Practical Methods for Estimating Snow Accretion of Overhead Power Lines and Its Impact on Tower Members

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Background & Motivation (1)

- Snow accretion is one of main causes of failures for electric power equipment.
  - The collapse of transmission line towers rarely happens in Japan.
  - Each electric power utility is tackling issues of the reinforcement of existing towers as well as the development of anti-snow accretion countermeasures.

- Central Research Institute of Electric Power Industry (CRIEPI) has been leading a research project with cooperation of major electric power utilities since FY2007.
  - Collecting field observation data at full-scale transmission line systems
  - Research targets: Modeling of snow accretion, quantitative evaluation of countermeasures, modeling the dynamics of wind-induce galloping, effects of salty snow on the electric performance of insulators

Background & Motivation (2)

- Mapping of hazardous heavy snow accretion is not statistical-based but experienced-based in Japanese design standards on structures for transmissions (for example, JEC*-127-1979).

  * the Japanese Electrotechnical Committee

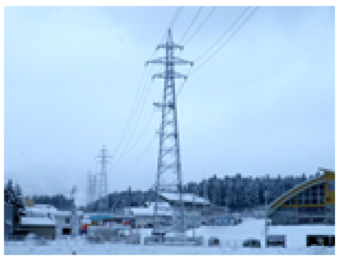
- Lack of reliable observational data of snow accretion, Likely not reasonable.
- The most common method to obtain snow accretion data is by means of snow accretion model. A complicated dynamical and physical model does not suit.

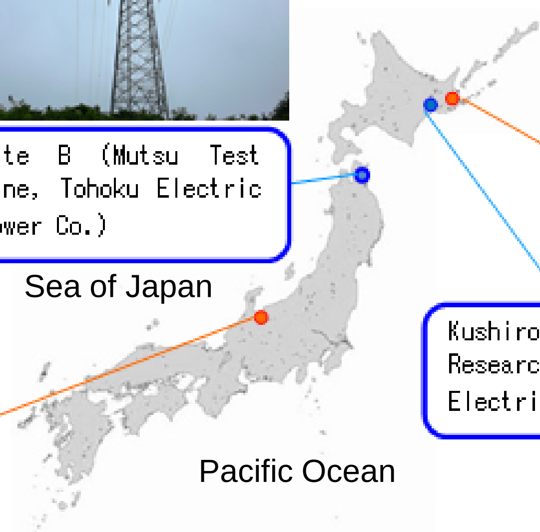
- The safety of a transmission line system had better be evaluated from the viewpoint of leg member capacity.

- A simplified method is required to evaluate snow and wind loads, and ideally it can handle the inputs of statistical hazard analysis.

Field Observations (1)

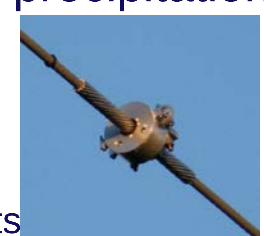
66-kV scale transmission line systems



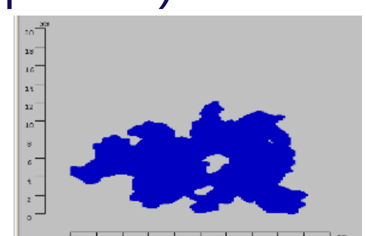


Four sites for observation of heavy snow accretion

- Tension of line conductors (the unit mass of snow accretion)
- Meteorological features (including precipitation particle)
- Rotational angle of conductors
- In-situ samplers
- Movie

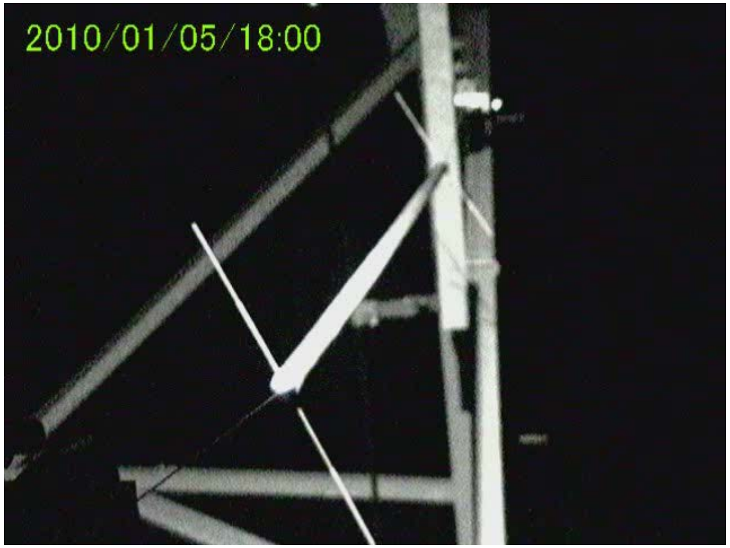


Infrared emission targets

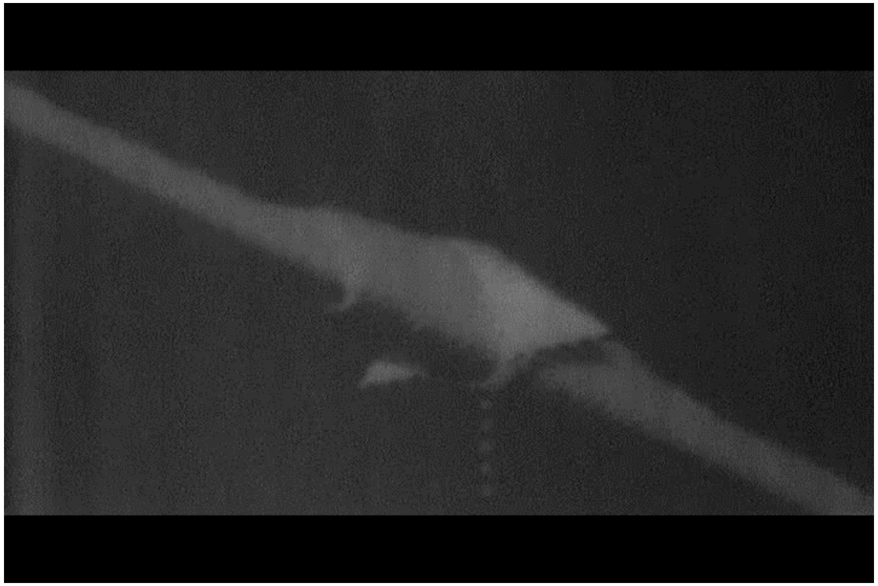


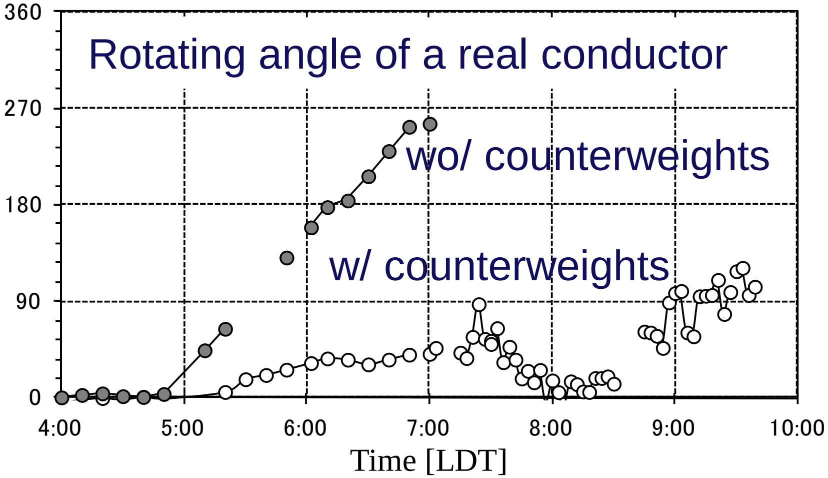
2-D video disdrometer

Field Observations (3)

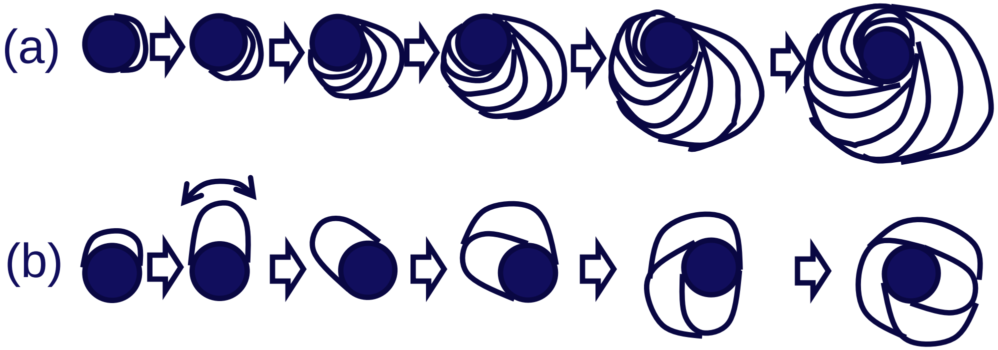


In-situ wet snow sampling under strong winds

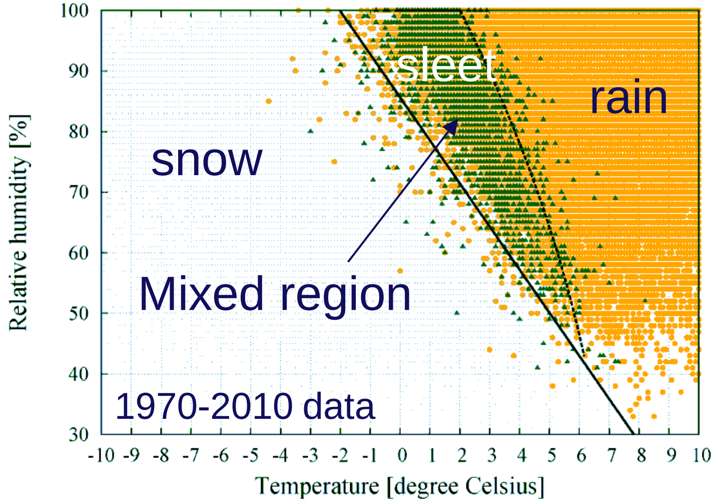




Dry snow accretion under calm winds



Snow Accretion Type Classification (1)



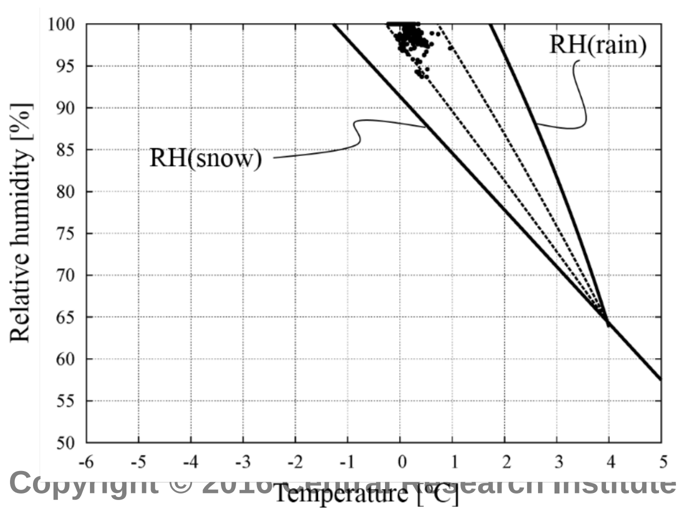
Precipitation type classification using two Discriminants

$$RH(snow) = -7.1122 \times T + 85.6523$$

$$RH(rain) = 44.3300\sqrt{7.1002 - T}$$

Discriminants for the mountainous in-land region are different from ones for the coastal region.

Relationship between the types of precipitation and corresponding surface temperature and relative humidity at surface stations in the in-land region.

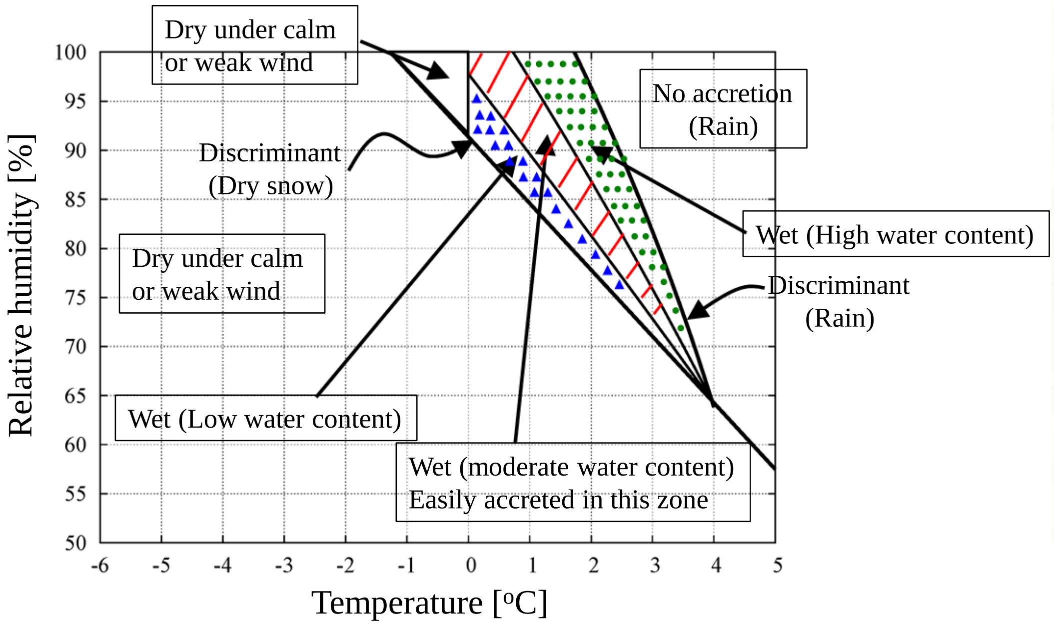


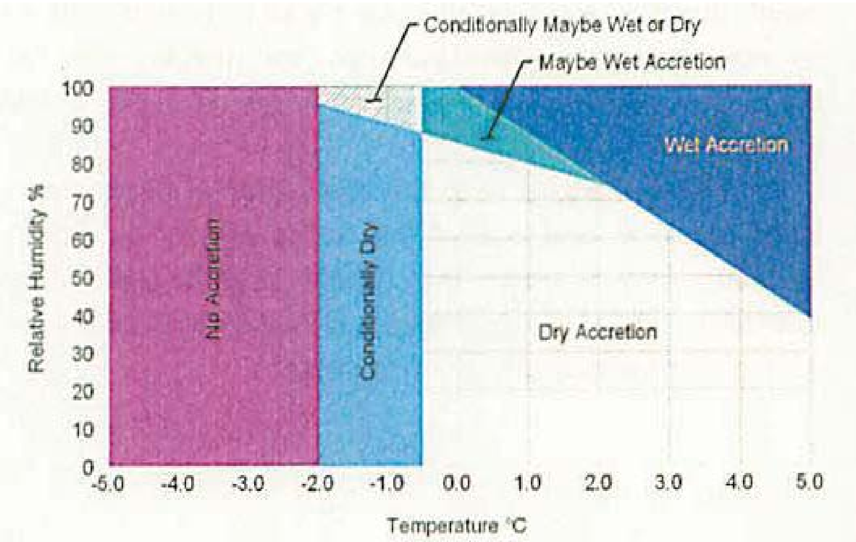
Wet snow accretion occurs only when temperature and humidity come into the mixed region, NOT depending on wind speed.

Snowflakes with little or too much liquid water content (LWC) are not favorable for wet snow accretion.

Plots of meteorlogical conditions for wet snow accretion at the site A.

Snow Accretion Type Classification (2)





Our chart proposed

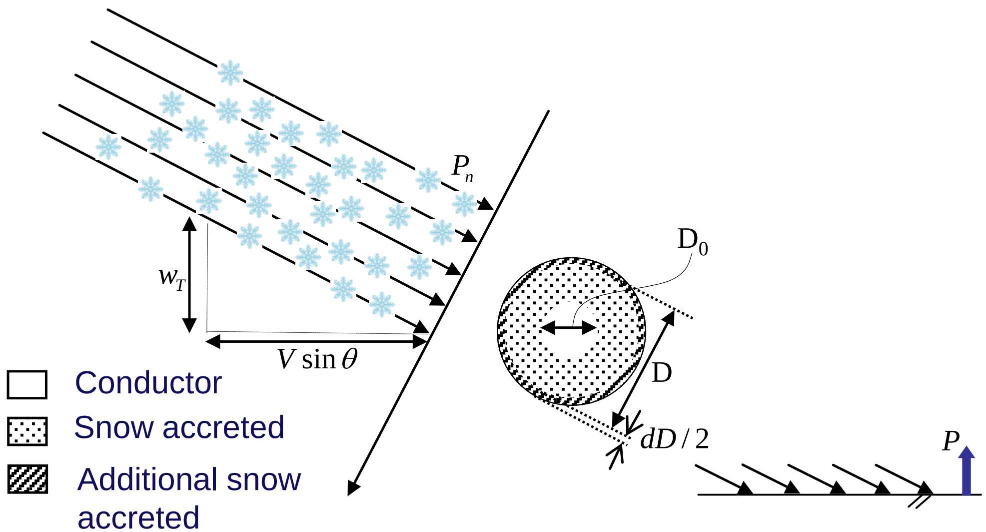
- Precipitation type
- Wind speeds (dry snow accretion < 3 m/s)

A chart for North America （Peabody et al. , 2007, IWAIS）

Our chart is based on long-term meteorological surface station data and field observation data of snow accretion at 4 special sites.

Snow Accretion Model

A traditional cylindrical sleeve model



- P : Precipitation
- P_n : Precipitation passing through the surface of a snow body
- V : Wind speed
- V_n : Wind speed in the direction perpendicular to span direction
- w_T : Fallspeed of precipitation particle (Wet: 1.5 m/s, Dry: 1 m/s)
- θ : Angle between wind direction and span direction
- D_0 : Diameter of a conductor
- D : Diameter of a snow sleeve
- D_{pre} : Diameter of a snow sleeve

Model parameters
→ density ρ_s & sticking efficiency β

Variation of diameter $dD = \frac{2}{\pi\rho_s}\beta P_n dt$

Variation of mass $dM = \left(\frac{\pi D^2}{4} - \frac{\pi D_{pre}{}^2}{4}\right)\rho_s = \frac{\beta^2 P_n^2}{\pi\rho_s}dt^2 + D_{pre}\beta P_n dt$

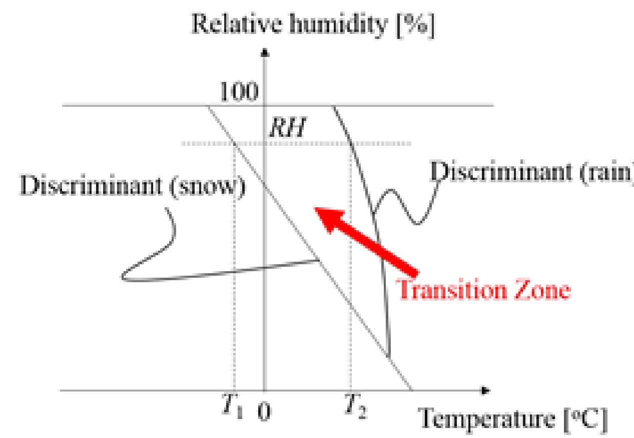
Concepts of our model

The density of snow sleeve

Empirical equation derived from in-situ sampling data and meteorological observations.

$$\rho_s = 55V_n \times (1 + 3.6 \times T^2)$$

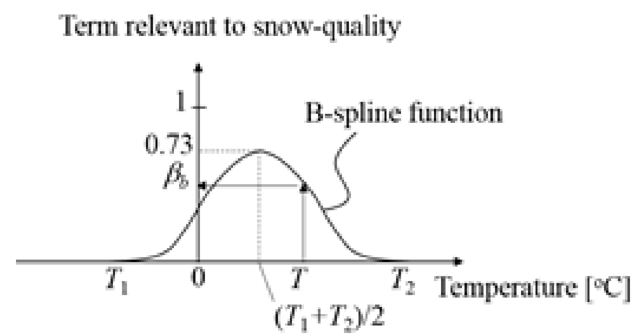
T: Temperature [Degree C]



The sticking efficiency

$$\beta = \beta_b \times \alpha \times \gamma \times \beta_w$$

- Effects of liquid water content
  → Use precipitation type classification (β_b)
- Effects of countermeasures (α)
  → Observation at full-scale transmission line systems
- Effects of wind speed and direction (β_w)
- Correction of precipitation amount according to the catchment efficiency (CR)

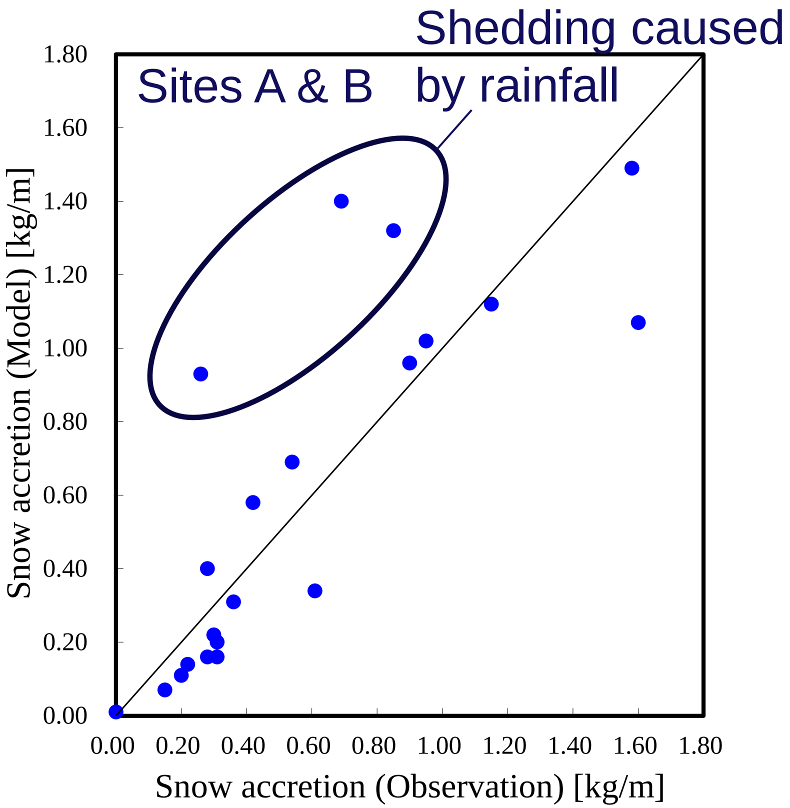


$$\beta_w = \cos\phi / (V^2 + w_T^2)^{0.25}$$

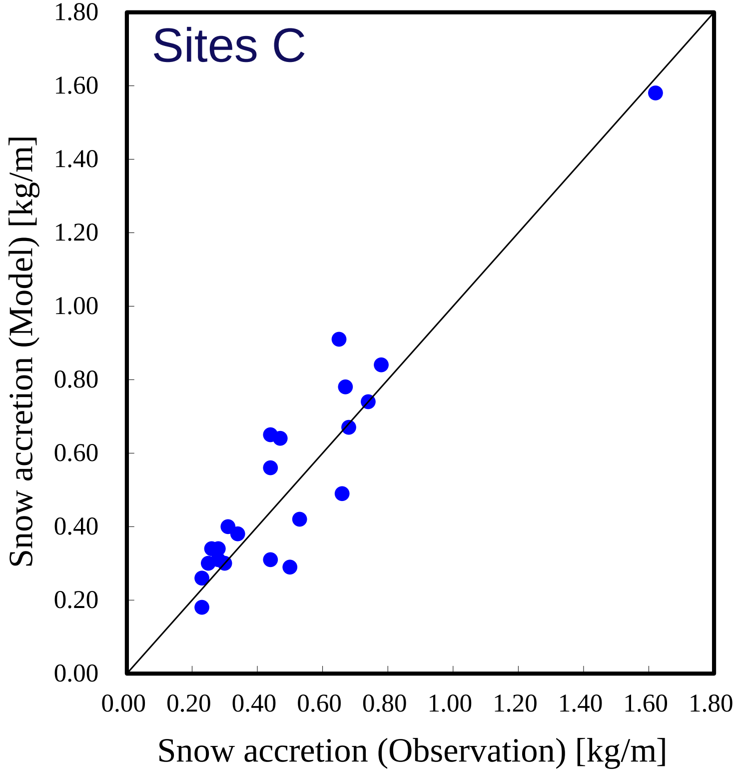
$$CR = 1/(1 + mV)$$

m: 0.128 (derived from field observations)

Evaluation of Our New Model



Wet snow accretion occurred likely under medium and strong winds

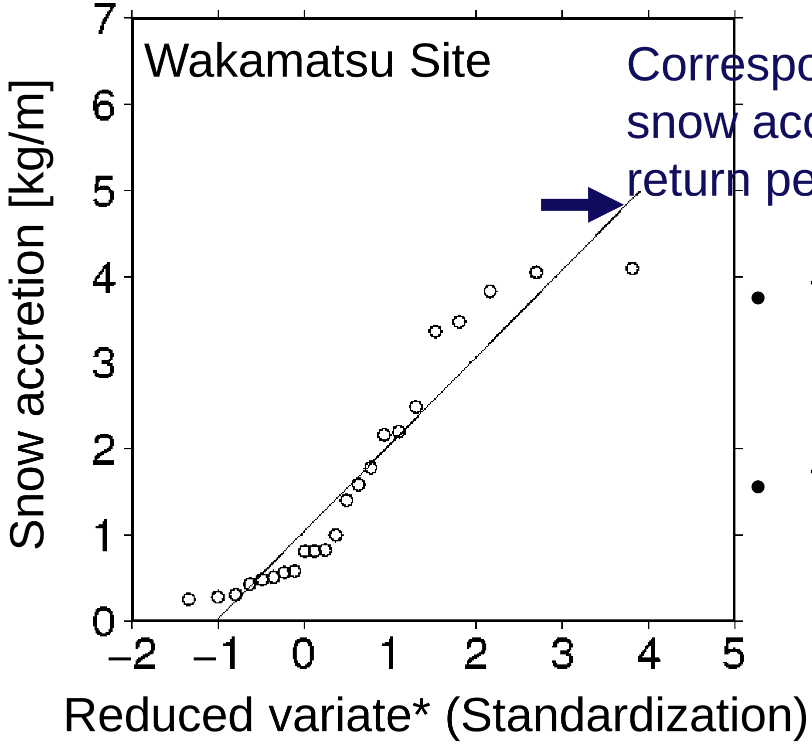


Snow accretion occurred under calm wind condition (wet & dry)

Comparisons between observation and model for the unit mass of snow accretion

Example of extreme value analysis

The yearly maximum ice loads are specified by means of the Gumbel extreme value distribution in IEC standard 60826.



- The yearly maximum snow accretion is calculated from JMA's routine observation data and our accretion model.
- The direction of span is assumed to be east-west.

* Reduced variate $y = -\ln(-\ln(F_w))$
Fw: non-exceedance probability

Fitting straight line of estimated snow accretion data on Gumbel probability paper

Practical Method for Load Calculation (TC-LOAD)

External loads on supporting structures

- Loads due to snow and wind on conductors
- Loads due to snow and wind on structure itself

→ Snow loads on structure are neglected in TC-LOAD.

External loads on transmission line conductors

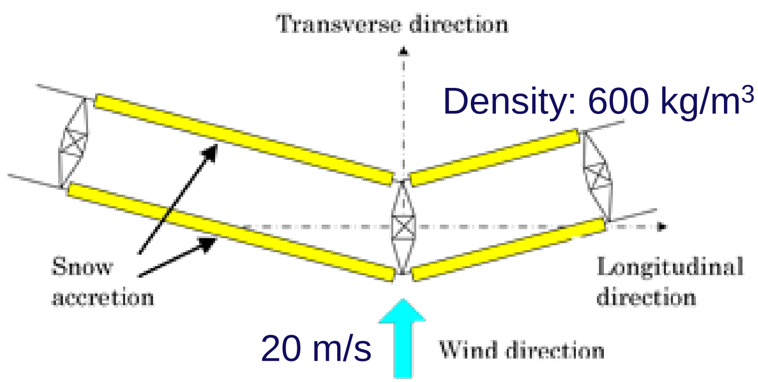
- Vertical loads on conductors due to snow accretion
- Transverse loads on bare conductors due to wind
- Transverse loads on snow-covered conductors due to wind
- Longitudinal loads on conductors due to unbalanced snow accretion on adjacent spans (torsional effects)

→ TC-LOAD considers transverse wind loads as equivalent static loads using the gust response factor.

Other assumption

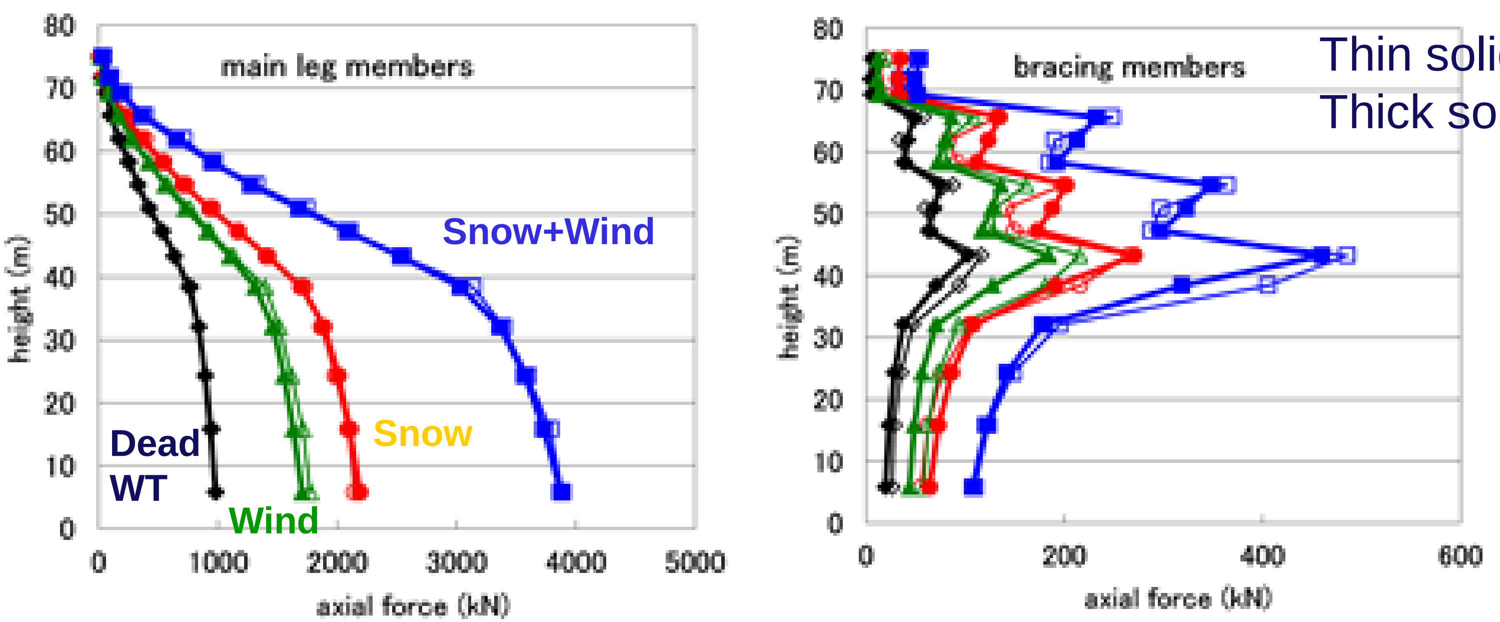
- The stresses on members of a tower are analyzed by a static analysis.
- A two-dimensional truss structure

Verification of TC-LOAD



Frame model:

- 500-KV tension-type with steel pipes
- Snow accretion on all of a span
- Balanced snow accretion on adjacent spans



Thin solid line: FEM
Thick solid line: TC-LOAD

Comparison of axial forces between two approaches (dynamical & static)

Summary

- Current Japanese standards need to be improved quantitatively to estimate more reasonable estimation of snow loading for the structural design of transmission line system.
- We continue field observations at full-scale transmission line systems with the cooperation of all of major power utilities in Japan.
- A widely-used cylindrical snow accretion model has been improved by the combined use of a physically-based method of snow type classification and observation-based model parameters.
- A practical tool has been developed with a static approach for calculating the axial force on leg and bracing members due to wind and snow loads.
- Results of our attempts are included in the technical report JEC-TR-00007-2015 (IEEJ, 2015), and they are expected to be adopted in updating of JEC-127-1979 (now under consideration).