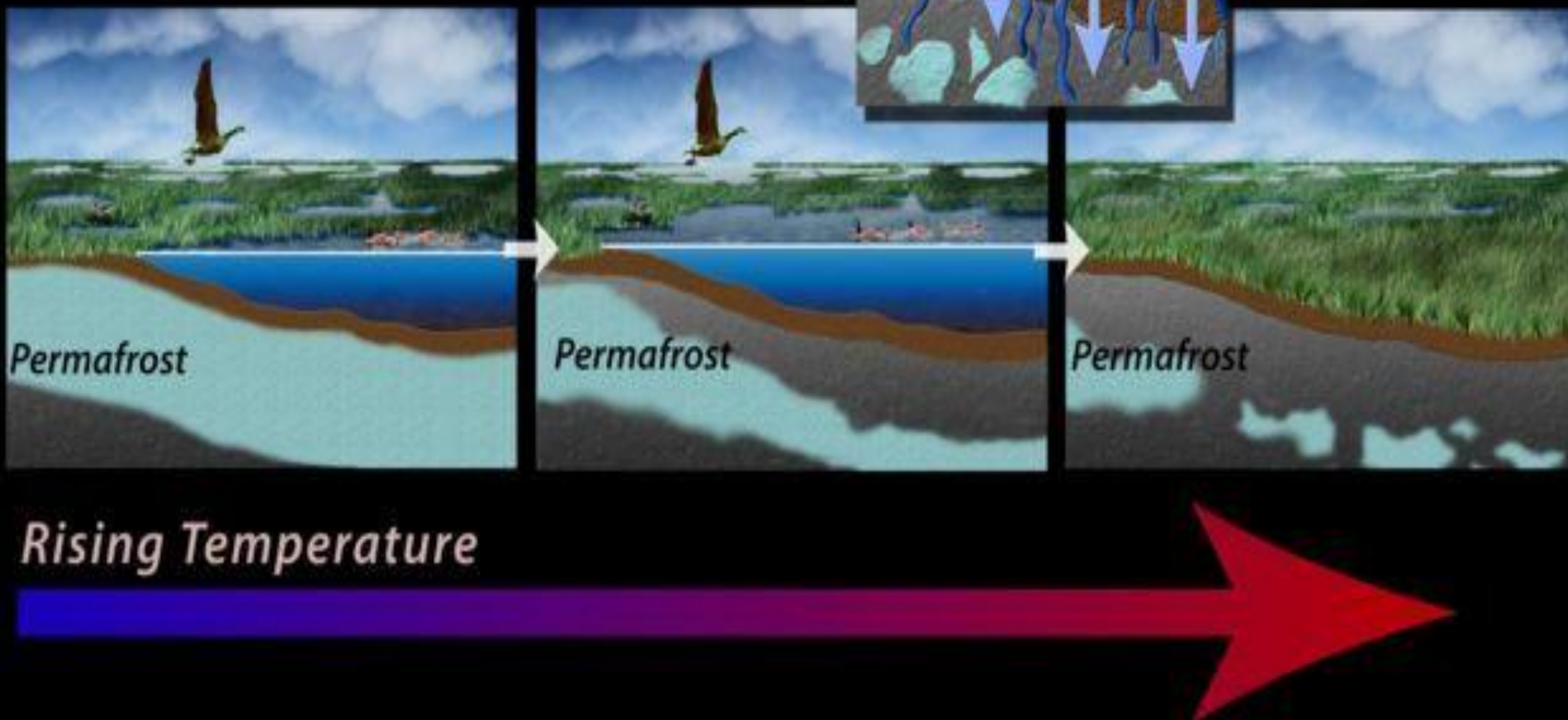
Disappearing Lakes

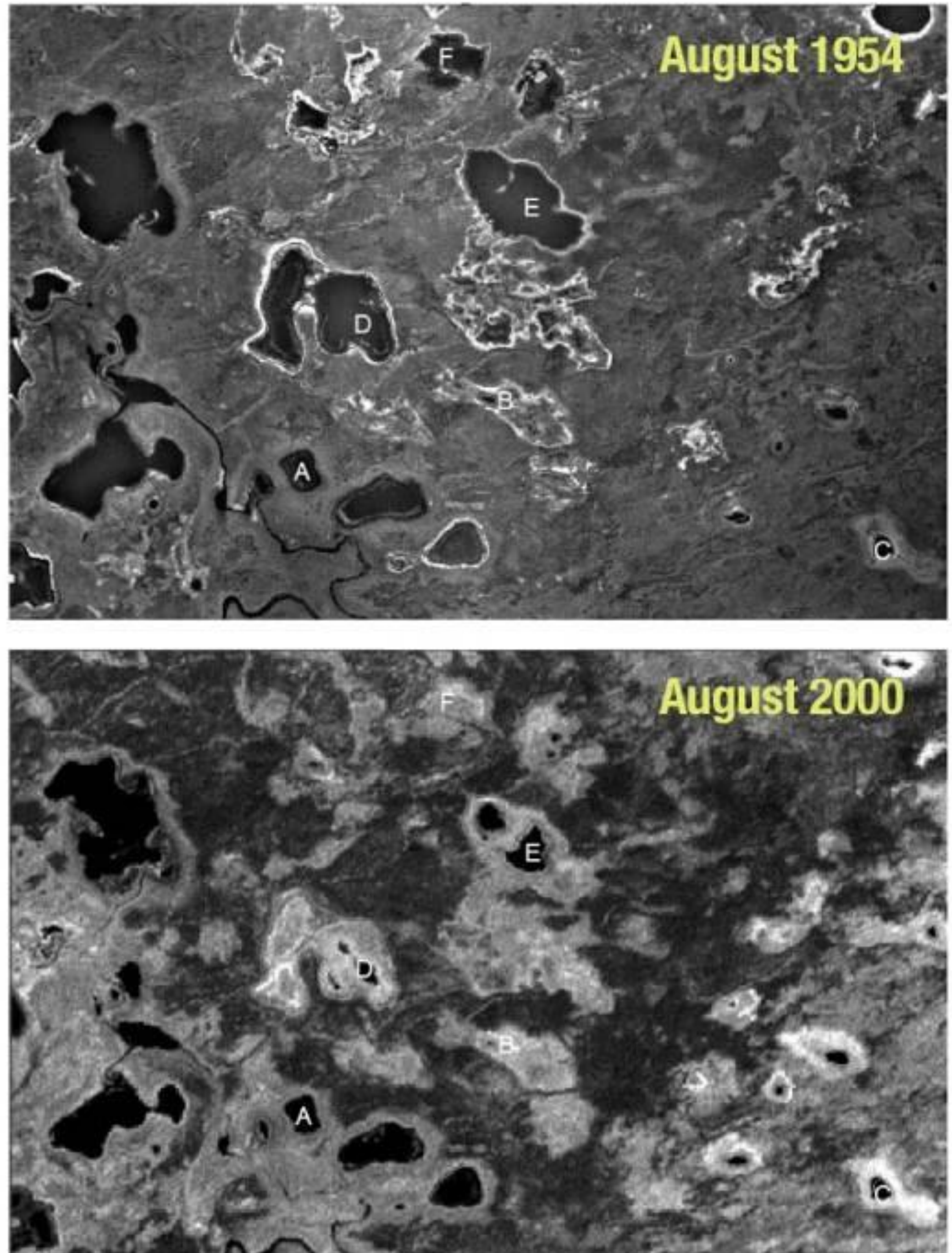
In summer, ice melts across much of the Arctic, forming thousands of lakes. Under each lake is a layer of permanently frozen ground, or permafrost. When the permafrost melts, the water seeps into the ground.





Credit: Nicolle Rager Fuller, NSF

Such processes can be noted today when one flies over the tundra and lake expanses of Western Alaska.



Diminished lake sizes on Alaska's Yukon Flats are evident between 1954 (top: aerial photograph) and the 2000 (bottom: Landsat ETM+ image). Image credit: Institute of Arctic Biology, University of Alaska Fairbanks.

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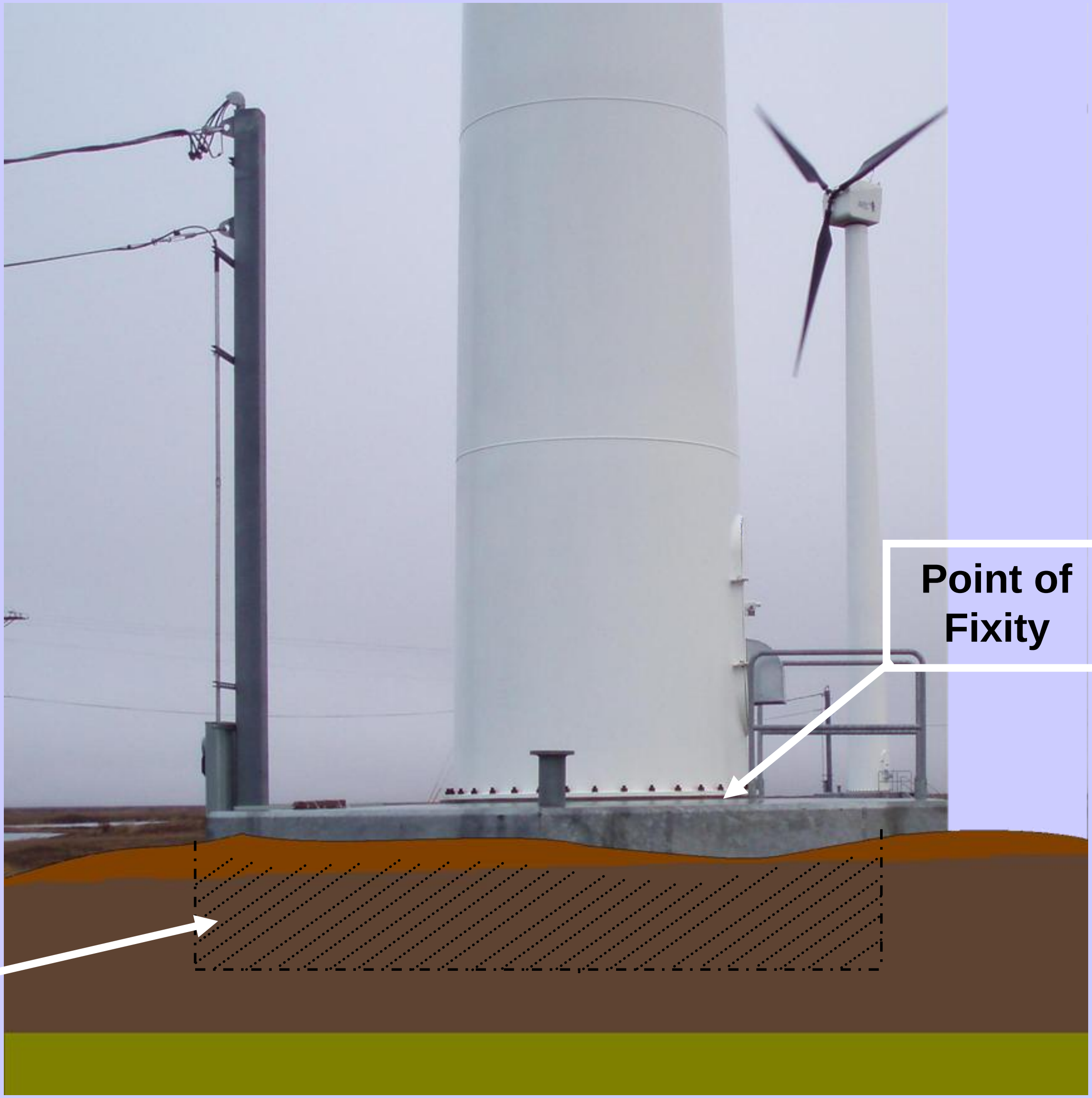
- In 2004, after two years of planning, AVEC and its construction manager, STG Inc., began mobilization of materials and equipment to the Toksook Bay wind project construction site.

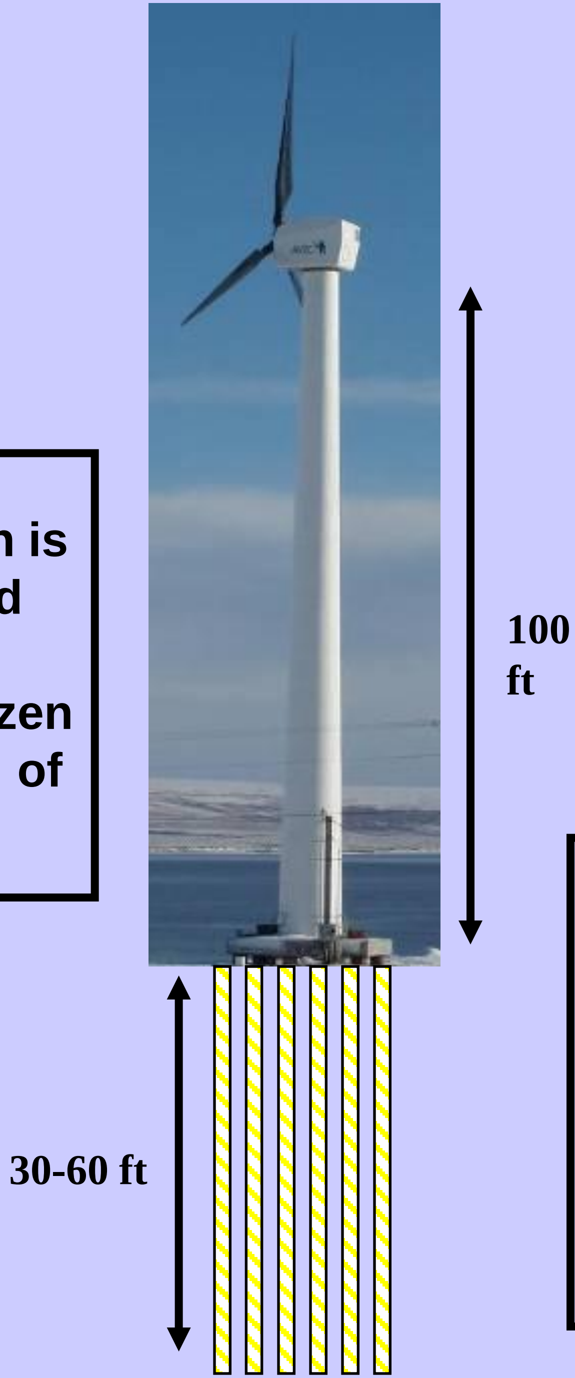
- The site was underlain by frozen soils extending 5 to 15 feet deep over a tilted bedrock base.

- During the course of shipping the towers and piling, the turbine vendor alerted participants to a concern about the deep point of fixity and possible adverse harmonic conditions that might result.

Wind towers on land in most of the world are built with a 'point of fixity' at the base of the tower where it typically rests on a massive concrete foundation.



The tower foundation is elevated to allow cold air to pass over the ground to keep it frozen and to avoid heaving of the tower base.



In order to be properly secured in permafrost, wind turbines may require pilings in the ground which are 1/3 to 2/3 of the height of the tower.

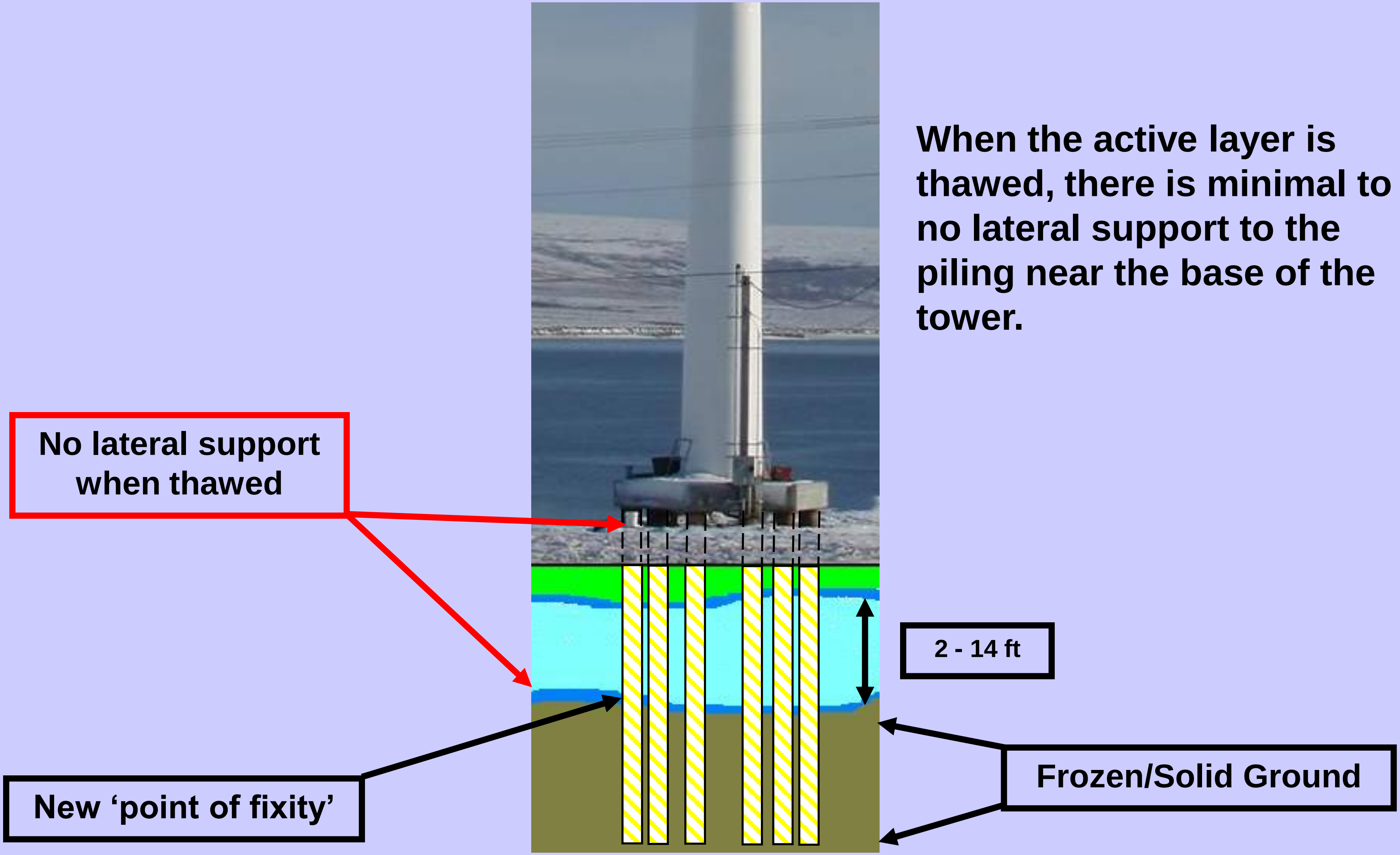
One problem with Alaska permafrost conditions is that the point of fixity may be below the ground surface and may vary throughout the year as the frost line of the active layer migrates.

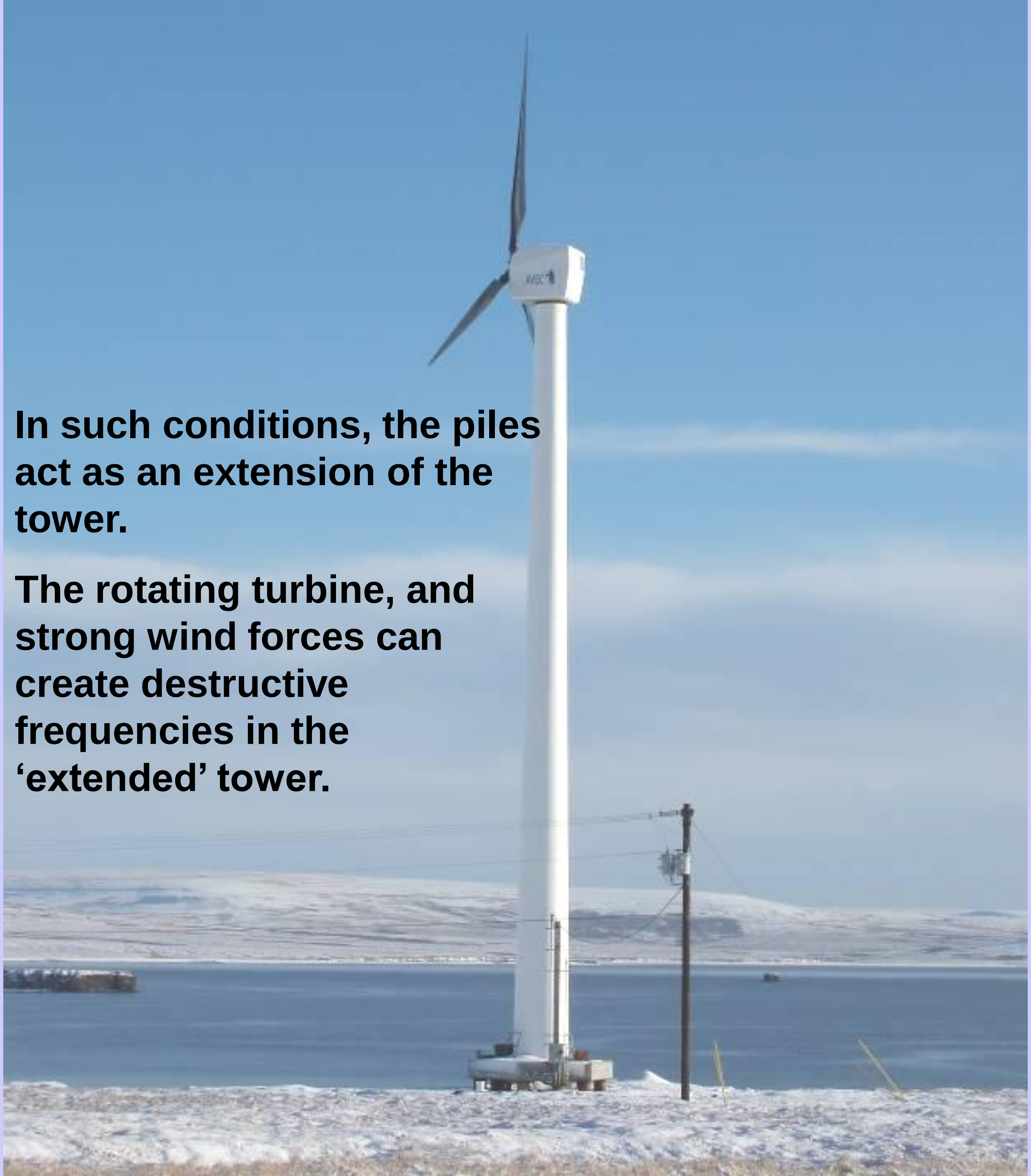
Frozen ground at surface in March

2 to 14 ft

Frost line in September/October after seasonal thaw

When the active layer is thawed, there is minimal to no lateral support to the piling near the base of the tower.





In such conditions, the piles act as an extension of the tower.

The rotating turbine, and strong wind forces can create destructive frequencies in the ‘extended’ tower.

This could be addressed by slowing down the turbine and losing valuable energy, especially in the late part of the year when the ground is thawed to its deepest, and when wind speeds are excellent for power production.

This approach loses energy and requires complex monitoring of the system operation.

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Alternative Solution

An alternative solution is to stiffen the foundation and damper the structure by adding mass.

In the case of two projects involving six towers in permafrost environments at Toksook Bay and Kasigluk, Alaska, pile foundations were modified by adding a 130,000 pound, concrete and steel mass between the tower base, and the piles.

In Kasigluk, foundation piles were used with 24 inch helices to resist uplift and with thermal siphons to keep the ground frozen. The objective was to reduce the thickness of the active frost layer, and bring the point of fixity closer to the tower base. Temperature Acquisition Cables (TAC) have been installed at each tower in Kasigluk to monitor changes in ground temperature and to detect thawing below each tower.

Overview – Toksook Bay

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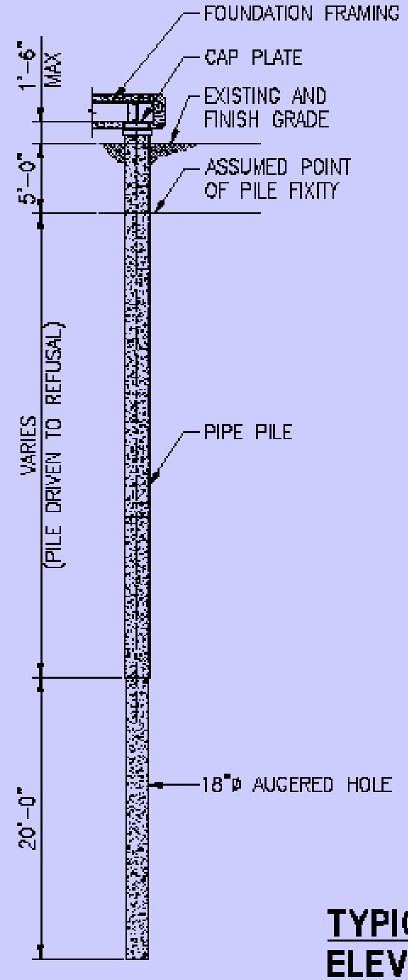

TYPICAL PILE ELEVATION

- Holes pre-drilled
- Piles driven to refusal
- Piles later cut

Drilling out center of piles to 20’ below end of pile

Rock bolts would be placed into the rock and tensioned to the pile cap.

Additional Mass was added by placing a rebar cage and concrete in the pile.

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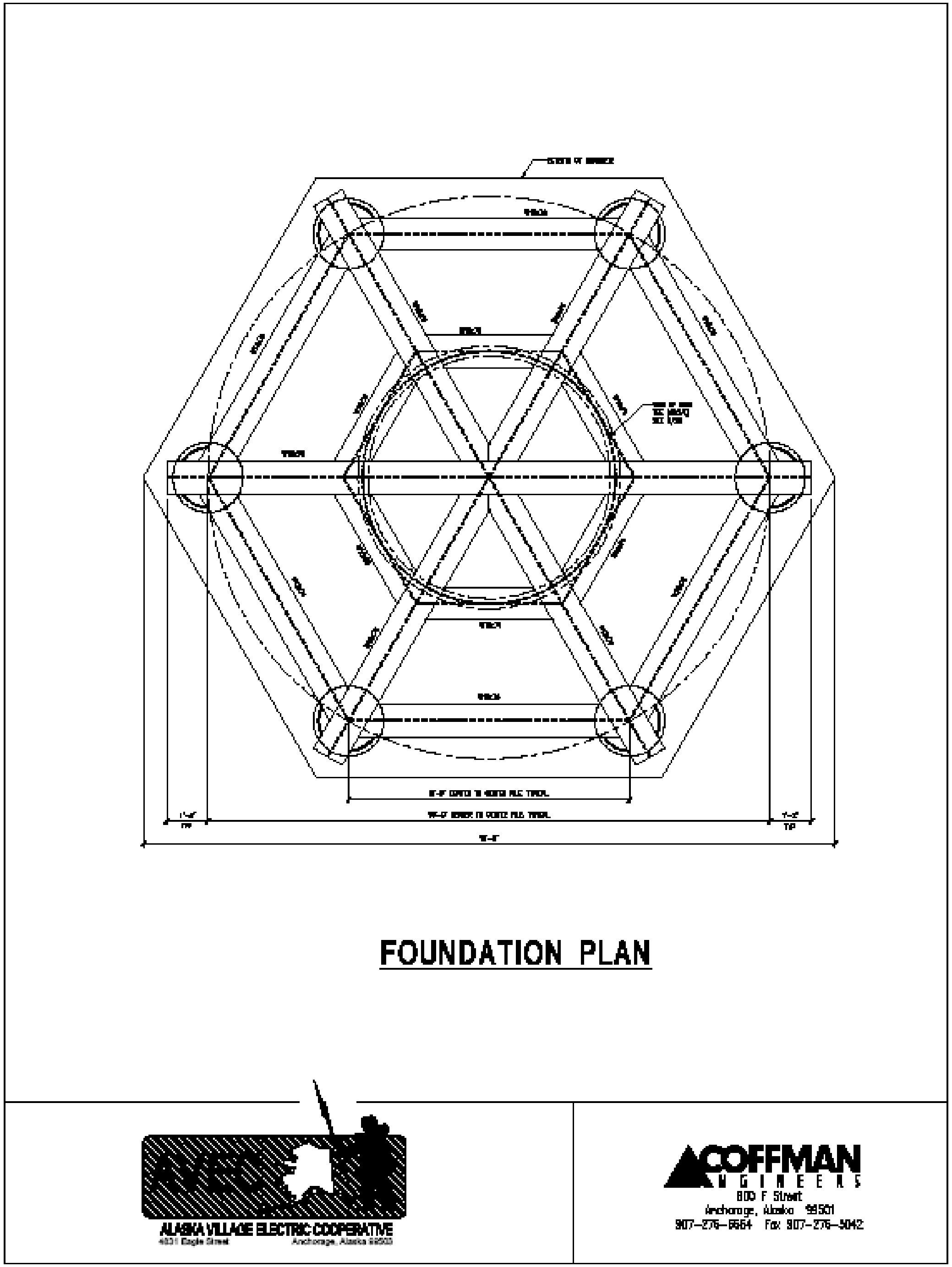
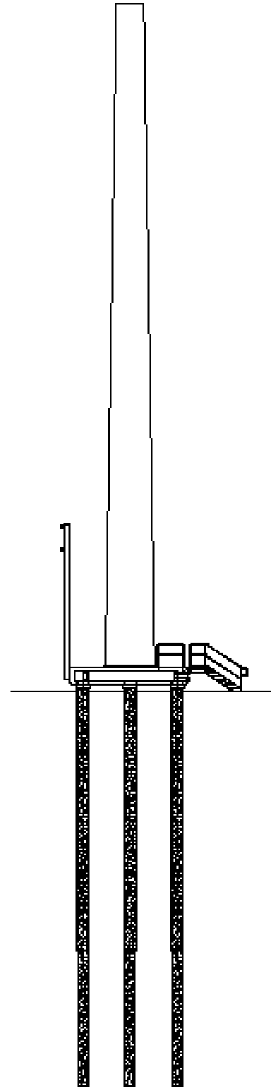
Six piles for a single tower foundation


Piles with Met tower

The steel foundation cap contains I-Beams to connect the piles and a ring to make the tower base.



Steel Foundation Star (Typical of 3)



TOWER & FOUNDATION SECTION

ALASKA VILLAGE ELECTRIC COOPERATIVE

COFFMAN ENGINEERS
800 F Street
Anchorage, Alaska 99501
907-276-6664 Fax 907-276-5042

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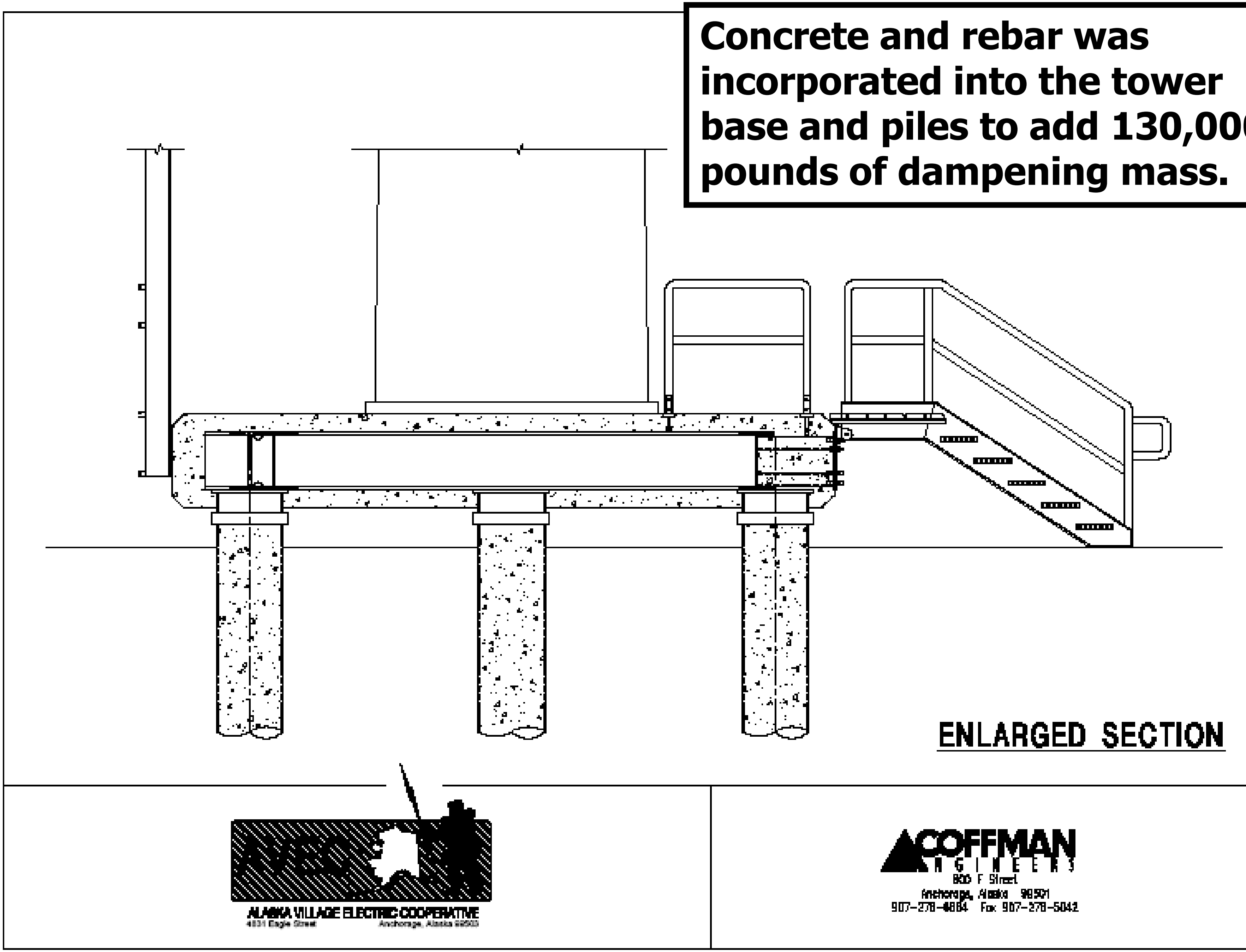
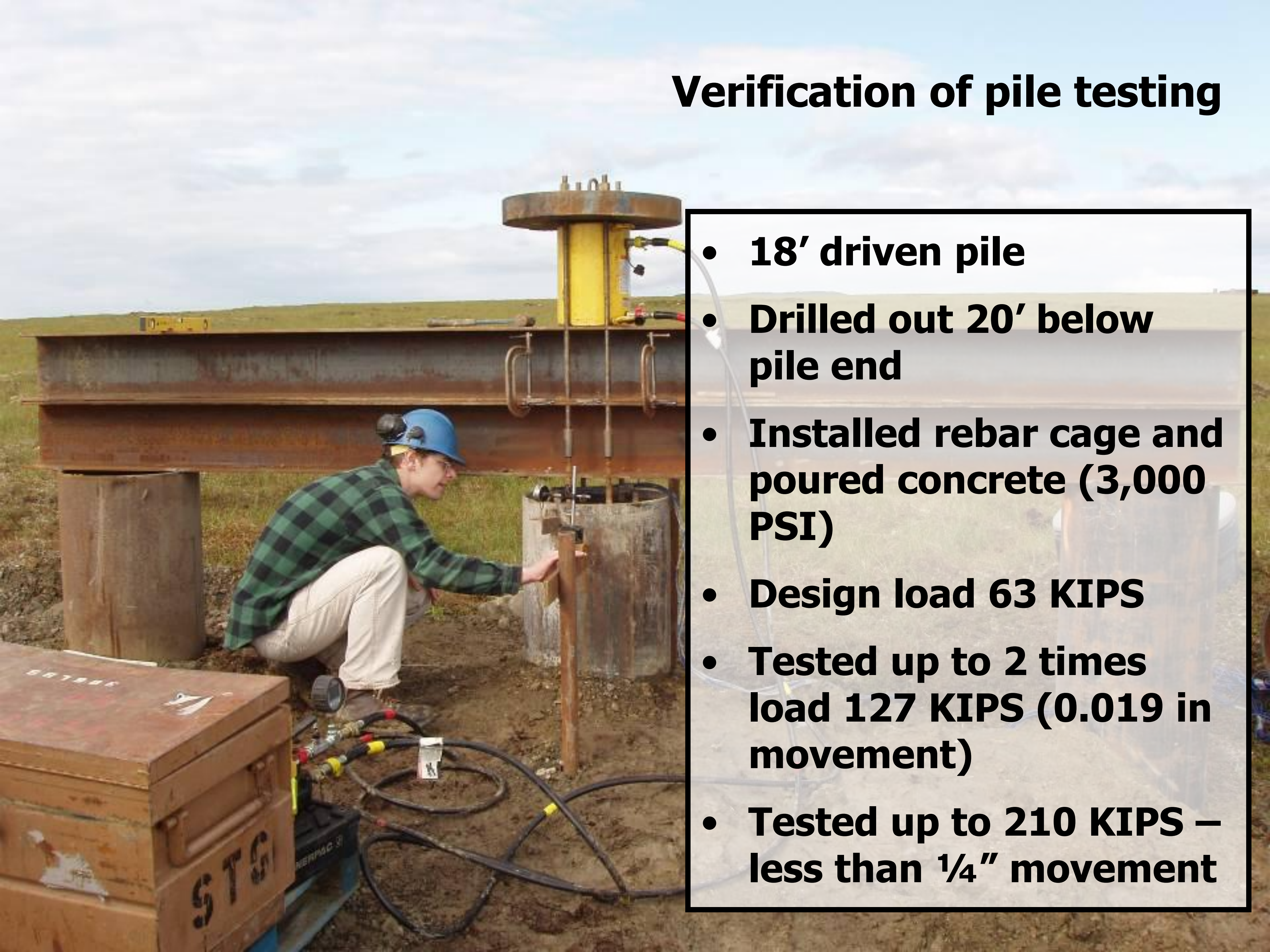
Concrete and rebar was incorporated into the tower base and piles to add 130,000 pounds of dampening mass.

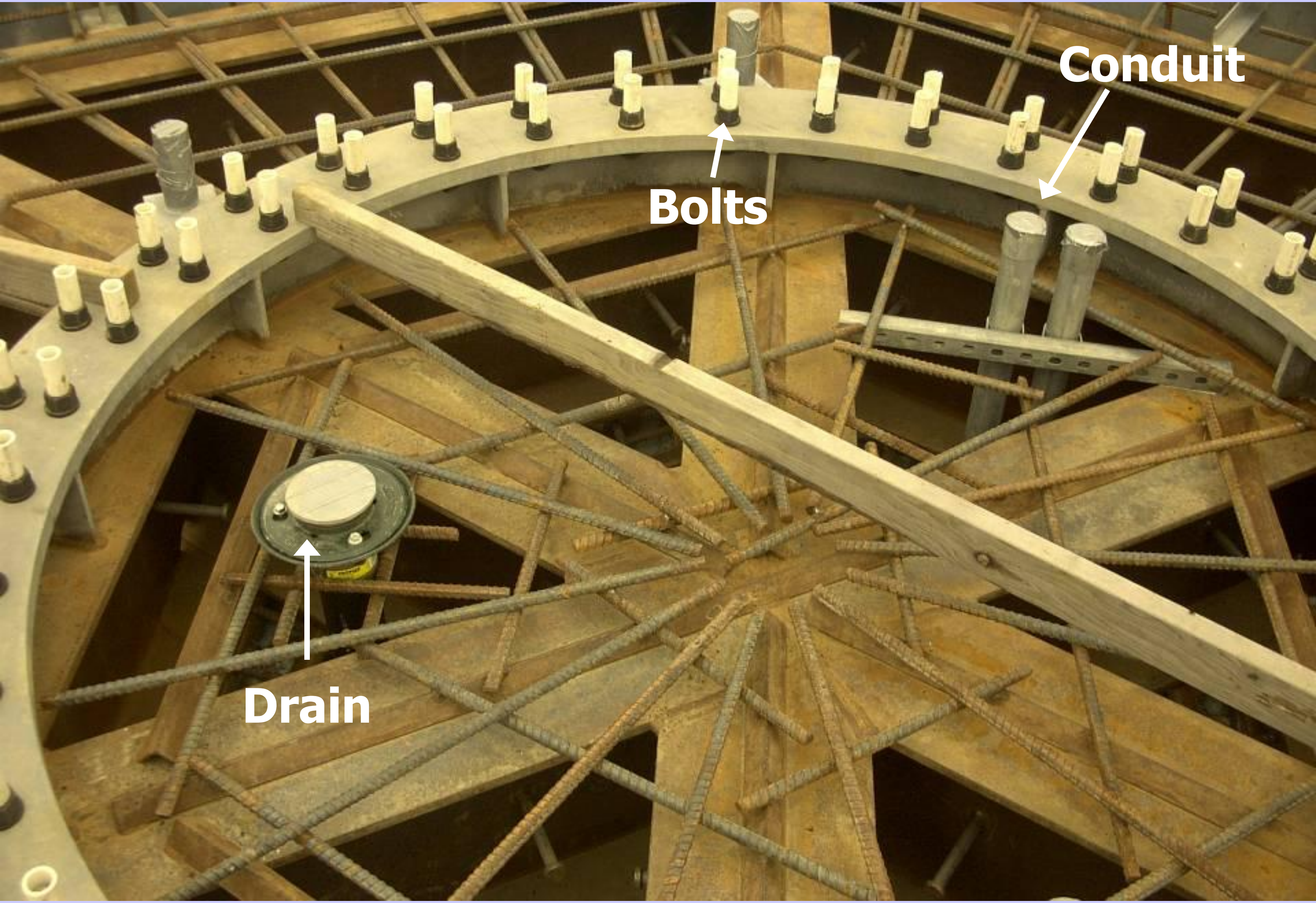


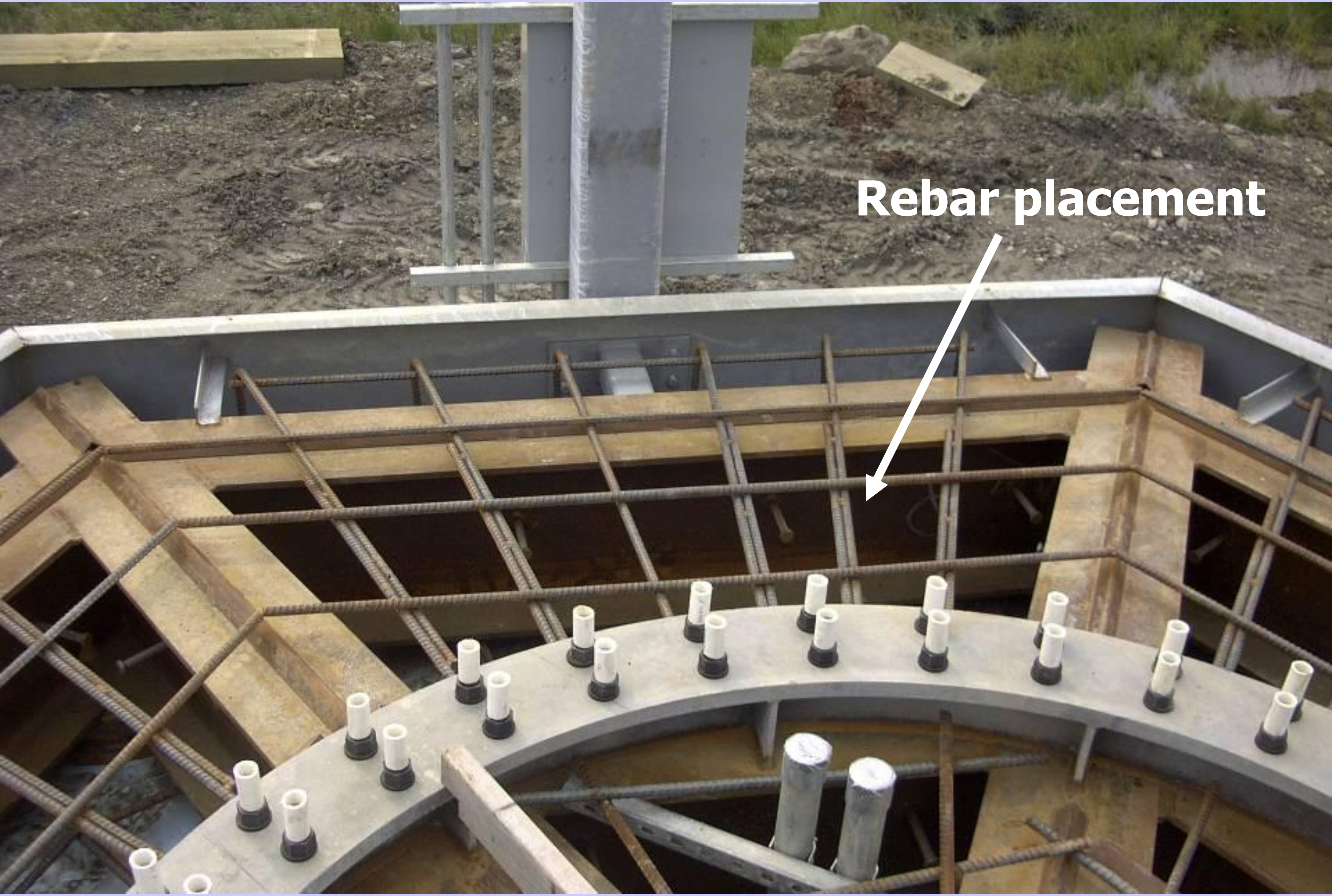
Rebar Cage to go into a pile.



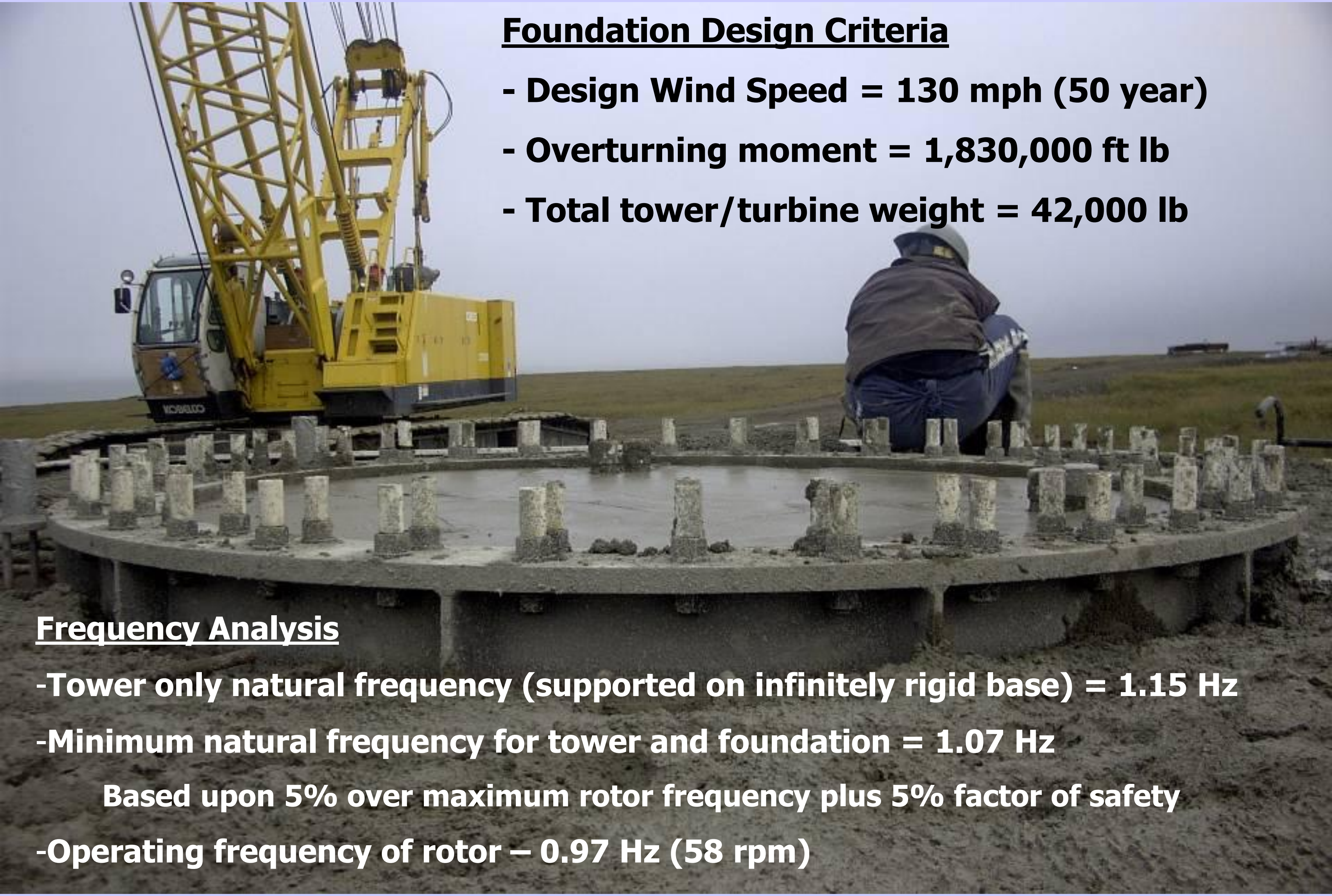
Verification of pile testing

- 18′ driven pile
- Drilled out 20′ below pile end
- Installed rebar cage and poured concrete (3,000 PSI)
- Design load 63 KIPS
- Tested up to 2 times load 127 KIPS (0.019 in movement)
- Tested up to 210 KIPS – less than ¼″ movement


Conduit
Bolts
Drain


Rebar placement


Meter base and riser to connect to overhead distribution system
Forms were placed underneath the foundation star to hold the concrete in place until it cured.



Foundation Design Criteria

- Design Wind Speed = 130 mph (50 year)
- Overturning moment = 1,830,000 ft lb
- Total tower/turbine weight = 42,000 lb

Frequency Analysis

-Tower only natural frequency (supported on infinitely rigid base) = 1.15 Hz

-Minimum natural frequency for tower and foundation = 1.07 Hz

Based upon 5% over maximum rotor frequency plus 5% factor of safety

-Operating frequency of rotor – 0.97 Hz (58 rpm)

The Wind Turbine Controller is placed before the tower is set.

Danwin Tower Midway Platform

Danwin Tower Inside Flange/Bolt Holes

Tower/Turbine Specifications

-108 feet from ground level to center of rotor

- Rotor diameter (3 blades) = 61 feet

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View from the top!
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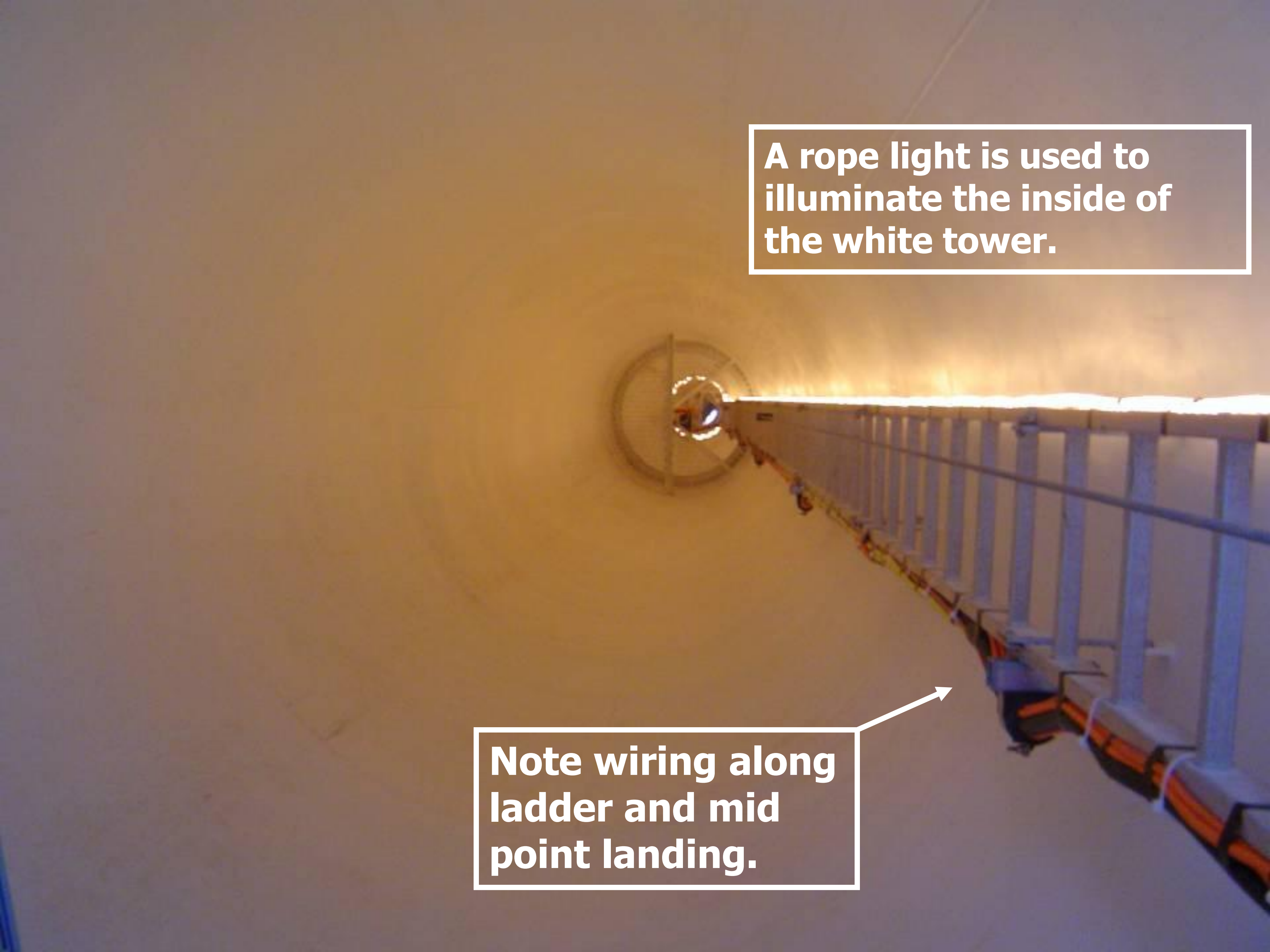
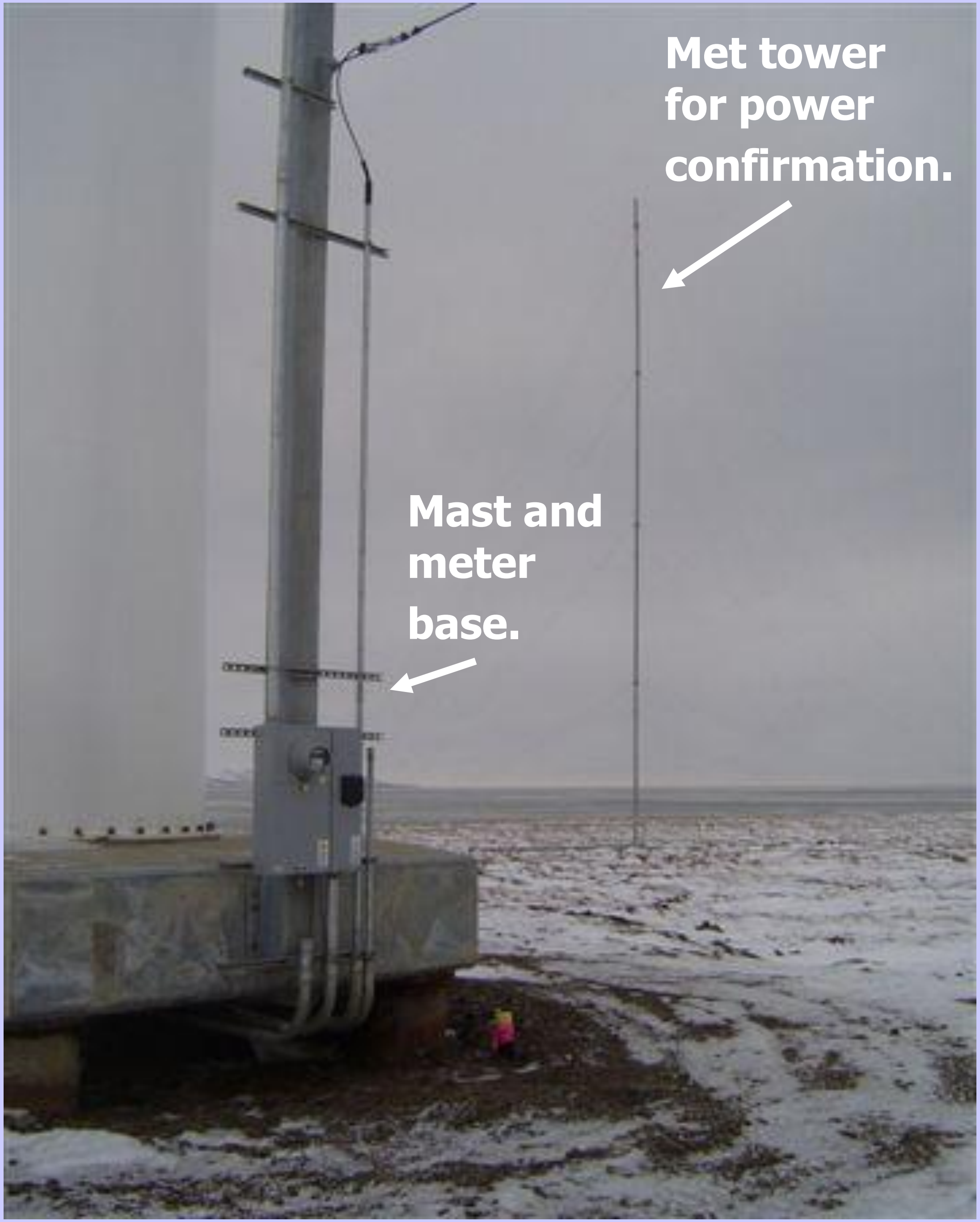
13,950 lb nacelle being prepared for its lift to the top of a 32 meter tower.


Cleaning the yaw gear teeth prior
to setting it on top of the tower.

A Nacelle and tower are placed on a cured foundation.

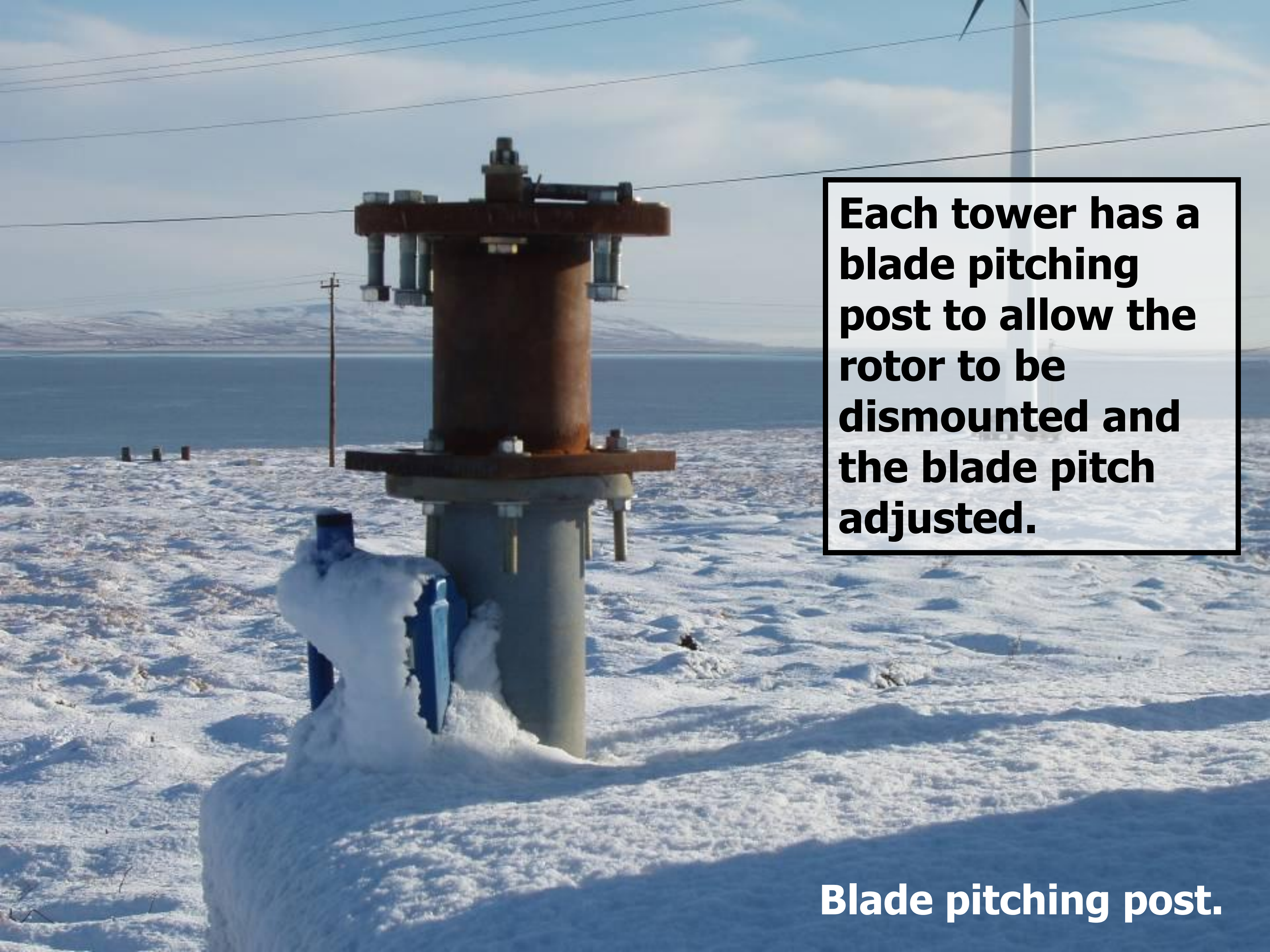

Second tower section
being put in place

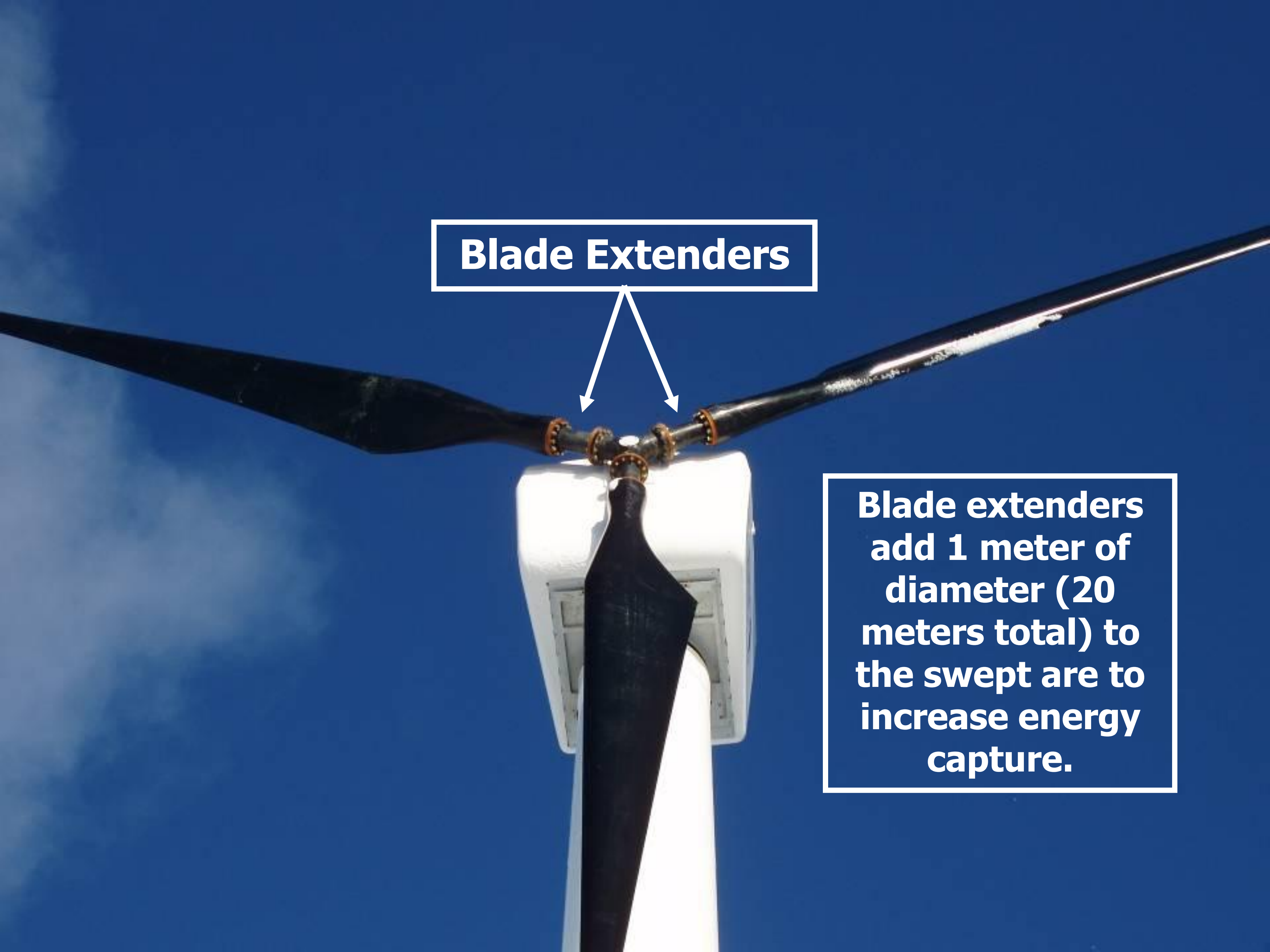

A rope light is used to illuminate the inside of the white tower.
Note wiring along ladder and mid point landing.


Met tower
for power
confirmation.
Mast and
meter
base.


Concrete & Steel Mass
Meter Base

Three wind turbines completed at Toksook Bay.


Each tower has a blade pitching post to allow the rotor to be dismounted and the blade pitch adjusted.
Blade pitching post.


Blade Extenders
Blade extenders add 1 meter of diameter (20 meters total) to the swept are to increase energy capture.

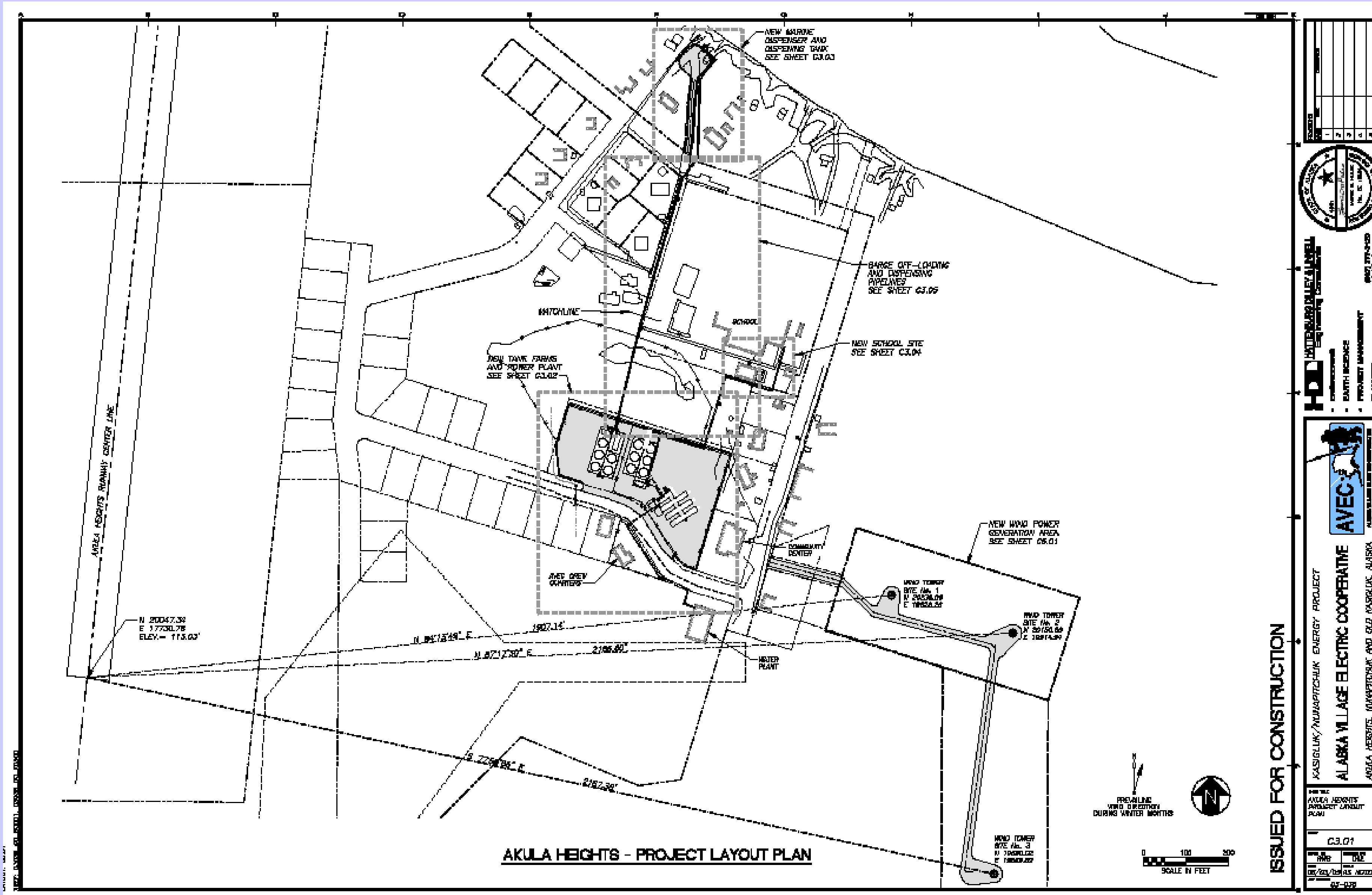

Tightening hub to turbine

Blades with blade extenders

At Akula Heights (also called Kasigluk) three NW 100 Turbines were installed east of the village on frozen sand and silt. No bedrock was encountered.

- Mass was added by filling the steel foundation star with concrete, as in Toksook Bay.
- Because there was no bedrock, piles with 24 inch helices were screwed into pilot holes predrilled into the ground.
- Thermal siphons were added between, and outward of the piles to extract heat from the soil.

Special Equipment was required to twist the helical piles into the ground


NEW MARINE DISPENSER AND DISPENSING TANK SEE SHEET C3.03
BARGE OFF-LOADING AND DISPENSING PIPELINES SEE SHEET C3.05
MATCHLINE
SCHOOL
NEW SCHOOL SITE SEE SHEET C3.04
NEW TANK FARMS AND POWER PLANT SEE SHEET C3.02
NEW WIND POWER GENERATION AREA SEE SHEET C6.01
COMMUNITY CENTER
AVEC CREW QUARTERS
WATER PLANT
AKULA HEIGHTS RUNWAY CENTER LINE
N 20047.34
E 17730.78
ELEV.= 115.03'
1907.14'
2186.80'
2187.38'
WIND TOWER SITE No. 1
WIND TOWER SITE No. 2
WIND TOWER SITE No. 3
PREVAILING WIND DIRECTION DURING WINTER MONTHS
SCALE IN FEET
0
100
200
AKULA HEIGHTS - PROJECT LAYOUT PLAN
ISSUED FOR CONSTRUCTION
KASIGLUK/NUNAPITCHUK ENERGY PROJECT
ALASKA VILLAGE ELECTRIC COOPERATIVE
AKULA HEIGHTS, NUNAPITCHUK AND OLD KASIGLUK, ALASKA
AVEC
HDR
EARTH SCIENCE
PROJECT MANAGEMENT
PLANNING
AKULA HEIGHTS PROJECT LAYOUT PLAN
C3.01

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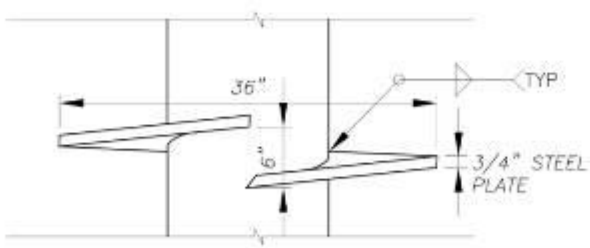

3 **SECTION - TYPICAL HELIX**

SCALE: NONE

NOTES

1. ALL PILES SHALL BE INSTALLED OPEN ENDED WITH ENDS CUT AT 45 DEGREES.
2. THE CONTRACTOR SHALL SUPPLY THE ENGINEER WITH THE INSTALLATION TORQUE OF EACH PILE. THE TORQUE VALUE SHALL BE AVERAGED OVER 24-INCHES DURING INSTALLATION OF EACH PILE WITHIN 5 FEET OF THE FINAL PILE INSTALLATION DEPTH.
3. ALL PIPE SPLICING SHALL BE FULL PENETRATION BUTT WELDS.
4. ALL WELDING, WELD PROCEDURES, PROCEDURES SPECIFICATIONS, AND WELDER QUALIFICATIONS SHALL BE IN ACCORDANCE WITH AWS D1.1. WELD ELECTRODES SHALL BE E70XX MINIMUM.
5. ALL WELD SIZES SHALL BE THE THINNER OF THE TWO METALS JOINED, UNLESS NOTED OTHERWISE.
6. FIELD WELD 1/2"x12" LONG, STEEL PLATE TO TOWER BASE AND CLAMP TO THERMOPROBE ADJUST WIDTH OF STEEL PLATE AS NECESSARY. DO NOT WELD TO THERMOPROBE.

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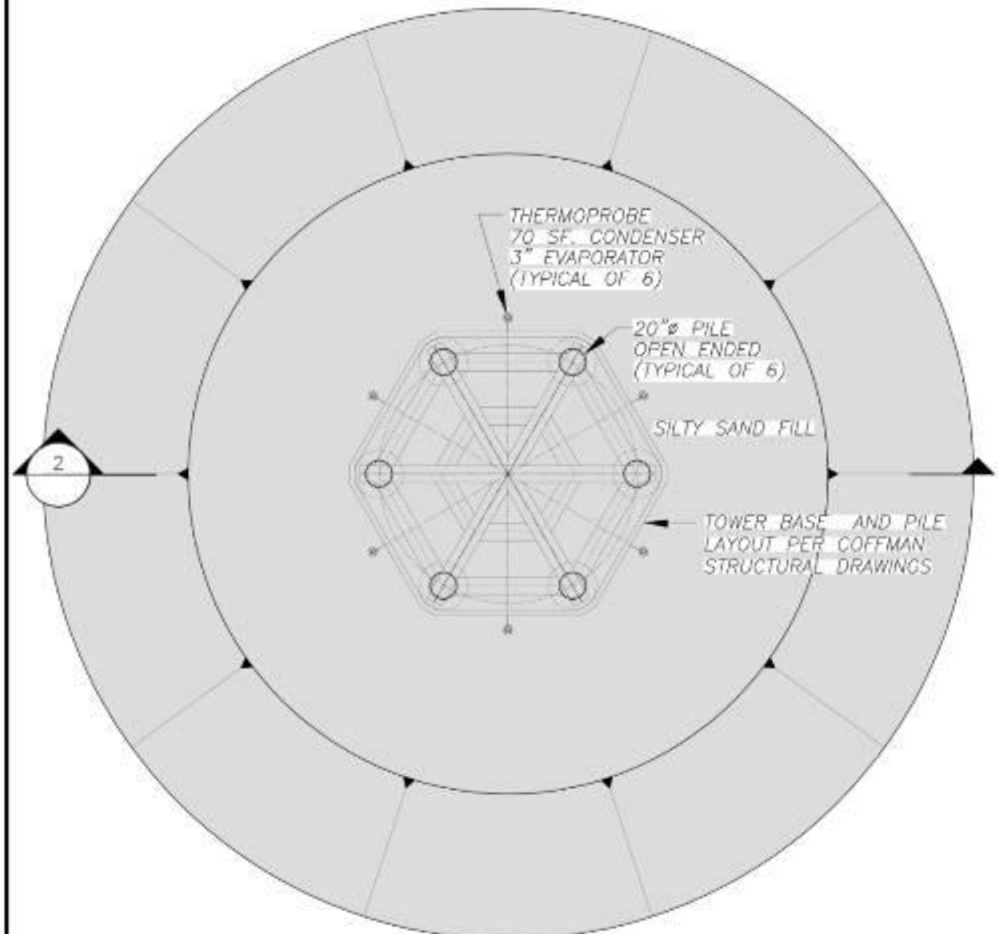

WIND GENERATION TOWER BASE PILE LAYOUT PLAN

SCALE: NONE

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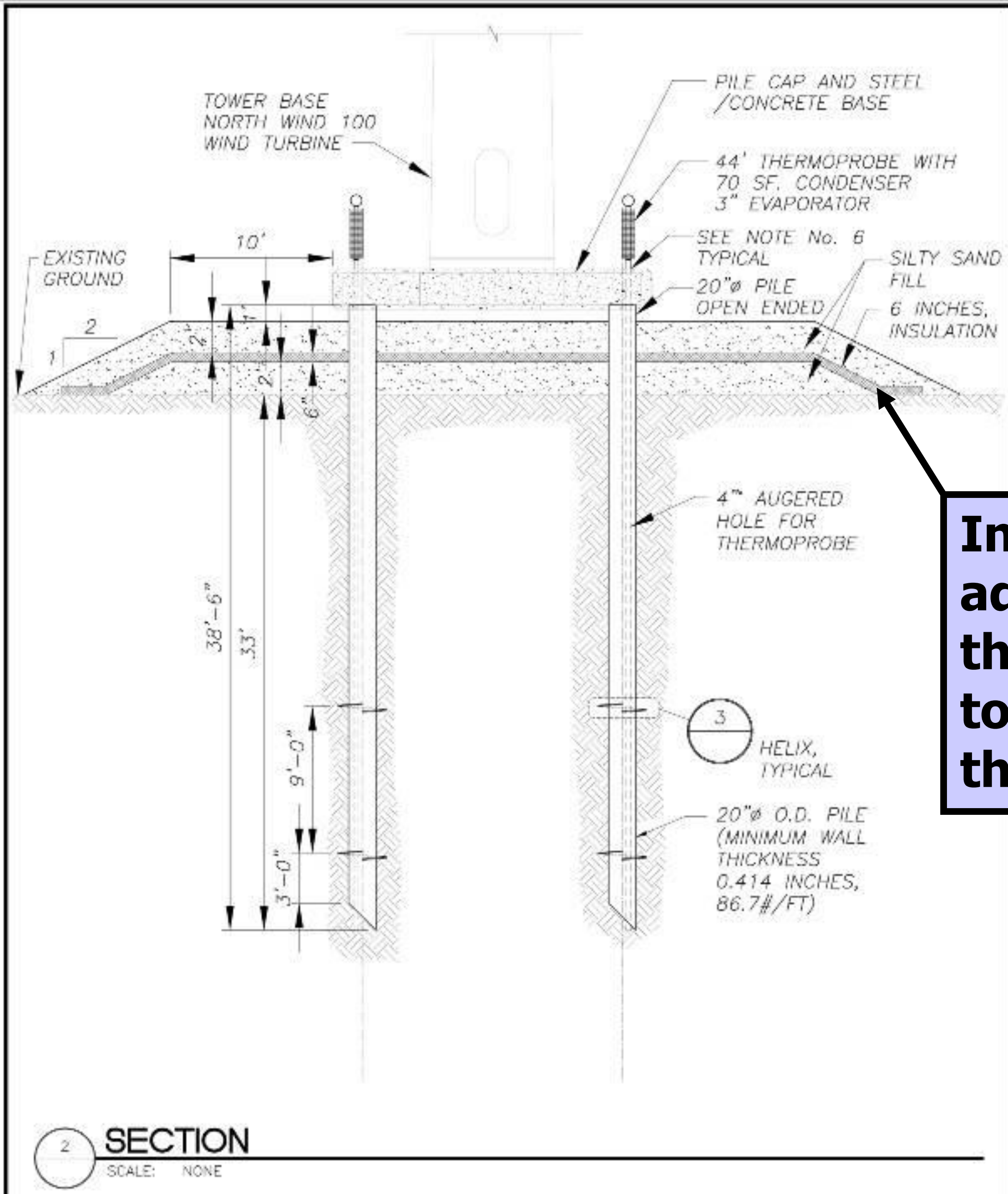

Insulation was added below the tower base to resist thawing.

Installing thermopiles during the Spring at Kasigluk


Installed thermopiles at Kasigluk

Temperature sensor strings, similar to the following, have been installed at Kasigluk to monitor seasonal and long term changes in permafrost temperatures.

TAC Images courtesy of Beaded Stream

TOP LEFT: Temperature Acquisition Cable (TAC) and Reader

BOTTOM LEFT: All TACs are permanently labeled with their serial number which ties in with owner information, last calibration date, number and spacing of sensors, & sensor identifications.

RIGHT: An artists image of what an installed TAC looks like.

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Lessons Learned

- Geotechnical information is critical
  - In areas of complex geology or a highly varied active layer, it is useful to have information from the actual turbine site in order to recognize local variances.
  - When acquiring geotechnical information, also acquire the permafrost temperature and, if possible, install a temperature acquisition cable to monitor temperatures up to the time of construction.
  - Continue thermal monitoring of the turbine site after construction.

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- Materials
  - The lack of appropriate local aggregate for concrete can increase costs. Appropriate aggregate may have to be imported in addition to importing cement and mixing equipment.
  - Waiting for the concrete to cure and then testing it can consume valuable time and may require a demobilization and remobilization of the crew.
  - An all steel foundation would require larger components to provide desired stiffness, but may reduce construction complexity by eliminating tasks involving concrete. Portions of such a foundation could be prefabricated and shipped to the site.

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- Frequency Modeling should include the pile foundation.
  - In a permafrost environment the point of fixity will rise and fall along the pile during the seasonal change.
  - Under such conditions the piles may behave as an extension of the tower and the turbine, tower and foundation systems may interact to develop a frequency that could be damaging.

- Mitigation
  - Adverse harmonics could be mitigated through:
    - Adjusting turbine rpm, but slowing the turbine would reduce valuable energy output.
    - Addition of mass to dampen system response at known frequencies.
    - Stiffening the piles, pile caps, or tower.

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