Japanese Country Report 2010

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ABSTRACT: This paper reviews domestic activities in the wind engineering field in Japan in the recent one year, including activities of the Architectural Institute of Japan (AIJ), the Japan Association for Wind Engineering (JAWE), and other organizations.

KEYWORDS: Wind Resistant Design, Cladding and Components, Wind-induced Disaster, Building Code, Tornado, Nuclear Facility

1 ACTIVITIES OF WIND LOADING COMMITTEE OF ARCHITECTURAL INSTITUTE OF JAPAN (AIJ)

The AIJ Wind Loading Committee (chaired by H. Kawai) consists of three working groups: Working Group on Wind Resistant Design System, Working Group on Wind-Resistant Performance of Claddings/Components and Working Group on Wind-Resistant Structural designing by CFD. The following describes the activities of each working group during the past year. This committee has begun to discuss the revision of AIJ-RLB-2004 in 2014.

1.1 *Working Group on Wind Resistant Design System*

This WG (chaired by H. Kawai) investigated the performance and usability of various building codes and standards to revise AIJ-RLB-2004. Flow-charts for estimating wind loads for AIJ-RLB-2004, ASCE7-05, AS/NZS1170.2, BS6399-2, EN1991-1-4 and ISO4354 (2009) were compared to check their performance and usability to clarify improvement points for AIJ-RLB-2004. This working group has also discussed dynamic responses of buildings, fatigue damage to members, design examples, calculation programs of wind loads and terminology of the revision of AIJ-RLB-2004.

1.2 *Working Group on Wind-Resistant Performance of Claddings/Components*

Recent wind-induced damage to buildings has demonstrated the importance of wind-resistant design of cladding/components as well as problems caused by wind-borne debris. The objective of the working group on wind resistant performance of claddings/components (chaired by Y. Uematsu) was to develop more reasonable wind-resistant design of claddings/components to reduce wind-induced damage. Following two years of activities of the working group, a textbook "*Wind Resistant Design and Evaluation of Wind Resistant Performance of claddings/Components*" was published in 2008. It consists of the following five chapters:

Chapter 1	Importance of claddings/components in wind resistance of buildings
Chapter 2	Lessons from recent wind-induced disasters
Chapter 3	Wind loads on claddings/components
Chapter 4	Evaluation of wind resistant performance of claddings/components
Chapter 5	Flying debris

This working group held symposiums using the textbook in Tokyo in 2008 and Osaka in 2009. It has also discussed wind force coefficients for structural frames and claddings/components as well as the effect of the wind-borne debris in the revision of AIJ-RLB-2004. The Working Group consisted of the following two sub-working groups:

1.2.1 *Sub-Working Group on Wind Loads on Claddings/Components*

The objective of this sub-working group (chaired by K. Ohtake) was to review the results of recent investigations on wind loads on claddings/components, and to thus develop methods for determining wind pressure and force coefficients, considering the time-space correlation of wind pressures acting on the tributary areas of claddings/components. It also focused on the internal pressure coefficients for buildings with openings of various sizes and locations.

1.2.2 *Sub-Working Group on Wind-Resistant Performance of Claddings/Components*

The objective of this sub-working group (chaired by H. Nishimura) was to propose reasonable methods for evaluating the wind-resistant performance of claddings/components, considering not only the dynamic load effects of wind pressures but also the wind-induced responses of claddings/components, including fatigue damage. This working group consisted of engineers and researchers from various industries. The following items were discussed: wind resistant performance to be considered in design, testing method for verifying performance, and safety factor.

1.3 ***Working Group on Wind-Resistant Structural Designing by CFD***

Recent speeding up of High-Performance Computers (HPCs) and achievements of numerical techniques enabled us to predict the time-dependent as well as the time-averaged structural wind forces using the modeling of Computational Fluid Dynamics (CFD) mainly formulated by unsteady analytical methods such as large eddy simulation (LES). Since CFD has some advantages over wind-tunnel experiments for data acquisition or modeling of terrain and urban surfaces, CFD-based design would introduce a new concept and a unique methodology for wind-resistant structural design. For example, vertical wind velocity profiles affected by elevated building blocks or terrain undulations could be estimated appropriately by CFD in each case of a specified area using data of the Geographic Information System (GIS). Thus, wind profiles need not to be classified for all areas in advance.

The objectives of this working group (chaired by T. Tamura) were to reveal the availability and effectiveness of CFD-based wind-resistant structural design and to discuss its novelty as a design methodology, and to verify its validity and accuracy as a design tool by carrying out CFD-based design of actual buildings. This working group showed state-of-the art results on CFD-based wind-resistant structural design of buildings at the workshop held at Tokyo in May, 2010. It has also discussed the items concerned with the design wind speeds of the revision of AIJ-RLB-2004. The working group consisted of the following two sub-working groups:

1.3.1 *Sub-Working Group on Methodology of Wind-Resistant Structural Designing by CFD*

This sub-working group (chaired by H. Kataoka) discussed the new wind-resistant design methodology exploiting CFD techniques. The following topics were examined: design based on a scenario of a disastrous virtual typhoon, the effect of atmospheric stability conditions on wind loads, evaluation of urban surface roughness or geographical conditions, wind load estimation for lattice structures and examination of the validity and accuracy of wind loads estimated by LES. Pilot guidelines of numerical techniques for CFD-based designing were also reviewed and checked.

1.3.2 *Sub-Working Group on Practice of Wind-Resistant Structural Design by CFD*

This sub-working group (chaired by K. Nozawa) planned to validate the accuracy of CFD for wind-resistant structural design of actual buildings. The numerically obtained design wind loads on structural frames and claddings were compared with those estimated from experimental data. Time-dependent simulations were performed using turbulent inflow generating techniques and LES was mainly applied to estimate fluctuating wind forces. In the model set up for CFD, target buildings with complex shapes as actual buildings were mounted in an urban terrain with neighboring buildings. Some of the simulations were performed using commercial codes but most of them were done using home-made codes.

2 ACTIVITIES OF RESEARCH COMMITTEE ON WIND-INDUCED DISASTER, JAPAN ASSOCIATION FOR WIND ENGINEERING (JAWE)

(http://www-windlab.ce.tokushima-u.ac.jp/kaze-saigai/)

Recently, local storms caused by tornados, downbursts and others have caused severe damage to buildings, structures, crops, etc in Japan. Figure 1 shows the location of such events in 2009. Furthermore, Typhoon No.18 of 2009 caused damage to wide area of Japan. Lessons learned from disasters can greatly contribute to countermeasures against future natural calamities. The Research Committee on Wind-Induced Disaster (RCWD), Japan Association for Wind Engineering, was founded in 1998 to organically cope with many problems related to wind-induced disasters. The aims of RCWD are as follows:

1) To establish investigation methods from which useful information can be secured.
2) To collect and analyze information of damage caused by strong winds.
3) To prevent or mitigate the effects of disasters.
4) To establish technologies to predict and prevent disasters.
5) To carry out positive awareness activities for administrative officials and citizens as well as for specialists, and to implement collaborative work.
6) To establish networks for the prevention or mitigation of disasters extending from villages, towns and cities to the world.

The RCWD was organized by approximately 50 members, mainly researchers and engineers in the fields of meteorology, civil engineering, transportation, agriculture, insurance and others. The practical activities of the committee in the recent one year are as follows:

2.1 *Damage Investigation*

The RCWD investigated the damage caused by Typhoon No. 18 of 2009 as well as by several tornados that occurred in the Kanto District during this typhoon. The results were published in Wind Engineers, JAWE, Vol. 35, No.3, 2010, as a special edition “Damage caused by Typhoon 0918 (Melor)”. The contents of this edition are as follows: (i) Meteorological features of Typhoon 0918 (Melor); (ii) Outline of damage and operation disturbances of railways in the Greater Tokyo Metropolitan Area caused by Typhoon 0918; (iii) Damage to buildings due to Typhoon 0918 (Melor); (iv) Damage by F1 tornado in Chiba Prefecture on October 8, 2009; (v) Damage by F1 tornado in Ryugasaki City, Ibaraki Prefecture on October 8, 2009; and (vi) Damage to buildings by F1 tornado in Tsukuba City, Ibaraki Prefecture on

October 8, 2009. Regarding the other tornado disasters, the results of damage investigations were published in the Journal of Wind Engineering, JAWE, and others. The 2009 Annual Report of RCWD was published in April, 2010 (see Fig. 3), in which wind-induced disasters in 2009 are summarized.

2.2 *Actions for Publicity to Society and Local Communities*

By means of seminars, forums, lectures and so on, which are usually organized with local governments, the outcomes of RCWD are conveyed to various constitutions of society, for example, in Kumamoto and Kochi in 2009. Many administrative officials and citizens participate and discuss disaster prevention. A textbook based on an elaborate revision of the original version of "*Changes and Lessons in Strong Wind-Induced Disaster*" is now edited by RCWD, and will be published in the next year.

2.3 *Accumulation and Analysis of Past Wind-induced Disaster Records*

Reports on past wind-induced disasters were collected to construct a database. Any member of the JAWE can use the data and carry out analysis from various viewpoints: meteorological conditions; wind characteristics; forecast and alert; damaged objects (structures, agricultural products, traffics and lifelines, etc.); and influence on society, economy and human behavior.

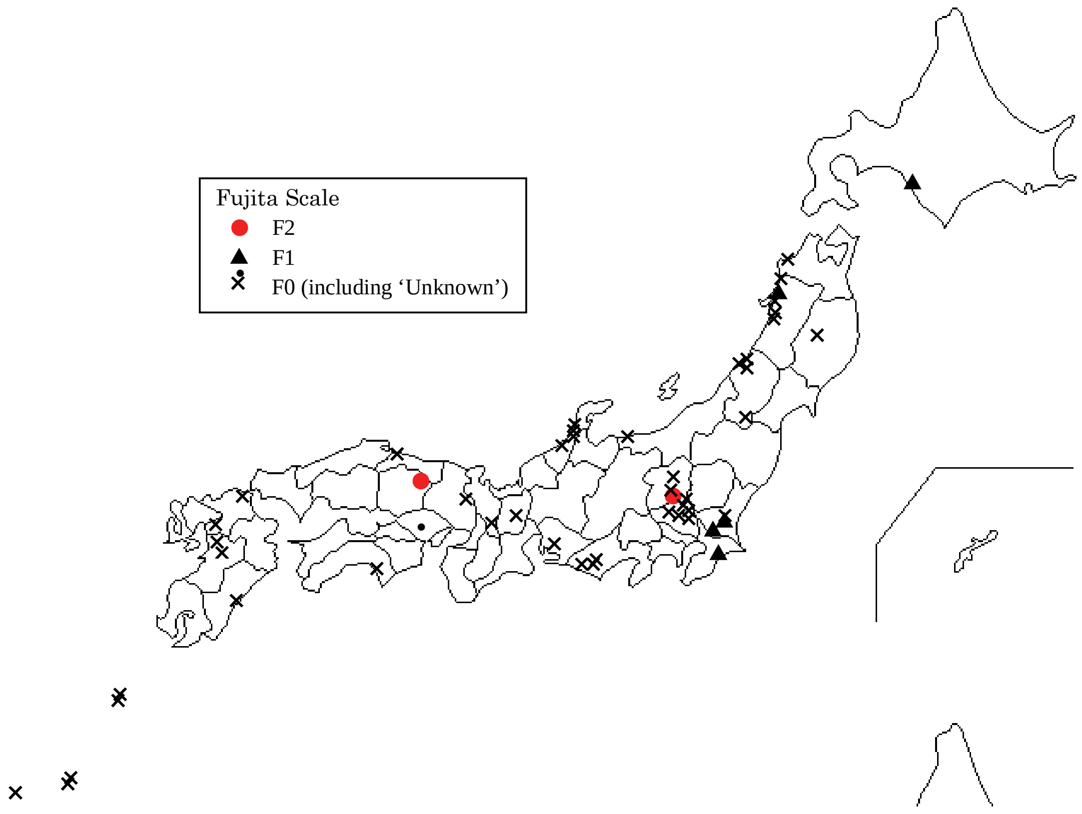

Figure 1: Locations of Tornado, Downburst and Other Severe Local Storms Occurring in 2009

風災害 No.7

日本風工学会
風災害研究会
2009年次報告

Annual Report 2009
Research Committee on Wind-induced Disaster
Japan Association for Wind Engineering

JAWE

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巻頭言

この「風災害」報告も数を重ね，充実した内容で，No.7をお届けできることを嬉しく思います。大きな被害をもたらした台風は一つでしたが，突風や竜巻による局所的被害はかなりの件数に達したのが，2009年の状況といえましょう。

災害研究は，実際の災害をつぶさに調査することが第一義です。被害とその要因を分類化，体系化することは災害低減には非常に大事なことですが，そのためには被害の状況を正確な形で資料として残すことが欠かせません。地震の場合は，K-netなどにより地震動の記録が定量的な形で確実に残るのに対し，突風などは気象庁のデータにも定量的なものとして残らない場合が多いと思われます。この「風災害」は地道ですが，その意味でも重要であり，あとあと資料の価値がますます大きくなることが期待されます。

日本風工学会は，これまで任意団体でありましたが，次年度から「一般社団法人」に移行する予定です。公的機関が委託する災害関連の研究調査にも正式に参加が可能となります。風災害研究の発展に何らかの良い影響がでることを期待しております。

災害研究は過去の被害を対象とするのが普通です。私の個人的意見ですが，地球温暖化が今後の風災害にどのような影響を及ぼすのかなど将来のことも検討していくことは，風災害研究の振興という意味では大事なことではないでしょうか？

風災害研究会のますますの活躍を期待しております。

(日本風工学会2009年度会長，東京大学・藤野陽三)

強風災害ニュース

災害フォーラム「地震と台風による地域・建物被害調査の地域防災への活用」

日本建築学会災害委員会との共催で2009年10月9日に熊本県庁大会議室で開催した災害フォーラムは強風災害と地震災害を同時に取り上げたもので，2008年の佐賀市に続く2回目のイベントである。熊本県は布田川・日奈久断層の活動による地震被害が危惧されるとともに大型台風による被害が近年頻発している経緯から，約70名の市民の参加があった。被害事例だけでなく，被害建物の調査内容や被災直後および災害復興時の住民間コミュニティの役割などの社会学的なプログラムも構成した。講演終了後の意見交換では，市民の生活に関連し，防災意識向上につながるような活動事例への関心を示す意見が多数あった。フォーラムの詳細は日本風工学会誌 Vol.35, No.1 (No.122)で報告している。

講演終了後の意見交換

(九州大学・ 前田潤滋)

風災害フォーラム「高知の風，あなどるべからず」

2009年11月15日に高知大学との共催，高知地方気象台と高知県の後援により，高知市の高新文化ホールで高知風災害フォーラムを開催した。フォーラムは，第1部が突風や強風の気象学的見地からの解説，第2部が耐風対策や減災対策などに関する解説，第3部がパネルディスカッションで構成され，高知県の風災害に対する意識改革などについて議論がなされた。また，休憩時間などを利用して竜巻の再現実験も公開された。詳細は日本風工学会誌 Vol.35, No.2 (No.123)で報告する。

公開実験の様子

(高知大学・佐々浩司)

日本風工学会風災害研究会 風災害 No.7，Annual Report 2009　1

Figure 2: Annual Report 2009 by RCWD, JAWE

3 NATIONAL PROJECT FOR MAINTENANCE OF BUILDING CODE IN JAPAN

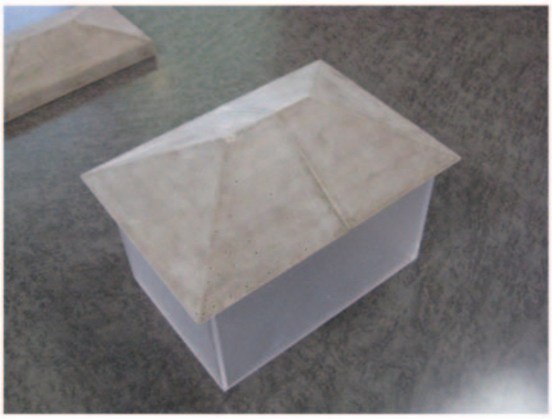
3.1 *Outline*

A project to promote maintenance of the Building Standard Law of Japan sponsored by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) started in August, 2008. It had 21 tasks. One of them related to studies on rationalization of wind load and wind resistance design, which was carried out as a cooperative study with the Building Research Institute. In order to carry out the project, driving institutions were recruited from the public. The Wind Engineering Institute and the Japan Housing and Wood Technology Center applied jointly with a proposal. Three items were proposed for the study: (1) complement of aerodynamic force/pressure coefficients, (2) improvement of method for evaluating wind resistance performance of cladding and components of a building and (3) rationalization of the structural design of tower-like structures. In order to carry out the study, a committee and three working groups composed of academic experts and practical engineers were proposed. A committee chaired by Y. Tamura was formed and three working groups were organized. Achievements of the committee from August, 2009 to March, 2010 are shown as follows.

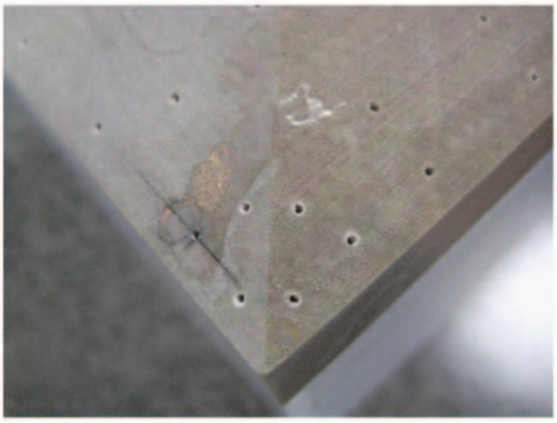
3.2 *Working Group on Wind Force/Pressure Coefficients*

In the Building Standard Law of Japan (hereafter referred to as BSLJ), wind force/pressure coefficients should be given. Wind force coefficients for fundamental building shapes are given in the BSLJ, but wind force coefficients with complex building shapes are not given. Furthermore, when the BSLJ was revised in June 2007, separate estimations of wind loads for main structural frames and for cladding and components were required. Thus, the wind force/pressure database given in the BSLJ needed enrichment. In this way, investigation for enhancement of the wind force/pressure database started as a 3-year consecutive study. Wind pressure coefficients for flat roofs and gable roofs have been provided in the BSLJ, but wind pressure coefficients for hipped roofs widely used in Japan are not shown. Furthermore, wind pressure coefficients for roofs with eaves are not given in the current BSLJ. To enrich the database of wind force/pressure coefficients for those roofs and eaves, wind tunnel experiments have been conducted and the results have been provided for use in design (see Figs.3 and 4). The results are outlined as follows.

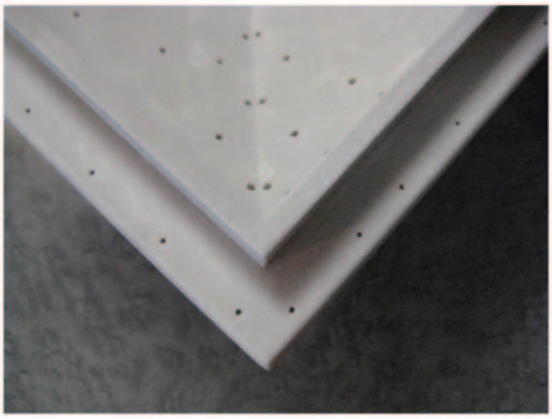
(1) The peak external pressure coefficient for cladding/components given in the BSLJ is based on the panel pressure acting on a $1m^2$ trivial area and the temporal average of 0.5s to 1 s. In this study, the peak external pressure coefficient from the wind tunnel experiment is evaluated based on the same conditions as the BSLJ.
(2) The peak external pressure coefficient of a hipped roof is provided. The peak pressure coefficient near the corner ridge cannot be larger than that near the main ridge.
(3) Wind tunnel experiments were conducted for roof pressures with eaves 30cm and 60cm long, and it was found that there is no significant difference among the peak external pressure coefficients on the upper surface of the roof. However, the peak pressure coefficients on lower surface of the eave is about ±2.0 for any slope angle of the gable roof and hipped roof.
(4) For the peak wind force coefficient evaluated as a resultant force acting on the eave, a comparatively large negative value is given. The largest value of the peak wind force coefficient for the eave is −7.0 for a flat roof, and almost the same value is obtained for gable roofs and hipped roofs with a slope angle of 10 degrees.



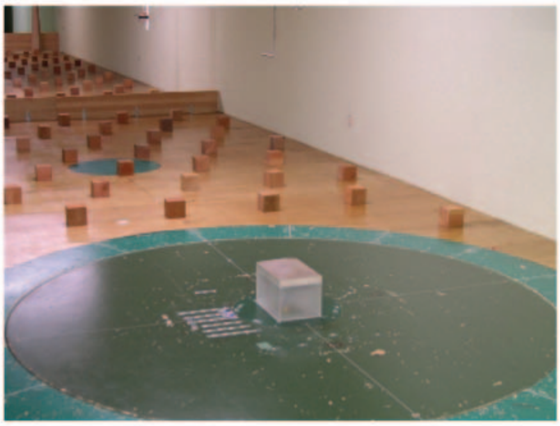
Hipped roof model with eaves



Upper surface of hipped roof corner

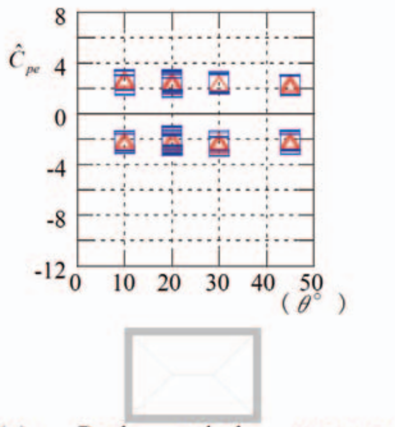


Lower surface of eaves of hipped roof model

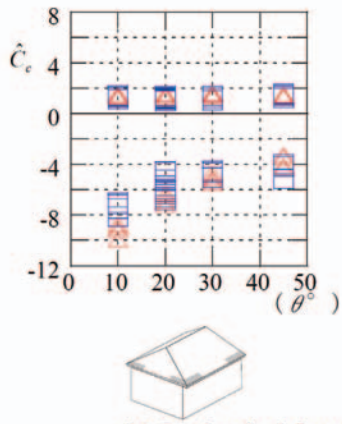


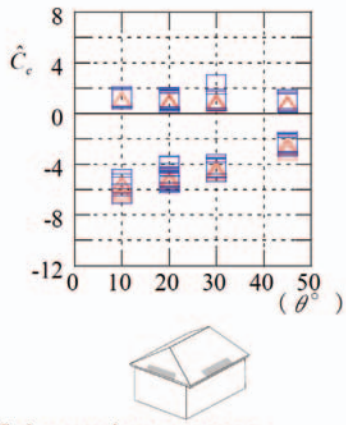
Model set-up in wind tunnel

Figure 3: Wind Tunnel Experimental Set-up



(a) Peak wind pressure coefficient of lower surface of eaves





(b) Peak wind force coefficient acting on eaves

Figure 4: Variation of Peak Wind Pressure Coefficient $\hat{C}_{pe}$ and Peak Wind Force Coefficient $\hat{C}_{C}$ of Eaves with roof slope angle (θ^{o})

3.3 *Working Group on Evaluation of Wind Resistance Performance of Cladding and Components*

In Japan, there were indefinite areas with regard to the responsibility of the designer, the constructer and building material makers for structural members and building envelope elements. In this working group, an investigation and questionnaire study on the current status of wind resistance design of building envelope elements were conducted. Questionnaires on the application area, required performance, structural method and structural calculation for building envelope elements, etc, were sent out to each building materials industry, such as clay tile roofing, slate roofing, metal roofing, asphalt single roofing, membrane waterproofing, sash, shutter, door, window glass, metal siding, ceramic siding, ALC panel and Japan Conference of Building Administration (JCBA). The findings are summarized as follows.

3.3.1 *Building materials industry*

(1) The boundary of design responsibility between the structural framework and building claddings is not clear for designers and building material makers.

(2) Many building material makers examined the wind resistant performances of each member, in which the wind resistant safety of all the claddings and supports are examined.

3.3.2 *Japan Conference of Building Administration (JCBA)*

(1) Necessary information on external wind forces and stresses in claddings/components are not yet sufficient to confirm the wind resistant safety of components and claddings at building inspection.

(2) If correct information on external wind forces and stresses in claddings/components are provided in "Structural Technical Standard and Commentaries for Buildings", inspectors can refer to them at the building inspection.

A severe lack of interest of structural designers in the performance and safety of claddings/components was cited. However, if the necessary information is provided to building inspectors to confirm the structural safety of claddings/components at building inspection, the lack of interest of structural designers in the structure safety of components and claddings is expected to be improved.

3.4 *Working Group on Tower-like Structures*

The BSLJ provides a prescription for tower-like structures such as chimneys and towers for advertisements. It is a Notification of the Ministry of Construction on Structural Calculation for Structures, 2000. It covers design wind loads, design seismic loads and structural calculations. Dynamic characteristics of structures have some influence on the loads. However, the notification does not seem to adequately reflect the influence on its design load prescriptions. As structures higher than 60m should be designed based on dynamic response analysis for seismic actions and a special design treatment is required for other loading conditions, the height of tower-like structures targeted in this study is equal or less than 60m. The following studies were made.

3.4.1 *Chimney*

(1) Distribution of bending moment and shear stress on self-supported chimneys along their height due to earthquakes

(2) Vibration of elements of supporting structure of steel-tower-supported chimneys due to wind

(3) Seismic loads on chimneys projecting from roofs of buildings

(4) Local buckling of steel chimneys

(5) Ultimate strength of RC chimneys and steel chimneys

3.4.2 ***Wind turbine supporting tower***

(1) Distribution of bending moment and shear stress along their height due to earthquakes
(2) Torsional moment on tower due to seismic loads on its nacelle, blades and so on
(3) Gust response factor during operation
(4) Variation of wind-induced stress at the base with yaw angle
(5) Wind loads on supporting towers of pitch-control-type wind turbines under operational conditions (see Fig.5)

In order to examine the distribution of stress in chimneys and towers of wind turbines due to earthquakes, time history analyses were carried out with several ground motions. As a result, it was found that the distribution of bending moment is almost linear. On the other hand, the distribution of shear stress has a larger value than the liner at mid-height.

For examining wind loads on towers of pitch-control-type wind turbines, wind-induced time history analyses were carried out and some important relationships between wind speeds and wind loads were obtained.

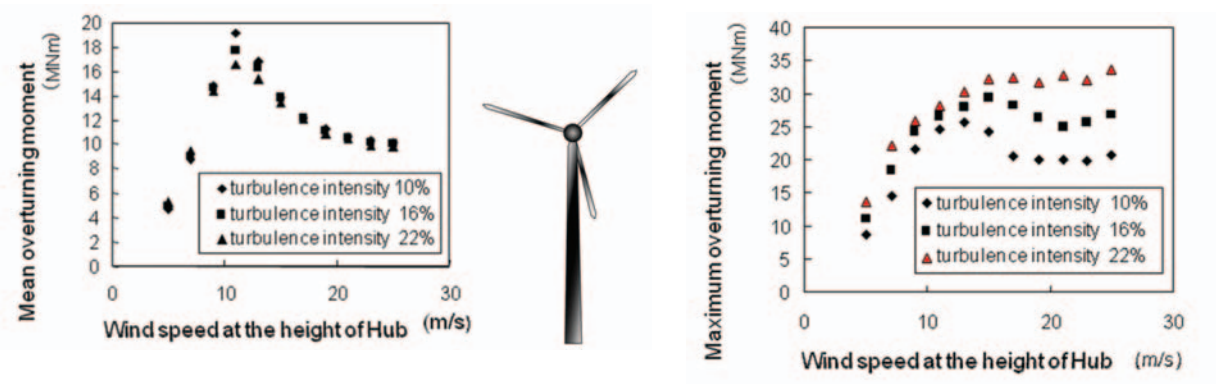


Figure 5: Mean and Maximum Overturning Moment of Wind Turbine Supporting Tower

4 RESEARCH ON EVALUATION OF TORNADO EFFECTS ON NUCLEAR FACILITIES IN JAPAN

Tornadoes and other local meteorological disturbances affect small areas but cause severe and extreme damage to people and structures. Against such meteorological disturbances, countermeasures taken by individuals and public administrations, and design methods implemented in the wind resistant design in Japan, have been insufficient compared to those in the US (US Nuclear Regulatory Commission, 2007). It has been considered that most tornadoes in Japan are a sort of water spout and that big tornadoes caused by super-cells are seldom generated. In recent years, however, extremely severe damage induced by tornadoes has occurred frequently in Japan. It has been suggested that some of them were generated by the same climates as super-cells. According to tornado damage reports, their major causes have been related to wind-borne debris, unlike those of typhoons and normal winds. As stated above, analysis and studies are required to ensure safety of nuclear facilities, considering the characteristics of Japanese tornadoes. Estimation is also required whether the countermeasures like those carried out in the US are necessary or not.

In Japan, studies on tornado effects on nuclear facilities started in 2008. Research items included tornado risk modeling, tornado effects on nuclear facilities and a design-based tornado model, study on existing foreign guidelines on tornado effects and trials for making guideline drafts.

4.1 *Tornado Risk Modeling*

4.1.1 *Tornado database*

In order to evaluate the occurrence rate of tornadoes and to study their distribution in Japan, a historical tornado database was created based on the Japanese Meteorological Agency data and original investigated data. This database showed a wide variety and large number of events, because the recording conditions changed for three different periods. These periods were from 1961 to 1990, from 1991 to 2006, and 2007 and later. To capture the actual situations of tornadoes, the latest dataset should contain more tornadoes. The geographical conditions for tornado generation were studied. It was found that the observed number within near the seacoast was significant as shown in Fig.6. The damaged area and the length of the tornado's path were examined, but clear relations were not seen between the Fujita-scale and the translation direction, the position relative to synoptic disturbance which cause tornadoes, and climate conditions.

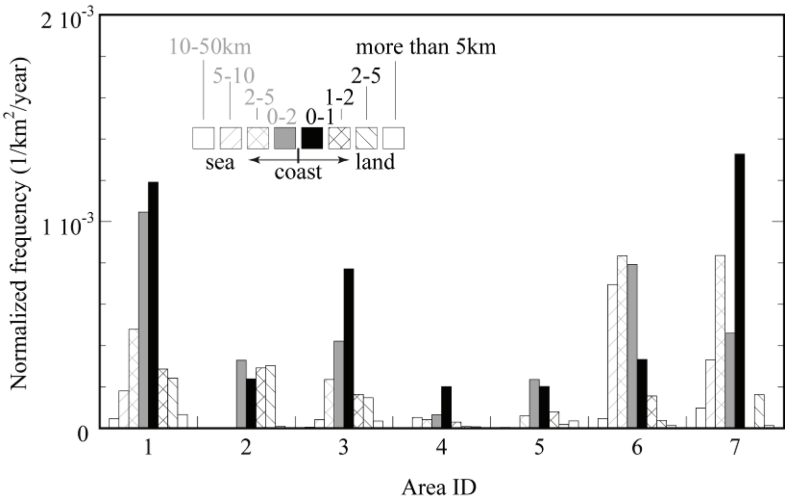


Figure 6: Annual Number of Tornado Occurrence per Unit Area for 7 Subareas [Statistical Period: 2007-2009 (on the sea), 1961-2009 (F2 and F3, inland), 1991-2009 (F0 to less than F2, inland), 2006-2009 (F0 and unknown, inland), Area ID is shown in Fig.7]

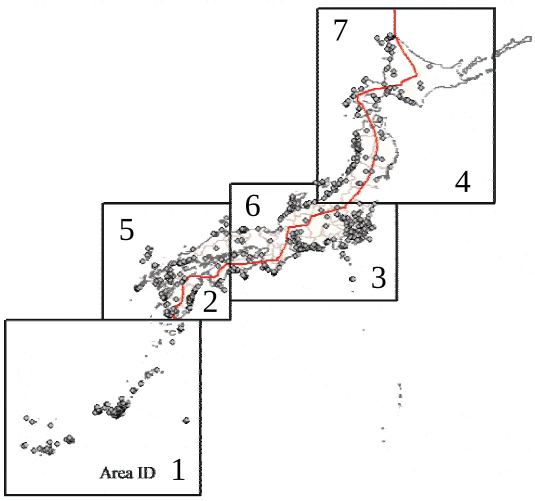


Figure 7: Subareas and Tornado Observed Points in Japan

Past studies on tornado risk modeling in the U.S. (Wen & Chu, 1973, Garson et. al., 1975a, 1975b) were surveyed to assist in development of the Japanese tornado risk model. The study items are as follows.

(1) Japanese tornado database, which was historically changing its characteristics, was studied.
(2) Application of Poisson's distribution and Polya distribution for the occurrence of Japanese tornadoes.
(3) To estimate the exceedance probability of tornado winds, basic statistics in 7 subareas of Japan (see Fig.7) were examined.

4.1.2 ***Modeling of tornadoes and their parameters***

Tornadoes are characterized by their absolute maximum wind speed, the radius of their maximum wind speed, their maximum swirling (tangential) wind speed, their vertical wind speed, their radial wind speed, their translational speed, their central pressure and their differential of central pressure. The following five parameters were selected from observation data:

(1) Absolute maximum wind speed
(2) Translational speed
(3) Tangential wind speed
(4) Radius of maximum wind speed
(5) Central pressure

250 tornadoes observed in Japan from 1997 to 2006 were examined. Tornadoes accompanying extra-tropical cyclones were observed all over Japan in all seasons (Kobayashi et. al. 2007). Tornadoes accompanying tropical cyclones (typhoons) or winter monsoon were observed at several specific locations. F3-tornadoes occur almost once every 10 years, and F2-tornadoes almost twice a year. Most tornadoes are categorized as F0 or F1. This means that the majority of tornadoes in Japan are non-super-cell type, unlike tornadoes in the mid-west US.

60% of tornadoes were observed near the seacoast, 32% over the sea and 28% over land less than 10km from the coast, and the remaining 40% inland (Kobayashi and Sugawara, 2008). Most tornados were observed in the afternoon (2pm to 6pm), which suggests that the majority were due to cumulonimbus generated in unstable atmospheric conditions in a warm climate.

The majority of inland tornadoes showed moving speeds around 5km/h (1.4m/s) and some around 50km/s (14m/s). This means there were two types of tornadoes: one under low ambient wind speed conditions and the other under high ambient wind conditions such as typhoons and monsoons. F2 or F3 tornadoes often accompany typhoons and winter monsoons. Their moving speeds are from 15m/s to 25m/s and they are relatively high.

4.1.3 ***Careful tornado damage survey from local mass media reports***

For tornadoes in the northern area of Japan, damage data were collected from a careful check of local newspapers and mass media and compensated the officially edited the JMA (Japan Meteorological Agency) tornado database. From the local newspapers and mass media reports, thin metal roofing panels were often reported as windborne debris in this area. As the panels had relatively light weight, they flew for long distances. This debris caused damage and successive inconvenience to communication and electric power lines, sometimes leading to railway tie up. It is important to reduce tornado damage to buildings and people, to prevent generation of windborne debris and to improve protecting performance of cladding materials against windborne debris.

4.2 *Site Investigation of Nuclear Power Plant*

4.2.1 *Hazard survey of a nuclear power plant*

Damage history related to meteorological phenomena was surveyed at a selected typical nuclear power plant site. 22 natural disaster events are reported at that site, and some reports on wind related damage were carefully examined. Most events occurred from December to February and from July to October. Those occurring in September and October were related to typhoons and developed cyclones (low-pressures). The number and cause of these events were 11 by cyclones, 5 by typhoons, and 2 by typical winter climates. Most were related to synoptic scale disturbances. Only one event was related to a non-synoptic scale event, a local summer heat thunderstorm, which might happen due to local cumulonimbus. The possibility of tornado or downburst occurrence in the yard cannot be neglected.

4.2.2 *Possible windborne debris in a nuclear power plant*

Windborne debris which might cause serious damage has one of the following characteristics.

(1) Windborne debris with high kinetic energy
(2) Windborne debris hard enough for penetration
(3) Windborne debris hard and small enough to pass through a protection of opening

Based on the site investigation of the nuclear power plant, objects corresponding to each category are found as follows.

(1) Automobiles (passage cars, dump trucks and buses), fork lifts, backhoes, cranes, machine tools, prefabricated temporal buildings, containers, sheds and tents in the power plant yard

These are heavy but aerodynamically light and easy to be blown, thus becoming windborne debris with high kinetic energy.

(2) Steel pipes, reinforcing bars, line-like metal materials lying on the ground of the stock yard outside the plant, and just lying loose on roof tops

These materials are stiff enough to penetrate.

(3) Gravel observed on the ground for pavement in the power plant

Most structures of main buildings are made of reinforced concrete. They are stiff enough to withstand windborne debris. Some auxiliary buildings and facilities, openings, window panes for office buildings are sensitive to windborne debris.

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