A New Attempt to Estimate Wet Snow Accretion on Overhead Lines

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***Abstract*—In the Kanto region, Tokyo Electric Power Co.(TEPCO)'s service area, there are almost clear days during winter, but occasionally, when passage of an extratropical cyclone overlaps with a cold air system moving south, wet snow accretions will occur on transmission lines. The amount of this snow accretion is estimated and compared with observed data using high-density meteorological data from the Japan Meteorological Agency and employing an existing equation for calculating amount of snow accretion. As a result, it is found that the estimates showed a tendency to be somewhat greater than observed values, and the margin of error is not small. The extreme-value distribution is roughly compatible with a Gumbel distribution.**

I. INTRODUCTION

In winter cold, damp seasonal winds bring large amounts of snow to the Japan Sea side of the Japanese island of Honshu, but after crossing the backbone of mountains that runs through the middle of Honshu they blow down on the other side in the form of dry seasonal winds; therefore the lowlands on the Pacific Ocean side of the island, namely the Kanto region constituting TEPCO's service area, normally experience many days of clear weather. However, sometimes an extratropical cyclone passing by off the south coast of Honshu will develop rapidly in the seas south of the Kanto region, bringing large amounts of precipitation and strong winds to the south of that region. If at the same time there is a cold air system moving south overhead and the temperature drops to close to 0˚C, large amounts of wet snowfall will result; that, in combination with strong winds, will cause snow accretion on overhead transmission lines, leading to power accidents caused by galloping, sagging conductors, and the like. In extremely rare cases remarkably thick snow accretions of 3-5 cm or more may develop, damaging power lines and support structures.

Fig.1 [1] shows the meteorological features associated with the occurrence of power accidents or damage to facilities caused by wet snow accretion on transmission lines in the Kanto region. It shows that in case a cyclone comes into the box at an air pressure written in the figure or less when a cold air mass of -25℃ at 500hPa altitude moves south to the line drawn in it, power faults or damages to facilities could occur.

For the above reason, when conducting structural design of overhead lines in the Kanto region, it is important to determine a reasonable level of wet snow accretion. Therefore whenever there is a snowfall TEPCO collects data from on site about snow accretion on power lines, but since large snow accretions are extremely rare data on observed snow accretions have not yet been obtained in sufficient quantities to enable statistical evaluation. Hence design snow accretion has hitherto been determined empirically based on for example eyewitness accounts of snow damage in the past.

However, almost thirty years have passed since the launch of the Japan Meteorological Agency's AMeDAS system (Automated Meteorological Data Acquisition System), which keeps an hourly record of meteorological observation data; thus in recent years Japan has built up a pool of meteorological data that is of high density in terms of both temporal and areal coverage. If highly accurate estimates of snow accretion can be derived from these data, it should be possible to determine design snow accretion in a more rational manner. This study attempts to estimate snow accretion on transmission lines by using meteorological data from the Japan Meteorological Agency and employing an existing equation for calculating amount of snow accretion. It then verifies the accuracy of those estimates by comparing them with data collected on observed snow accretions.

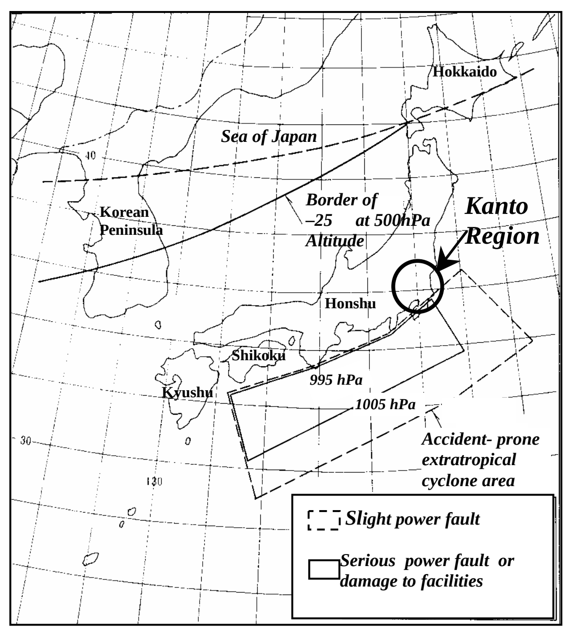

Fig.1. Meteorological features associated with occurrence of snow damage in the Kanto region [1]

II. METHOD OF ESTIMATING AMOUNT OF SNOW ACCRETION

A. Equation for Calculating Amount of Snow Accretion

The formula employed for calculating amount of snow accretion is Equation (1), which was proposed by Sakamoto et al.[2].

$$W = 4.5 \frac{\exp\left\{-6\left(T/T_d - 0.32\right)^2\right\}}{V_n^{0.2}} \sum P_n \qquad (1)$$

where W: the mass of the accreted snow on a wire (g/cm),
T: temperature (˚C), T_d : interface air temperature(the temperature at which rain turns to snow) (□),
$\sum P_n$: assumed amount of precipitation in collision with a wire:

$$\sum P_n = \sum \left(P\sqrt{1 + (V_n / V_s)^2}\right) \quad (\mathrm{g/cm^2})$$

P: precipitation (g/cm^2), V_s :speed of snowflake descent (≡ 1m/s), and V_n : normal wind speed to a wire.

Equation (1) was deduced by regression analysis such as to agree with data collected in the past in Japan on observed snow accretions on transmission lines. It assumes that snow accretions on transmission lines always maintain a cylindrical configuration as they develop. Like Admirat et al. [3] and Finstad et al.[4] it adopts the view that the rate of snowflake accretion (of those snowflakes entering the projected area of the power transmission line or wire to which snow is accreting, the percentage that accrue without being repelled from the surface of the power transmission line or wire) is in inverse proportion to wind speed, and like Finstad et al.[4] it adopts the view that that rate is also in inverse proportion to transmission line diameter (snow accretion diameter). Fig.2 gives sample calculations performed using (1). This equation is highly sensitive to air temperature.

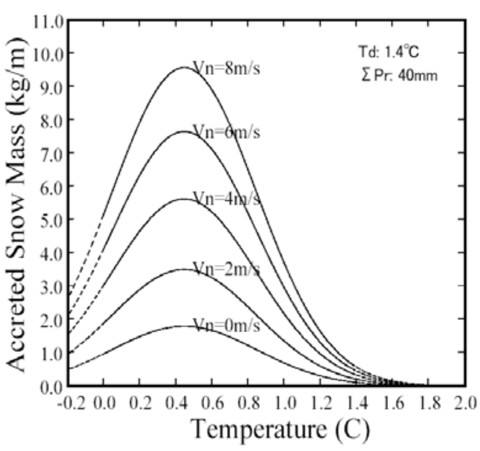

Fig.2. Sample calculations performed using the equation for calculating amount of snow accretion

B. Meteorological Data Used

Since snow accretions develop over time, calculating the amount of snow accretion requires meteorological data of a chronological nature. The types of chronological data available in Japan in electronic format are the regular observation data (recorded every three hours or every hour) kept by weather offices since 1961, the hourly observation data kept by AMeDAS observation stations since 1976, and the hourly rainfall data kept by Radar-AMeDAS since 1995. Radar-AMeDAS records data on amount of precipitation at lattice points located at approximately 5km intervals (approximately 2.5km intervals since April 2001).

Fig. 3 shows the location of weather offices and AMeDAS observation stations situated in the Kanto region and environs, where TEPCO's power transmission facilities are located. For the purposes of this study it was decided to use the chronological data from these weather offices and AMeDAS observation stations in estimating snow accretion. However, it was decided, upon on-site inspection, to avoid using observation data from locations that are susceptible to local impact from nearby structures etc. due to for example low elevation of the anemometer from the ground.

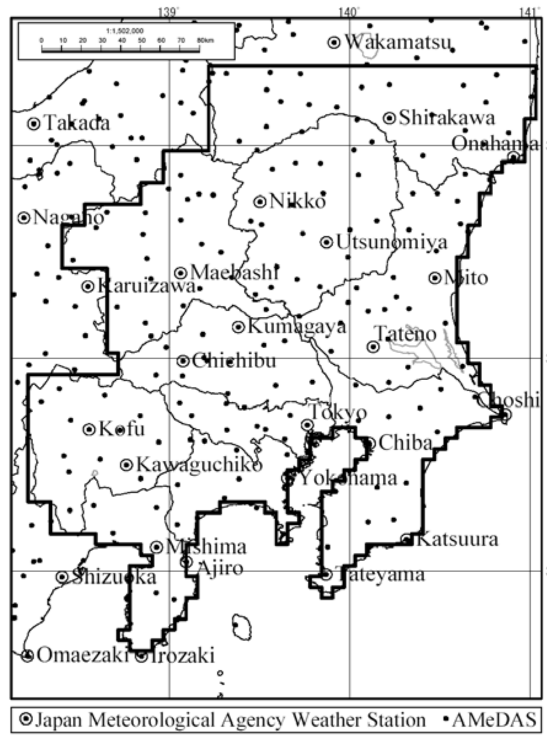

Fig.3. Meteorological observation points

C. Method of Estimating Snow Accretion at a Given Point

1) Approach

There are two conceivable approaches to estimating the amount of snow accretion at a given point:

- Make an interpolated estimate of the amount of snow accretion at the point based on the results of calculation of the amount of snow accretion at particular observation points.
- Calculate the amount of snow accretion based on the results of an interpolated estimate of meteorological data at the point.

However, wet snow accretion is an event highly sensitive to changes in temperature and other meteorological conditions, which are greatly affected by elevation and topography. With the former method, therefore, it is difficult to adjust for variations in topography and the like between observation points. For that reason it was decided to make use of the latter method in this study.

2) Equation for Estimating Meteorological Values

Equation (2) constitutes the basic formula for interpolating and estimating meteorological values at the given point based on meteorological data from meteorological observatories and AMeDAS. This equation represents the weighted average of the inverse of the square of the distance between the observation points and the point of estimate (vector synthesis in the case of wind direction).

$$v_g = \sum_k \frac{v_k}{r_k^{\,2}} \Bigg/ \sum_k \frac{1}{r_k^{\,2}} \qquad (2)$$

where v_g: estimated meteorological values at the given point, v_k :observed meteorological values at the observation point, and r_k : the distance between the observation point and the given point.

Considering differences in the environment around observation points, as well as the impact on meteorological conditions of variations in elevation and topography between observation points, it was decided to make the following corrections during the interpolation process.

a) Correction of wind speed

Wind speed is greatly affected by height above ground, the surrounding topography, and roughness of the ground surface. Therefore roughness around the observation point was assessed by wind direction, and the observed wind speed data were, in line with the method prescribed in "Recommendations for Loads on Buildings [5] ", homogenized at a height of 10 m above ground and a surface roughness of Category II (flat land, such as rural districts and grassland with crops or similarly sized obstacles, or flat land with sporadic trees, low-rise buildings, or the like). The accelerating effect of minor topographic features located in the vicinity of the observation point was eliminated by assessing that effect by wind direction according to the method prescribed in "Recommendations for Wind Loads on Transmission Towers: A Draft-" proposed by Ohkuma et al. [6]. Hence, the formula to homogenize observed wind speed is totally shown by Equation (3)

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$$V_{ho} = V_o \Big/ k_1 \cdot 1.7 \left(Z_G / Z_o \right)^{\alpha} \qquad (3)$$

where V_{ho}: homogenized wind speed, V_o: observed wind speed, k_1:accelerating ratio of minor topography on the wind-ward, Z_G: gradient height, Z_o: observed height, α:exponent

Note: Z_G and α are given from the roughness category on the windward of the point.

Furthermore, in an effort to take proper account of major topographical impacts, it was decided to employ the results of broad-area analysis using Nakamura et al.'s air current simulation codes [7], and correct for differences in topographical impact between the observation point and given point using (4) before conducting interpolation using (2).

However, the appropriateness of incorporating the results of broad-area analysis in this fashion will need to be examined further from meteorologists' viewpoints.

$$V_k = V_{ho} \cdot v_g \big/ v_o \qquad (4)$$

where V_k :corrected wind speed, V_{ho} :homogenized observed wind speed, and v_g and v_o : air current simulation wind speed at the given point and observation point respectively.

As a result, estimated wind speed at the given point factors in the impact of major topographical features but excludes the impact of minor topographical features; in addition, surface roughness is corrected to Category II and height to 10 m.

In order to calculate amount of snow accretion based on this wind speed, it becomes necessary to correct every wind speed data to take account of height of transmission lines, surface roughness and impact of minor topographical features at the point in question, calculating back (3) by substitution of parameters of the point .

In its wind observations, the Japan Meteorological Agency used a three-cup anemometer between 1961 and 1974, and it has used a windmill anemometer since 1975. The observation values obtained using a three-cup anemometer are estimated to be roughly 10% too high[8], for which reason they were, whenever used, corrected by multiplying the figure by 0.9.

b) Correction of air temperature

When estimating air temperature at a given point through interpolation based on the temperature at the observation point, corrections were made to take account of temperature lapse rate due to elevation. The temperature lapse rate is said to be on average -0.6˚C/100m, but it is possible that the rate may diverge from the average when a cyclone passes off the coast of the Kanto region and snow falls on the flatland area of the Kanto. Therefore, in this study, not above-mentioned temperature lapse rates but the value calculated from aerological observation data taken twice a day at the Tateno Aerological Observatory, which is located in the Kanto plain, were used to estimate air temperature at the given point. Computation of the temperature lapse rate at lower levels during passage of cyclones bringing precipitation to the Kanto plain yielded an average figure of -0.39℃/100m (standard deviation of 0.34℃/100m, 272 items of data); this average is employed where no aerological observation data are available.

3) Interface air temperature

As Equation (1) shows, the interface air temperature (the temperature at which rain turns to snow) has a considerable impact on the outcome of the calculation of snow accretion. Interface air temperature is generally said to be around 2˚C, although in reality it varies from precipitation event to precipitation event; indeed, it even varies over time within the same precipitation event. It also differs from region to region.

It was shown that the types of precipitation are dependent on humidity as well [9], however the authors use no humidity data since AMeDAS stations have not observed them. Therefore, in the case of precipitation events for which the interface air temperature could be deduced based on observation records of meteorological phenomena and air temperature data kept by weather offices, the value at a given point was computed, through interpolation, from the interface temperature recorded by those weather offices; that value then served as the interface air temperature for the precipitation event in question. In the case of precipitation events for which the interface air temperature could not be deduced using weather office data (e.g., where the precipitation took the form of snow at both the commencement and termination of the event), the average interface air temperature was worked out in accordance with Equations (5) and (6) below.

If precipitation in the three hours prior to the time in question measured less than 5 mm:

$$T_d = 1.57 - 0.0697 \ln(h) - 0.00251 r \qquad (5)$$

If precipitation in the three hours prior to the time in question measured 5 mm or more:

$$T_d = 1.65 - 0.161 \ln(h) \qquad (6)$$

where Td :interface air temperature at the given point (C˚), h: elevation at the given point, and r : minimum distance from the given point to the coast (km).

In this study, interface air temperature T_d is defined as the temperature at which the probability of rain/snow is 50%. Equations (5) and (6) were formulated by conducting regression analysis of observation records of meteorological phenomena, as well as of temperature observation data for every hour or ten minutes, kept by weather offices located in and around the region.

4) Calculation of snow accretion at a given point

Thus amount of snow accretion at a given point can be worked out by compiling time-series meteorological values for, and determining interface temperature at, that point based on time-series observation data for the surrounding area, then plugging those figures into (1), also taking line direction into consideration. However, in making the calculation one must also set the conditions under which the snow will slide off, which conditions (1) does not take into account. This study postulates that the snow will drop off if any of the following conditions is fulfilled:

- Air temperature rises above 3˚C, or air temperature remains above the interface air temperature for two hours (four hours at night).
- There is a temperature rise of over 1.5˚C within a three-hour period.
- Accumulated duration of sunshine exceeds one hour.
- More than six hours has elapsed (twelve hours at night) since the snowfall stopped.

These conditions were determined just by experience and have no academic background.

III. Verifying Estimation Accuracy

A. Accuracy of Estimation of Meteorological Values

Seven representative AMeDAS locations that are situated mainly in the flatland area of the Kanto and frequently experience wet snowfall during passage of cyclones were selected: Urawa, Tokorozawa, Ogochi, Hachioji, Shinkiba, Ebina, and Yokohama. On the supposition that no observations had been conducted at these locations, observation data taken at AMeDAS locations in the vicinity were used to estimate, according to the method already described, what the wind speed, temperature, and precipitation at those locations was at the same time of day. The accuracy of those estimates of meteorological values was then verified by comparing them with actual observation data. As for weather conditions at the time that these comparative data were obtained, there was precipitation in the Kanto region, with a cyclone passing through, and the air temperature had dropped below 10˚C. The results of the comparison are given in Fig.4.

Table 1 shows the average of the difference between the estimated and observed values and the standard deviation between them. The estimation accuracy is relatively high, although there are considerable discrepancies.

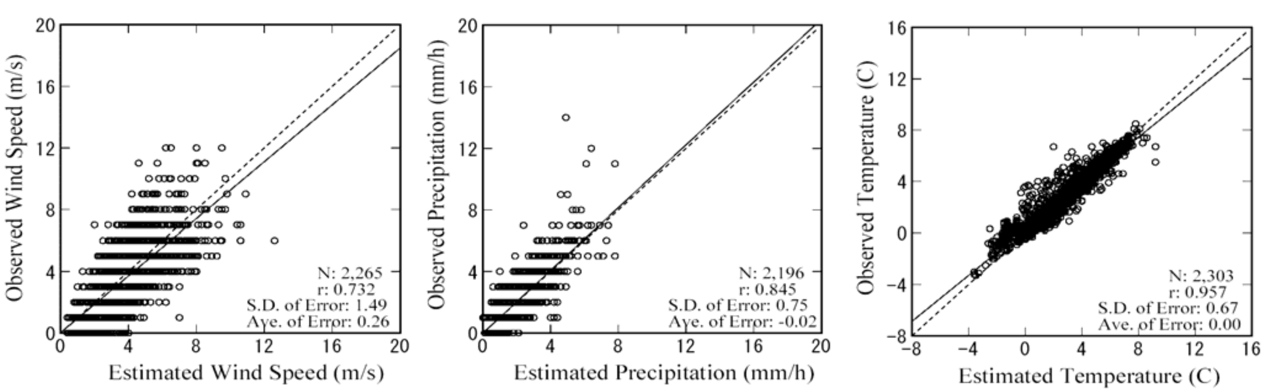

Fig.4. Comparison of estimated and actual values at seven AMeDAS locations in the flatland area of the Kanto

TABLE I Estimation accuracy

	Wind Speed	Precipitation	Temperature
Ave. absolute Error	1.21 m/s	0.53 mm/h	0.46 □
Standard Error Deviation	1.49 m/s	0.75 mm/h	0.67 □
Correlation Coefficient	0.732	0.845	0.957

B. Accuracy of the Estimation of Snow Accretion

Next, the accuracy of the estimation of snow accretion was verified using data collected by Tokyo Electric Power Co. on observed snow accretions on power transmission lines. The observed values were for thickness of snow accretions; therefore the mass of the accreted snow in (1) was converted to thickness (in mm) assuming a uniform accretion density of 0.6g/cm3. Most of the data on observed snow accretions on transmission lines used for verification purposes were obtained on the ground, by using a monocular to measure the diameter of the snow accretion; hence they contain a certain degree of error. Furthermore, they include no meteorological data corresponding to the time period over which snow accretions form. For that reason meteorological values at each point where snow accretions were observed were estimated by means of the method described in the preceding section, using meteorological data from nearby weather offices and AMeDAS (in the case of wind speed, account was also taken of the height of the transmission lines at the site, roughness of the ground surface, and the impact of minor topographical features). Hence the meteorological data used in calculating snow accretions also contained errors, which were of comparable magnitude with those assessed in the preceding section. Fig.5 gives the results of the comparison. In the majority of cases (around 70%) the estimates were roughly the same as or larger than (i.e., on the safe side of) the observed values, but in around 25% of the cases the observed values proved larger. The estimates were on average approximately 7 mm larger than the observed values; the standard deviation was approximately 14 mm.

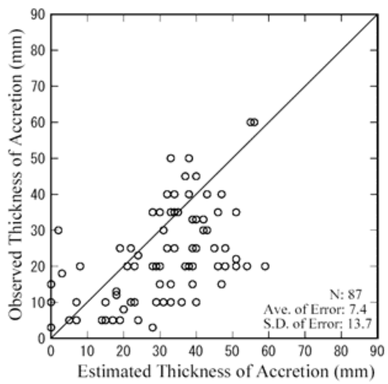

Fig.5. Comparison of estimated and actual thickness of snow accretions

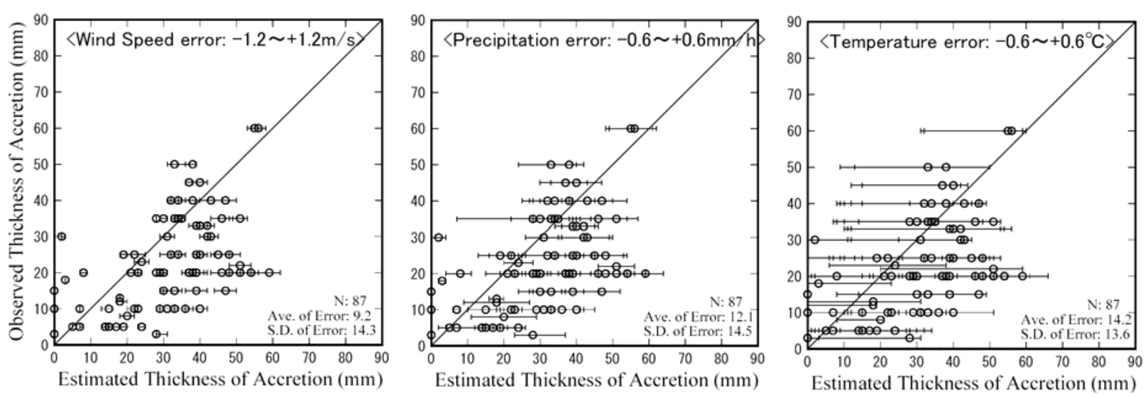

Fig. 6. Impact of errors in estimating meteorological values on estimated snow.

This considerable discrepancy in the estimation results can probably be attributed to the overlap of errors in estimating meteorological values, errors in estimation using the equation for calculating amount of snow accretion, and errors in the observed amount of snow accretion. One conceivable reason for the fact that the estimates tended to be somewhat greater is that the data on snow accretions on transmission lines used in formulating (1) were obtained using the results of regression analysis performed on data collected when remarkably thick snow accretions occurred.

C. Impact of Errors in Estimating Meteorological Values on Estimated Snow Accretion

The impact of errors in estimating meteorological values on the margin of error of estimated snow accretion was examined by treating meteorological values as interval estimates in calculating amount of snow accretion. The resulting impact was then analyzed. The range of interval estimates was defined as the estimated value ± average absolute error. Fig. 6 shows how the amount of snow accretion as determined in this fashion -- in the form of interval estimates -- compared with observed values. Estimation of temperature displayed the highest level of accuracy (the highest correlation coefficient), yet had the greatest impact on error in estimated snow accretion; conversely, estimation of wind speed displayed the lowest level of accuracy (the lowest correlation coefficient), yet had the least impact on estimated snow accretion. When one also considers the discrepancy in the estimates' margin of error, there seems to be a high probability that errors in estimating meteorological values have a considerable impact on the margin of error of estimated snow accretion.

IV. Analysis of Extreme Value Statistical Distribution

So far this paper has described a method of estimating the amount of snow accretion at a given point in consideration of line direction. It has also described the results of an attempt to verify the accuracy of this method. Employing this method of estimation to determine design snow accretion will require assessing amount of snow accretion for a specific return period, using long-term meteorological data. Generally Gumbel distributions are used for extreme value distribution of wind speed, depth of snow cover, and such. Here, therefore, maximum amount of snow accretion per year was calculated using hourly meteorological observation values as recorded by weather offices; the results were then plotted on a double-exponential probability paper using the Thomas method, and their compatibility was examined. In calculating the amount of snow accretion, the wind speed data used were, in accordance with the method described in the preceding chapter, corrected for a height of 10 m above ground and a surface roughness of Category II; line direction was assumed to be east-west; wire were assumed to ACSR610mm^2 (with an external diameter of 34.2 mm). The results are given in Fig. 7. Although there were cases, such as that of Yokohama, of the upper value reaching saturation point, most weather offices displayed a more linear distribution, and compatibility with a Gumbel distribution was relatively good.

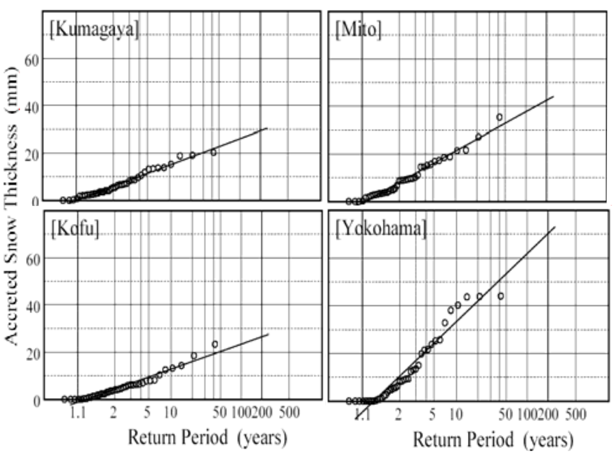

Fig.7. Estimated annual maximum thickness of snow accretion at weather offices, and its Gumbel distribution

V. CONCLUDING REMARKS

This study, which focused on the Kanto region in Japan, proposed a method of estimating snow accretion at a given point and attempted to verify the accuracy of that method. As a result the following conclusions were reached:

(1) The estimates obtained using the method of estimating snow accretion at a given point proposed in this study tend to yield slightly higher figures than the observed values for amount of snow accretion. The accuracy depends on both the accuracy of estimation of the meteorological values for that point and the accuracy of the equation for calculating amount of snow accretion, can at present hardly be described as sufficient. Snow accretion is a complex phenomenon affected by a wide variety of factors, including weather, state of facilities, and operating conditions. Estimation accuracy will need to improved by, for example, building up a pool of high-quality observation data.

(2) The margin of error in estimating snow accretion is not small; a large number of factors would appear to be at play here, including errors in estimating meteorological values (wind direction and speed, precipitation, and temperature), errors in calculating amount of snow accretion resulting from using the equation of empirical model, and errors in observations. There are indications that errors in estimating temperature have an especially large impact, but it was not possible to clarify the exact impact of each factor. Consideration will also need to be given to methods of factoring into design the uncertainties attendant upon estimating snow accretion.

(3) When maximum amount of snow accretion per year at major weather offices was calculated and the results plotted on a double-exponential probability paper, compatibility with a Gumbel distribution was found to be relatively good. The extreme value statistics obtained in this study suggest that a Gumbel distribution can be applied, but in certain cases the compatibility was not good. As discussed in Sakamoto [10], thought should also be given to what to do about a phenomenon peculiar to snow accretions, namely the occasional manifestation of extraordinarily high values.

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