SNOW CREEP INVESTIGATIONS NEAR THE SNETTISHAM TRANSMISSION LINE 609-76

IN SOUTHEAST ALASKA NEAR JUNEAU

By

Robert L. Meyer 1/

Introduction

Juneau, capital of Alaska, is located in the southeast panhandle of the State and with its suburbs has a population of 18,000 people. The area developed as a gold mining community in the late 1800's, and mining continued to be the primary source of employment until the late 1930's. Timber harvest, commerce, commercial fishing, and employment by government agencies have provided the major cash income for the Juneau area in recent years.

The electrical power generation system for the community evolved from relics of hydropower and diesel generators, some of which remain from the gold mining days. In November of 1961, Congress authorized the development of the Snettisham project to meet the increasing needs for electrical power in the Juneau area.

The Snettisham Project

The Snettisham hydroelectric project is located 28 miles (44 km) southeast of Juneau in the Tongass National Forest and utilizes storage and runoff from Long and Crater Lakes. The area is very rugged and almost completely unpopulated, with no existing roads other than those constructed at the project site, and is accessible only by boat or air. The climate is characterized by relatively warm winters, cool summers, and heavy precipitation. Average annual rainfall is approximately 140 inches (355 cm), with snow accumulations of 10 feet (305 cm) or more. Forest cover, predominately western hemlock and Sitka spruce, extends from sea level to about 1,500 feet (460 m). Ultimate capacity of the three-unit sea level underground powerplant will be 74,000 kw. The two first-stage units (23,350 kw each) are powered with water from Long Lake, carried through 8,200 feet (2500 m) of tunnel and 1,700 feet (518 m) of penstock. Power is carried to a substation just south of Juneau through 41.6 miles (66.9 km) of overhead line and 15,400 feet (4,750 m) of underwater cable energized to 138 kv. Crater Lake development will provide an additional 27,000 kw of capacity.

The Problem

Electrical power from Snettisham was first supplied to Juneau in October of 1973. In February of 1974, the city of Juneau, Alaska, experienced power outages caused by the failure of three towers on the transmission line connecting the Snettisham hydroelectric project with the city of Juneau. The towers which failed were all located on Salisbury Ridge, approximately 10 miles (16 km) southeast of Juneau. The topography of this area is typical of southeast Alaska, consisting of rugged mountains and deep fjords. The lower slopes of Salisbury Ridge are covered by spruce and hemlock forests, and the upper slopes contain permanent snowfields and glaciers. Because of the remoteness of the area, absence of roads, and ruggedness of the terrain, access to the transmission line is by helicopter. During the fall and winter season, Salisbury Ridge is often shrouded by heavy cloud cover or buffeted by high velocity winds. Actual accessibility to Salisbury Ridge is very limited and may not be possible for several consecutive weeks during the winter months.

The first tower failed 15 February 1974, and it was 21 February before it was possible to inspect the site on the ground. By this time a total of three towers were down. There was considerable speculation on the causes for the tower failures, but unfortunately no on-site information on wind velocity, snow creep, or icing conditions along the ridge existed.

The transmission line had been designed to withstand winds of 113 mi/hr (182 km/hr) with bare cables, or 40 mi/hr (64 km/hr) with 1/2-inch (1.27 cm) of ice or no wind with

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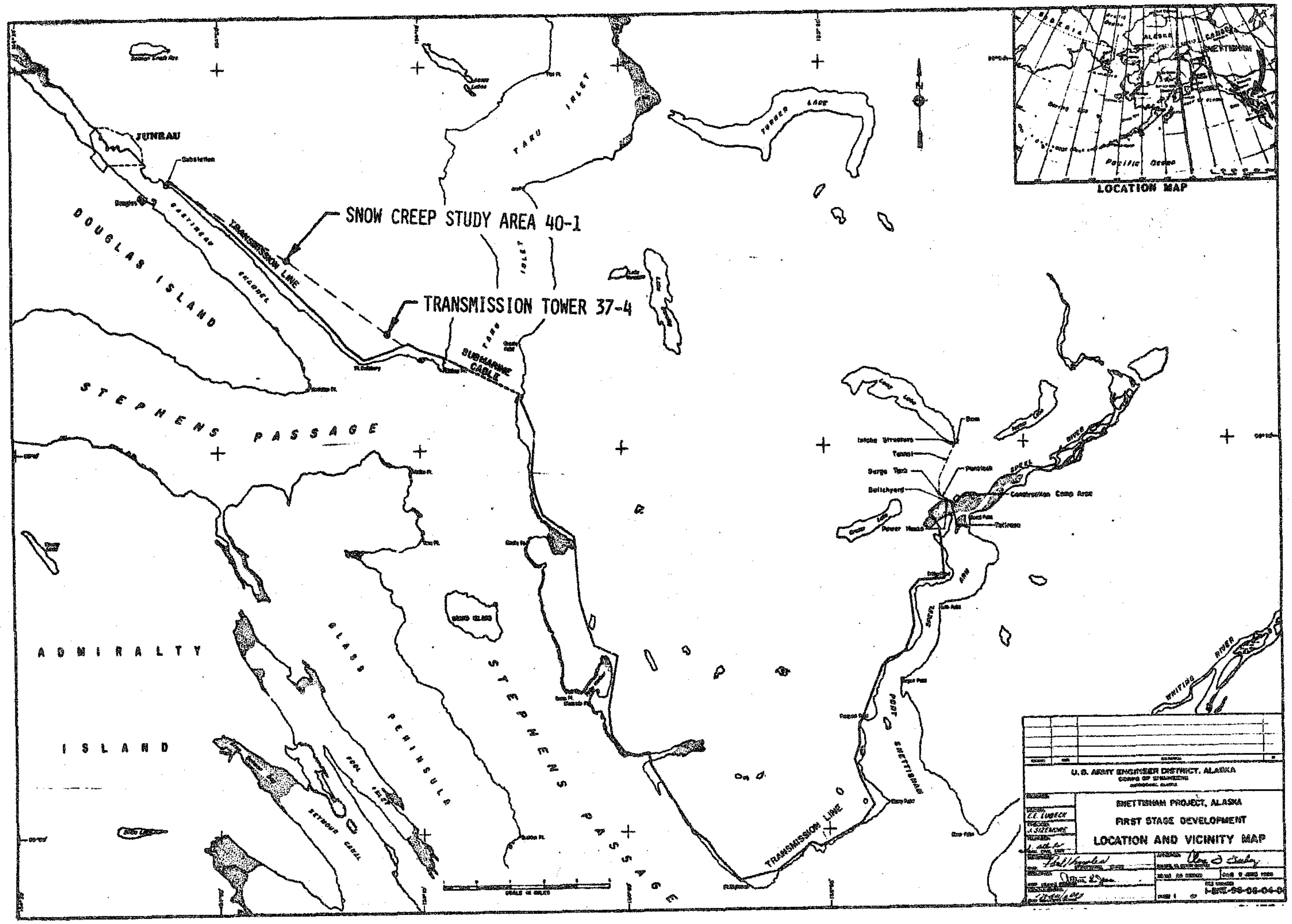

LOCATION MAP
JUNEAU
Substation
SNOW CREEP STUDY AREA 40-1
TRANSMISSION LINE
TRANSMISSION TOWER 37-4
SUBMARINE CABLE
DOUGLAS ISLAND
TAKU INLET
STEPHENS PASSAGE
ADMIRALTY
ISLAND
GLASS PENINSULA
STEPHENS PASSAGE
TRANSMISSION LINE
PORT SNETTISHAM
Dam
Intake Structure
Tunnel
Surge Tank
Switchyard
Power House
Construction Camp Area
SPEEL RIVER
WHITING RIVER
U. S. ARMY ENGINEER DISTRICT, ALASKA
SNETTISHAM PROJECT, ALASKA
FIRST STAGE DEVELOPMENT
LOCATION AND VICINITY MAP

2 inches (5.08 cm) of rime ice. Basis for the design criteria was National Weather Service generalized estimates of winds in the vicinity. Unfortunately, the only data available to the National Weather Service was obtained from near sea level locations. When the tower failures were initially inspected on the ground, the cause of failure was not apparent. They were aluminum tangent type, guyed towers attached with a flexible coupling to a base plate imbedded in concrete. The lower 15 feet (4.6 m) of the first tower which failed was buried in high density, "hard" packed snow, and the base plate was not visible for inspection. Following field inspection of the damaged towers, there were several theories about why the towers failed. The principal theories were:

a. Snow creep pushed the base of the tower off of its pad and/or deformed the base, causing structural failure.

b. A combination of high winds and icing conditions overloaded the towers and caused them to collapse.

c. Very high winds overloaded the towers and caused structural failure.

Because of the inconclusive results of the field inspection, it was decided that basic data on wind velocity and snow creep would be necessary for analysis of the tower failures. Because of the severe winter conditions, it was impractical to excavate the base of the tower and locate the anchor plate.

A literature search was conducted for information on snow creep, and no empirical information was found. The available theoretical information was primarily related to avalanche control structures and was based on theories related to soil mechanics (Haefeli) or fluid flow (Bucher).

The Data Gathering Program

A snow survey was conducted in the vicinity of the downed tower 37-4 on 14 March 1974. The apparent location of the tower base was in a slight ravine with rock outcrops on both sides. The snow in the ravine was extremely hard packed and severely eroded by wind action. The snow course was set up with stations located on a line which was approximately at right angles to the axis of the ravine. Four sampling sites were located at 10-foot (3 m) intervals in the deeper part of the ravine. The objective was to sample the snowpack in close proximity to where the tower base was located.

A Federal sampler with a 16-tooth cutter manufactured by Carpenter of Seattle was used to measure snow depth and density. Because of the highly compacted nature of the snow, it was extremely difficult to cut through the snowpack, and in the deeper snow the core length was greater than the snow depth. It required approximately 45 minutes to cut through 10 feet (3 m) of snow using the Federal sampler equipped with a driving wrench. The measured snow depths and densities in the vicinity of tower 37-4 are as tabulated below.

ALASKA
LOCATION: Salisbury Ridge
SNOW COURSE: Transmission Tower 37-4
PARTY: Meyer & Renschler
14 March 1974

Sample Number	Depth of Snow Inches	Length of Core Inches	Water Content Inches	Density Percent
80	33 (84 cm)	33 (84 cm)	19 (48 cm)	57
90	93 (236 cm)	115 (292 cm)	62 (157 cm)	66
100	115 (292 cm)	140 (356 cm)	73 (185 cm)	63
110	57 (145 cm)	69 (175 cm)	33 (84 cm)	57

The original plan was to locate a snow creep measurement system adjacent to the fallen tower, but it was impossible to locate a satisfactory anchor point with the existing snow conditions. Another site was selected where a gnarled mountain spruce served as an anchor point for the initial snow creep system. The selected site was chosen because it offered a uniform slope with a substantial depth of high density snow which would be typical of the more extreme conditions of depth and density existing at various locations along the transmission line.

The 1974 Snow Creep System

The snow creep system installed in 1974 was designed primarily to determine the size dynamometer required for use in snow creep systems planned for installation the following year. It was assumed that the disturbance to the snow pack caused by installation of this initial system could introduce significant errors into the results, and that use of the data for design criteria would be risky. The following plan and profile illustrate the design of the snow creep system installed on 17 and 18 March 1974.

The snow creep system consisted of a 4-inch x 4-inch x 3/8 inch (10.2 cm x 10.2 cm x 0.95 cm) steel angle 6 feet (1.8 m) long embedded into the snow at approximately right angles to the slope of the hill, which at that point was 27^{o}. A 1/2-inch (1.3 cm) steel cable attached the angle iron to the dynamometer which was in turn anchored to a spruce tree of approximately 7 inches (18 cm) diameter. The cable was run through a hole cut into the snow using the Federal snow sampler. The total length of cable, dynamometer, and turnbuckle was 60 feet (18.3 m). The angle iron was painted white to reduce the absorption of radiant energy.

After the snow creep unit was in place, the lower and middle work holes were filled and packed with snow in an effort to reduce the effect of disturbing the snow pack in the test area. Finally, the tension was adjusted up to 1,500 pounds (680 kg) by means of a turnbuckle and then backed off to 1,000 pounds (454 kg) tension.

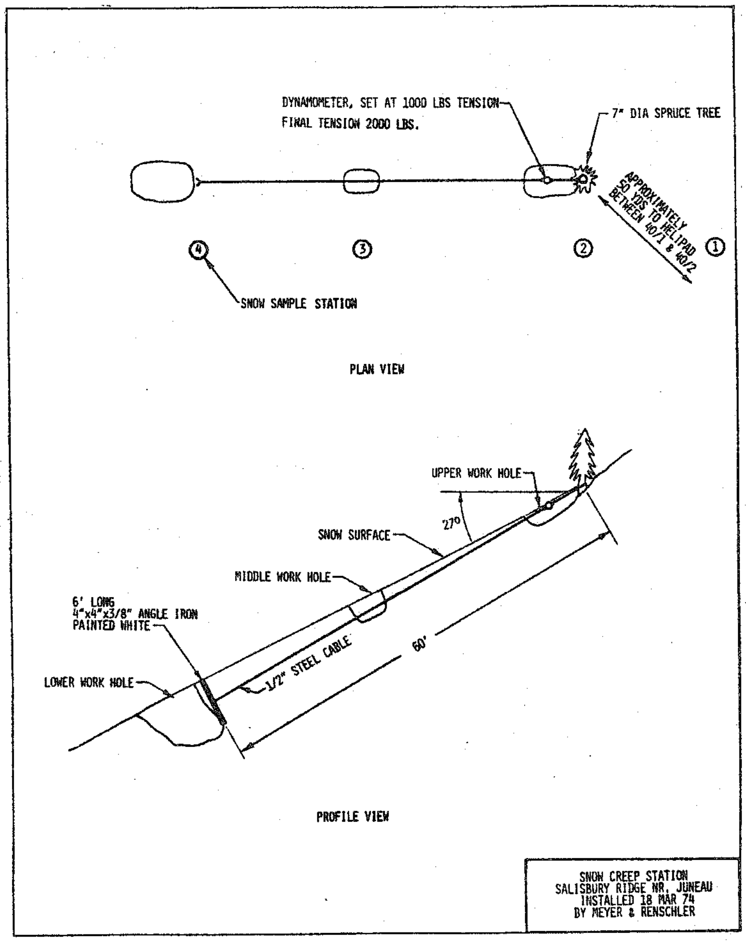
Snow samples were taken in the vicinity of the system, and the depth ranged from 67 inches (170 cm) above the anchor tree to 130 inches (330 cm) at the middle work hole. We were unable to reach the bottom of the snow pack adjacent to the snow creep angle iron because of frozen snow in the sample tube. The depth was in excess of 104 inches (264 cm) at that point. The measured densities ranged from 48 percent to 52 percent, and there was extreme difficulty in sampling both because of ice layers in the snow and due to snow sticking to the snow sample tube.

The following snow survey note sheet tabulates depths and densities near the snow creep station. The sample numbers correspond to sample sites shown on the plan view.

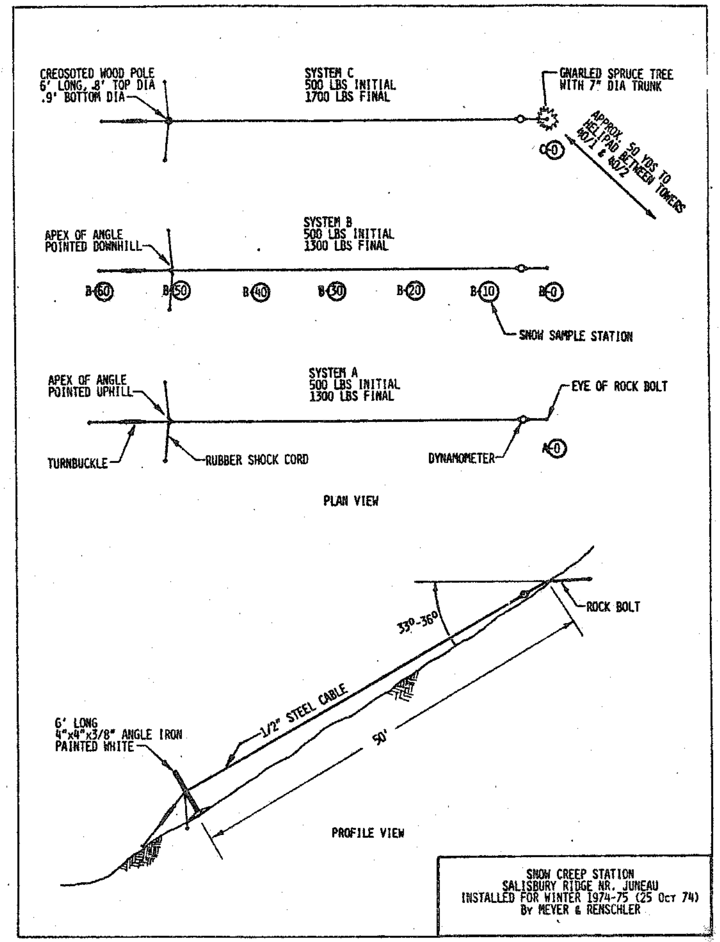
ALASKA
LOCATION: Salisbury Ridge
Snow Creep Study Area 40-1
PARTY: Meyer & Renschler
18 March 1974

Sample Number	Depth of Snow Inches	Length of Core Inches	Water Content Inches	Density Percent
1	67 (170 cm)	74 (188 cm)	35 (89 cm)	52
2	116 (295 cm)	127 (323 cm)	61 (155 cm)	52
3	130 (330 cm)	102 (259 cm)	66 (168 cm)	50
4	104 (264 cm)	102 (259 cm)	50 (127 cm)	48

On 10 May 1974, the snow creep dynamometer showed a maximum reading for the winter of 2,000 pounds (8,896 nt). Since the system was installed after the snow had fallen, it was felt that the data may not be representative of natural conditions where the snowpack



DYNAMOMETER, SET AT 1000 LBS TENSION
FINAL TENSION 2000 LBS.
7" DIA SPRUCE TREE
APPROXIMATELY 50 YDS TO HELIPAD BETWEEN 40/1 & 40/2
④
③
②
①
SNOW SAMPLE STATION
PLAN VIEW
UPPER WORK HOLE
27°
SNOW SURFACE
MIDDLE WORK HOLE
6' LONG 4"x4"x3/8" ANGLE IRON PAINTED WHITE
LOWER WORK HOLE
1/2" STEEL CABLE
60'
PROFILE VIEW
SNOW CREEP STATION
SALISBURY RIDGE NR. JUNEAU
INSTALLED 18 MAR 74
BY MEYER & RENSCHLER



CREOSOTED WOOD POLE 6' LONG, .8' TOP DIA .9' BOTTOM DIA
SYSTEM C 500 LBS INITIAL 1700 LBS FINAL
GNARLED SPRUCE TREE WITH 7" DIA TRUNK
C-0
APPROX. 50 YDS TO HELIPAD BETWEEN TOWERS 40/1 & 40/2
APEX OF ANGLE POINTED DOWNHILL
SYSTEM B 500 LBS INITIAL 1300 LBS FINAL
B-60
B-50
B-40
B-30
B-20
B-10
B-0
SNOW SAMPLE STATION
APEX OF ANGLE POINTED UPHILL
SYSTEM A 500 LBS INITIAL 1300 LBS FINAL
EYE OF ROCK BOLT
TURNBUCKLE
RUBBER SHOCK CORD
DYNAMOMETER
A-0
PLAN VIEW
ROCK BOLT
33°-36°
1/2" STEEL CABLE
6' LONG 4"x4"x3/8" ANGLE IRON PAINTED WHITE
50'
PROFILE VIEW
SNOW CREEP STATION
SALISBURY RIDGE NR. JUNEAU
INSTALLED FOR WINTER 1974-75 (25 OCT 74)
BY MEYER & RENSCHLER

settles around a structure throughout the winter season. This data was used for sizing the dynamometers used in the 1974-1975 snow season.

The 1974-75 Snow Creep System

In the fall of 1974, the snow creep station on Salisbury Ridge near the helipad at 40/1 was reactivated. Two rock bolts were installed to provide rigid anchor points for additional snow creep units.

Three snow creep systems were installed to evaluate the forces exerted against typical transmission tower members and wood pole structures. The following is a description of the three systems.

System A - 6-foot (1.8 m) long 4-inch x 4-inch x 3/8 inch (10.2 cm x 10.2 cm x 0.95 cm) steel angle oriented with the long axis at right angles to the slope of the hill and the apex of the 90^{o} angle pointed uphill. The angle iron was painted white to reduce absorption of radiant energy.

System B - Similar to System A except the apex of the 90^{o} angle was pointed downhill.

System C - 6-foot (1.8 m) long creosoted wood pole with a top diameter of 0.8 foot (24.4 cm) and bottom diameter of 0.9 foot (27.4 cm). The long axis of the pole was oriented at right angles to the slope of the hill. The wood pole was creosote colored. Both of the angle iron pieces and the wood pole were resting on a loose rock surface and were guyed with robber shock cord to keep them upright until the snowpack surrounded them. One-half-inch (1.3 cm) steel guy cable was used to interconnect the dynamometers, anchor bolts, and snow creep members. All systems were pretensioned to 500 pounds (227 kg) by means of turnbuckles to remove slack from the cables.

The following plan and profile shows the arrangement of the systems used in the winter of 1974-1975.

All three snow creep units had essentially the same length of guy cable connecting them to their anchor points. They were located in the same snow drift area; however, during the March snow sampling trip, it was observed that the wood pole member was near the edge of the high density wind-packed snow. The hillside on which the snow creep members were located was reasonably uniform in respect to slope and vegetation cover. There was a scrub spruce tree and rock outcrop located uphill from the creosote-treated wood pole which may have altered the snow creep characteristics for that system.

The snow in the vicinity of the snow creep station was undisturbed by man except for one snow sampling session on 10 March 1975. The following snow survey notes show depth and density for that survey, and the sample numbers correspond to the sample sites shown on the plan and profile for 1974-75. All samples were made using a standard Federal sampler. (See Table on next page).

The following dynamometer readings were taken after the snow melted away in the spring.

System A - 1,300 lbs. (5,782 nt) or 460 lbs/ft^2 (2,046 nt/m^2) cross sectional area (apex of angle uphill)

System B - 1,300 lbs. (5,782 nt) or 460 lbs/ft^2 (2,046 nt/m^2) cross sectional area (apex of angle downhill)

System C - 1,700 lbs. (7,562 nt) or 333 lbs/ft^2 (1,481 nt/m^2) cross sectional area (wood pole structure).

In conjunction with the snow creep gages, anemometers available in March of 1974 had a velocity range of 0 - 155 mi/hr (250 km/hr). Before the winter was over, the winds on Salisbury Ridge had exceeded the limits of the anemometers.

ALASKA
LOCATION: Salisbury Ridge
Snow Creep Study Area 40-1
PARTY: Meyer & Renschler
10 March 1975

Sample Number	Depth of Snow Inches	Length of Core Inches	Water Content Inches	Density Percent
A-0	20 (51 cm)	20.5(52 cm)	8.1 (21 cm)	40
B-0	95 (241 cm)	59 (150 cm)	24.9 (63 cm)	26
C-0	79 (201 cm)	61 (155 cm)	25.6 (65 cm)	32
B-0	95 (241 cm)	59 (150 cm)	24.9 (63 cm)	26
B-10	61 (155 cm)	58 (147 cm)	24.7 (63 cm)	40
B-20	40 (102 cm)	37 (94 cm)	15.2 (39 cm)	38
B-30	55 (140 cm)	52 (132 cm)	22.0 (56 cm)	39
B-40	72 (183 cm)	37 (94 cm)	17.8 (45 cm)	24
B-50	103 (262 cm)	77 (197 cm)	49 (124 cm)	47
*B-60	60 (152 cm)	30 (76 cm)	21.9 (56 cm)	36

*B-60 Total Depth 103", Lost Core

For the winter of 1974-75, new anemometers were purchased which had a range of 0 - 200 mi/hr (321 km/hr). On 7 and 8 January 1975, peak gusts were recorded at full scale deflection on the anemometers. A 5/16-inch (0.79 cm) propeller shaft was snapped on one of the anemometers, the propeller and shaft spun out on another, and a 1-1/2-inch (3.81 cm) threaded pipe on the mounting bracket of a third unit snapped off at the threaded section. Guy cables for the mounting brackets were broken and vinyl insulated transmitter wire which was not securely taped to the transmission towers was beaten against the transmission towers until the vinyl sheath and the insulation were broken away down to the copper wire.

Additional damage was done to the plywood instrument boxes by wind-driven snow particles. In less than two months' time, wind-blown snow eroded through two layers of paint and up to two laminations of plywood on exposed surfaces. Where the edge grain of plywood was exposed, the softer layers were eroded bewteen 3/8-inch (0.95 cm) and 1/2-inch (1.27 cm). Exposed wood 2-inch x 4-inch (5 cm x 10 cm) material had the appearance of being sandblasted.

Final Conclusions

The following sequence of events was pieced together based on the two years of accumulated snow creep and wind velocity data, and on site inspection of the failed towers after the snow melted away in the spring.

It appeared that high density, highly compacted snow accumulated around the bottom 15 feet (4.6 m) of the base of the tangent type tower and held it rigidly in place. The tower was unable to move in its base socket, and the connection became a fixed connection rather than a pinned connection as designed. When winds considerably in excess of its design strength occurred, it failed. Icing on the tower and lines may have contributed to the failure if present at the time of the high velocity winds. It was concluded that snow creep did not contribute to the failure since the base socket of the tower was still in place, and the bottom 13 feet - 15 feet (4m - 4.6 m) of the tower was undamaged as evidenced when the snow melted away in the summer.

Since the line has been constructed, there have been many instances where there has been 15 feet (4.5 m) to 20 feet (6 m) or more of snow around both guyed and self-support towers with no apparent damage due to snow creep in 3 years of service.