Wind Effects

Wind Effects on Buildings and Urban Environment

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Graduate School of Engineering
Tokyo Polytechnic University

INDEX

More Efforts on Promotion of Project!

Nobuyuki KOBAYASHI
President, Tokyo Polytechnic University

Currently, the research program in the "Wind Engineering Research Center" of Tokyo Polytechnic University was adopted as a concentrative base-founding project (COE) under the direction of the Ministry of Education, Science and Technology, and it is now in its second year. The primary aim of this project is not only to carry out research activities in the wind engineering field but also to build up bases for study and research through presentation and collection of information relating to wind engineering, to train and educate research staff, and to arrange and store a technical database. Particular emphasis is placed on activities in Asian countries.

It has been 19 months since the present project was initially adopted. During this period, project staff have been making every effort to tackle problems such as recruitment of research staff, rearrangement of research facilities, establishment of "APEC Wind Hazard Mitigation Center" and "Wind Engineering Information Center", admission of graduate students both overseas and domestic, and organization of international symposiums and weekly seminars. In addition to those in charge of the project's promotion, participants recruited so far are: 9 COE researchers including 4 overseas researchers, 4 short-term fellowship members from overseas on a program for the training of wind engineering technicians, and 8 students on doctoral courses. Thanks to the tremendous efforts of Professor Yukio Tamura, who is acting as the representative of the study program, and of those in charge of project promotion, the research facilities and the system for human resources have been arranged well, and we are now entering the stage of organizing and coordinating the study results. We pay tribute to those who have participated and contributed to the project. As Tokyo Polytechnic University, we are planning to continuously support the project for further successful promotion of its activities.

The subjects of the study "Wind Effects on Buildings and Urban Environment" deal with problems such as disasters caused by strong wind on cities and buildings, air ventilation, diffusion of contaminants, and air flows in cities and buildings. In the research field of wind-resistant structures, the primary aim is mitigation of disasters caused by strong wind on cities and buildings. The subjects of the study include evaluation of design wind velocity, preparation of economic and adequate wind-resistant design methods, wind response monitoring during strong wind, and construction of anti-disaster systems in urban building groups. In the research field of air ventilation flow, the subjects of the study include research and development of ventilation design methods that enable us to utilize natural energy for indoor thermal comfort and to reduce energy consumption for air-conditioning in our daily lives. A study to attain a sustainable society with lower environmental load is also included. In the research field of wind environment and air pollution, the subjects of the study cover air pollution problems ranging from sick-house syndrome to urban air pollution. These are essential for continuing safe and hygienic conditions.

In the middle of October last year, serious damage was caused by the Niigata-Chuetsu Earthquake, and efforts are now being made for reconstruction. However, a lot of typhoons attacked our country one after another last year. There were many victims from Typhoons No. 22 and No. 23 in October. These natural disasters not only took a heavy toll of human lives but also caused tremendous economic losses. It is reported that cumulative economic loss was much higher in typhoons.

Thus, we expect much from the results of the study program "Wind Effects on Buildings and Urban Environment", and hope that the results will be useful, from both realistic and substantial viewpoints, for prevention of wind disasters, the purification of air environment, and energy-saving, and that we will be able to make great contributions to the construction of cities and buildings with longer service life and better environment-oriented behaviors.

Professor Tamura Awarded with Jack E. Cermak Medal from ASCE

Professor Yukio Tamura, the leader of our COE project, was awarded the Jack E. Cermak Medal from ASCE (the American Society of Civil Engineers), and he was officially honored at the banquet of the 17th Engineering Mechanics Conference of the ASCE on June 15, 2004.

This prize was initiated to commemorate the achievements of Professor Emeritus Cermak of Colorado State University, who made great contributions to the consolidation and development of various scientific and technical fields relating to wind technology and to raise it to the level of a new technology named "Wind Engineering". This medal has previously been awarded to Professor Kareem of Notre Dame University and to Professor Davenport of Western Ontario University.

Professor Tamura was awarded this medal for "his outstanding contributions to the analysis of dynamic effects of wind on tall and flexible structures, and his leadership in wind engineering education and research". This means that the broad extent and high quality of his research and study activities up to now have been officially recognized worldwide and that his meritorious deeds in organizing the COE project in Japan has also been highly appreciated globally.

As Professor Tamura himself once said, we are now filled with deep emotion when we recall earlier days when we Japanese researchers visited in groups some world-famous research institutes. In those days, Professor Tamura must have dreamed to have world-class research institutes in our own country. His dream certainly came true with this COE project. We hope that this spirit and zeal will continue to grow among us in the future.

(Invited Professor Takeshi Ohkuma)

Report on Workshop on Regional Harmonization of Wind Loading and Wind Environmental Specifications in Asia-Pacific Economies (APEC-WW)

Date: November 19 and 20, 2004
Venue: Tokyo Polytechnic University

A two-day international workshop on Regional Harmonization of Wind Loading and Wind Environmental Specifications in Asia-Pacific Economies (APEC-WW) was held at Tokyo Polytechnic University, Atsugi, Kanagawa, Japan on November 19th and 20th, 2004 with sponsorship from the 21st Century Center of Excellence (COE) program at the Graduate School of Engineering, Tokyo Polytechnic University (TPU). The purpose of the APEC-WW was to harmonize structural loading standards/codes and bylaws/specifications on wind environmental problems in the APEC area. The workshop participants, about 70 persons in total including 24 delegates from 14 APEC countries, contributed to the discussions.

On November 19, Dr. Nobuyuki Kobayashi, president of Tokyo Polytechnic University, and Prof. Yukio Tamura, COE director of Tokyo Polytechnic University, welcomed the participants and emphasized the significance of collaboration, harmonization, and exchange information on wind loading and wind environment related codes and recommendations in the APEC countries.

Then, along with the concept of this workshop, reports from 15 countries were presented by the delegates and active discussions took place. Through these presentations and discussions, the participants were able to understand the status in other APEC countries.

On November 20, semi-closed workshops were held to promote more detailed discussions. Participants were separated in two special sessions, i.e. wind loadings and wind environment. In the session for wind loading, supplementary country reports, design wind speed, and habitability/ISO were actively discussed. It was confirmed that harmonization of wind loading codes/standards and investigations on discontinuity in design wind speeds in the APEC countries were necessary. In the session for wind environment, several Japanese speakers made presentations on the pedestrian wind environment and outdoor/indoor air pollution, and discussions took place. Differences and similarities in current social situations related to these problems and environmental assessment among APEC countries were clarified.

As a result of the two-day workshop, resolutions for wind loading and wind environment were made and approved. The resolutions and brief minutes will be shown on the COE Web site. The next workshop will be held in Hong-Kong. The 21st century COE program will continuously support the workshop. It is hoped that this activity will contribute to solve wind related problems among APEC countries.

(RyuichiroYoshie and Masahiro Matsui)

Titles of Country Reports

Australia/New Zealand: The Australia/New Zealand wind actions standard. Wind control regulations for Pedestrian level, wind environment in two New Zealand Cities

China: Standardization of wind loading for buildings and bridges in China

Hong Kong: Wind code and air quality standards in Hong Kong

India: Scope and current status of wind engineering - Indian Scenario

Indonesia: Standards for wind effect on structures and environment in Indonesia

Japan: Documents for wind resistant design of buildings in Japan. Current status of wind environmental issues and strategy for environmental conservation in Japan

Jordan: Wind energy research and development in Jordan

Korea: Wind loads standard and present developments of wind environment problems in Korea

Malaysia: Wind Loading for Structural Design in Malaysia

Philippine: New wind load provisions in Philippine structural code

Singapore: Report on the status of codification on wind loading in Singapore

Taiwan (Chinese Taipei): Specifications on building wind resistance design and wind environmental issues in Taiwan

Thailand: Wind loading code for building design in Thailand

Vietnam: On the wind pressure zone map of the Vietnam territory

Delegates and Speakers

Australia: John Holmes (JDH Consulting), John Cheung (Monash University), Bill Melbourne (MEL Consultants Pty Ltd)

China: Yaojun Ge (Tongji University), Xinyang Jin (China Academy of Building Research)

Hong Kong: Kenny C.S. Kwok and S.C. Kot (Hong Kong University of Science and Technology)

India: Ajay Gairola (Indian Institute of Technology Roorkee)

Indonesia: Fariduzzaman and Surjatin Wiriadidjaja (UPT-LAGG BPPT)

Japan: Yukio Tamura, Masaaki Ohba, Ryuichiro Yoshie, Masahiro Matsui, and Kazuhide Ito (Tokyo Polytechnic University), Hiromasa Kawai (Kyoto University), Takeshi Ohkuma (Kanagawa University) Hiroshi Yoshino and Yasushi Uematsu (Tohoku University), Hisashi Okada (Building Research Institute), Kunio Fujii (Environmental Wind Research, Inc.), Hiroaki Nishimura (General Building Research Corporation), Toshimasa Ohara (National Institute for Environmental Studies), Kazukiyo Kumagai (University of Tokyo)

Jordan: Omar Badran (Al-Balqa` Applied University)

Korea: Young-duk Kim (Kwandong University), Young Cheol Ha (Kumoh National University of Technology)

Malaysia: Faridah Shafii (Universiti Teknologi Malaysia)

New Zealand: Richard Flay (The University of Auckland), Andrew King (Institute of Geological and Nuclear Sciences)

Philippine: William T. Tanzo (Vibrametrics, Inc.)

Singapore: Edmund C.C. Choi (Nanyang Technological University)

Taiwan (Chinese Taipei): Chii-ming Cheng and Cheng-Hsin Chang (Tamkang University)

Thailand: Virote Boonyapinyo (Thammasat University), Phoonsak Pheinsusom (Chulalongkorn University)

Vietnam: Nguyen Dang Bich and Nguyen Vo Thong (Institute for Building Science and Technology)

Workshop on CFD Simulation on Turbulent Boundary Layer

Date: October 22, 2004
Venue: Tokyo International Forum
Supported by: Architectual Institute of Japan / Japan Society of Civil Engineering / Japan Association for Wind Engineering / Japan Wind Energy Association

A lot of research has recently been carried out on numerical simulation of Atmospheric Turbulent Boundary Layer (ABL) flow in the field of wind engineering, not only to investigate the physics of the ABL but also to generate a turbulent inflow. In order to improve exchange of the latest information, a workshop on the CFD simulation on turbulent boundary layer was held by the 21 Century COE Program at the Tokyo International Forum on Oct. 22, 2004.


Prof. T. Tamura


Prof. A. Mochida

Keynote presentations entitled "Generation of Inflow Turbulence and its Application in Computational Wind Engineering" and "Recent Progress in CWE and its Applications to Environmental Problems" were given by Prof. T. Tamura (Tokyo Institute of Technology) and Prof. A. Mochida (Tohoku University). Recent progress in CFD studies in the structural and environmental wind engineering fields were reviewed. The invited lectures, Dr. S. Iizuka, Prof. T. Ishihara, Dr. T. Uchida, Dr. H. Kataoka, Dr. K. Kondo, Prof. M. Tsubokura, Prof. Y. Tominaga, Dr. K. Nozawa and Prof. T. Maruyama introduced their researches. A total of 64 persons mainly from universities and research institutes participated in the CFD workshop, preceded by active discussion.

The 21st Century COE Program will continue to hold workshops or symposia in order to improve the development of CWE, which plays increasing roles in the wind engineering field.

(Shuyang CAO)

from left photo:
Dr. S.Iizuka
Prof. T. Ishihara
Dr. T. Uchida

Dr. H. Kataoka
Dr. K. Kondo
Prof. M. Tsubokura

Prof. Y. Tominaga
Dr. K. Nozawa
Prof. T. Maruyama

Invited Article

Field Measurement of Wind Pressures on Buildings During Hurricanes

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Background:

In 1998, the Florida Department of Community Affairs (FDCA) began a project aimed at monitoring the performance of homes during hurricanes. The short-term goals were to provide an assessment of the actual magnitude of the winds and resulting wind loading and to evaluate the performance of homes retrofitted using common recommendations for improving their resistance to high winds. The long-term goal was to provide data on wind pressures in hurricanes and wind characteristics in suburban exposures that would serve as a basis for assessing and improving the wind tunnel modeling of wind loads for buildings subjected to hurricanes, cyclones or typhoons.

To date, thirty homes have been pre-wired along the East Coast and Panhandle regions of the Florida coast. Two additional homes have been pre-wired in the Naples Florida area and another six have been prepared along the coasts of South and North Carolina. Four Universities, the University of Florida, Clemson University, Florida International University and Florida Institute of Technology, are cooperating in the program which has received funding support from FDCA, the South Carolina Sea Grant Consortium, the Institute for Business & Home Safety, the National Institute for Standards and Technology, and Florida Sea Grant. The homes are located at intervals of 16 to 24 km along the coast and most are within 1.5 km of the coastline. The houses are typically one to two stories tall, have composition shingle roof coverings, are located in suburban areas and are relatively free of tree cover.

These instrumented buildings are private homes where the homeowners have agreed to participate in the instrumentation project in exchange for assistance in retrofitting their homes to improve their resistance to hurricanes winds and wind effects. When a storm is not threatening the area, the only visible traces of the instrumentation are stainless steel brackets installed under the shingles that have small exposed clips for

Figure 1. Photos of Wiring System and Roof Brackets for Instrumented House

anchoring the sensors and a pipe system holding instrumentation cables that is tucked up under the soffits of the home as shown in Figure 1. Just before a storm strikes, sensors and a computer system with backup power is installed. It takes about three hours to set up one of the homes and the instruments are recovered after the threat of the storm has passed. Typical retrofits have included replacing the roof covering which includes re-nailing the roof sheathing, installing secondary water protection over the joints between the sheathing, and installing wind resistant shingles. Other retrofits included replacing the garage door with a wind and impact rated door and providing shutters for protection of windows and doors.

Prior to the 2004 hurricane season, six different houses had been subjected to tropical storm force winds with the highest 3-second duration gusts on the order of 18 to 22 m/s. During the 2004 hurricane season, sixteen homes were instrumented. All sixteen were exposed to wind speeds in excess of tropical storm force and six were exposed to hurricane force winds.

Performance of The Retrofitted Homes in the 2004 Hurricanes:

The retrofits performed on the homes did provide significant protection from the storms. However, several of the homes had relatively new roofs (less than 4 years old) at the time that the homes were retrofitted and instrumented. Consequently, new roofs were not installed on those homes. The two homes that were not re-roofed and that were subjected to wind gusts of 35 m/s or higher did suffer damage to the roof covering and water damage to the interior of the home. Another home that was re-roofed and was exposed to open country equivalent 3-second gust speeds of about 50 m/s (41 m/s 2-second gust just above the roof) did suffer damage when the roof of a screen porch was lifted off its columns, flew over the roof of the house and knocked the chimney off the house, opening a hole in the roof. However, none of the shingles on the roof were displaced. Figure 2 shows the house with the damaged porch in the foreground and the chimney damage. Note the sensors installed around the edge of the roof. Overall, the homes exposed to tropical force winds and low to middle level hurricane force winds suffered no damage provided the roof cover had been replaced and the home was fully shuttered. Homes that had not been re-roofed with wind resistant shingles did suffer loss of roof covering when the wind gusts reached or exceeded about 35 m/s.

Figure 2. Photograph of Instrumented House with Roof of Porch and Chimney Damage

Analysis of Field Data:

The wind speed data from the homes and from four mobile 10 m meteorological towers deployed near the homes have been analyzed. The pressure data is being analyzed but it will take some months before the analysis of the 2004 data is complete. The field measurement system uses absolute pressure transducers with a modified sensitivity and offset to allow detailed measurements of pressure time histories with a resolution of 0.005 kPa. Since absolute pressure transducers are used, it is necessary to back out atmospheric pressure changes and a weak sensitivity to temperature variations. The initial nominal accuracy of the measured pressures is +/-0.1 kPa, but earlier analyses of data from tropical storms suggests that the uncertainty can be reduced to about +/-0.025 kPa through comparisons with maximum, mean and minimum pressure coefficients obtained from wind tunnel tests.

Preliminary Results of Wind Tunnel Simulations:

Comparison of pressure coefficients obtained from field measurements on two houses in Tropical Storm Isadore with results of boundary layer wind tunnel model tests [1] showed very good agreement between maximum and mean pressure coefficients and a reasonable comparison between minimum pressure coefficients. A photo of one of the model homes in the Clemson University boundary layer wind tunnel is shown in Figure 3. The new data from the 2004 hurricane season greatly expands the data base for these comparisons and the universities involved expect to be able to provide data sets on the world wide web for access by researchers around the world once sufficient resources are obtained to support this activity. The new data sets should provide considerable improvements in the quality of the full-scale data and analysis since the magnitudes of the wind induced pressures are about four times greater than those obtained from the measurements in Tropical Storm Isadore. One of the homes instrumented for Tropical Storm Isadore was also instrumented during Hurricane Ivan and the winds at the site were about twice as high in Hurricane Ivan for wind directions similar to those experienced in Tropical Storm Isadore.

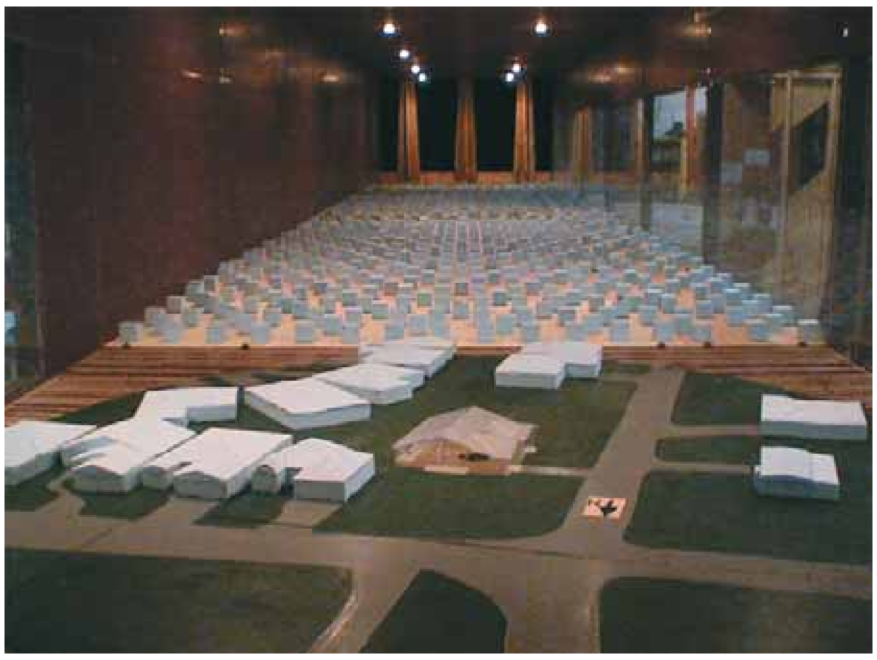

Figure 3. Photograph of Model of Full-Scale Instrumented House in BLWT.

Potential Implications for Wind Load Standards:

Peak negative pressure coefficients obtained from the field measurements obtained during Tropical Storm Isadore frequently exceeded the ASCE 7 coefficients for the corresponding roof zones. The wind tunnel results were generally equal to or smaller that the corresponding coefficients based on the field measurements for the same wind directions and clearly showed that other wind directions were more critical at most of the pressure tap locations than those encountered during Tropical Storm Isadore. The result is that the ASCE 7 peak negative pressure coefficients, instead of enveloping the expected highest negative peak pressures, are likely to significantly underestimate the uplift for critical wind directions. This raises questions about the move towards allowing component and cladding loads on low-rise buildings to be calculated for the particular building exposure using a single set of pressure coefficients, that were developed from testing of models in open terrain conditions. The pre-1995 ASCE 7 method of requiring that design pressures for components and cladding on low rise buildings be computed for open terrain conditions in all cases may have been a better approach than that being used at present.

The arguments for requiring that all low-rise buildings be designed using exposure C conditions were never specifically spelled. But, the general arguments put forward by the wind tunnel experimenters and others with some knowledge of the limited field test results available was that the flow was so uncertain in the region where these buildings were buried amongst objects of similar size that reductions in loads could not be justified. Furthermore, the limited number of tests conducted for isolated low-rise buildings subjected to both generic open and generic suburban flow conditions produced peak local pressures that were of similar magnitude. While it was well understood that the mean wind speed at roof height would be reduced in a suburban exposure, the increased turbulence intensity tended to generate higher peak pressure coefficients with the net result that the peak local pressures were of similar magnitude but probably slightly lower for the building in the suburban setting.

In 1995, ASCE 7 changed its definition of basic design wind speeds from the use of fastest-mile wind speeds to 3-second gust wind speeds. This shift involved both adjustments in the peak local pressure coefficients used in the code and in the exposure adjustment factors, Kz. It was during the adjustment of the Kz factors that an error in the calculation of the older Kz factors was discovered. The new factors were calculated so that they better reflect the expected differences between gust wind speeds for the various terrain exposures. Today, the increase in design wind loads for exposure C conditions as opposed to exposure B conditions is more like 35 percent and the ASCE 7 Standard allows the use of exposure B design winds in calculating design wind loads on low-rise buildings. However, it should be noted that the pressure coefficients used in the code were originally determined for models tested in nominal exposure C turbulence conditions.

Reference:

Dearheart, E.A., "Comparison of field and model wind pressures on residential buildings in tropical storm winds," Master of Science Thesis, Clemson University, Civil Engineering Department, December 2003.

Invited Article

Wind-induced Dispersion of Pollutants from Building Exhaust

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Current standards for building ventilation systems recommend that rooftop stacks from industrial, laboratory or hospital buildings be designed such that their emissions do not contaminate fresh air intakes of the emitting building or nearby buildings. This may require extending the height of the stack or increasing its exit velocity. Unfortunately, the state-of-the-art has not been sufficiently advanced to allow building engineers to apply appropriate design criteria to avoid this problem for new construction or to help alleviate it for existing buildings. Consequently, numerous incidents of poor air quality have been recorded and documented.

In most previous studies plume dispersion was evaluated for a single isolated building model in the wind tunnel. Fluid modeling studies have demonstrated the benefits of high exit velocities and increasing stack height in reducing pollutant concentrations at critical receptors. However, field studies have shown that even with high exit velocities and moderately high stacks, pollutant concentrations may be unacceptably high at particular locations [Wilson and Lamb (1994), Saathoff et al. (2002)]. Several factors such as the location of the stack relative to regions of flow separation and flow re-attachment, the presence of rooftop structures (penthouses) and high upstream turbulence, may account for the occasional poor performance of rooftop stacks. It is important to validate the results of fundamental fluid modeling studies with full-scale data. Although most flow features (e.g. wake size, reattachment lengths etc.) under neutral atmospheric conditions can be accurately simulated in wind tunnels, it is necessary to determine the limitations of fluid modeling with respect to plume dispersion. Relatively few studies have compared wind tunnel concentration data with field data for near-field diffusion cases (i.e. receptors within 50 m of a stack). This is one of the most difficult fluid modeling applications, since the plume characteristics may be sensitive to a number of local factors (building wake effects, the position of the stack relative to rooftop recirculation zones or delta-wing vortices, stack Reynolds number etc). On the other hand, for far-field applications, plume characteristics are much less sensitive to these factors. Several studies have evaluated the accuracy of wind tunnel dispersion measurements [Stathopoulos et al. (2002), Saathoff et al. (2002)] and found good agreement (mostly 20-30% and generally within a factor of two) between wind tunnel and field data. The accuracy of the wind tunnel typically increased as stack-receptor distance increased.

Various models have been developed for estimating near-field dilution of plumes emitted from rooftop stacks for open fetch situations. Two such models are recommended in ASHRAE (1999) and ASHRAE (2003). The latter also provides a geometric method to predict the likelihood of a plume making contact with a critical rooftop receptor. The accuracy of these models is evaluated using some of the recently obtained field data, for cases the emission source was either exposed to the approaching flow (open fetch) or it was in the wake of a tall building. For the case of a tall building upwind of an emitting building, dilution estimates are required for receptors on the adjacent building's leeward wall, as well as the roof of the emitting building. To date, no acceptable dilution model for such cases has been developed.

Gaussian dilution model (ASHRAE 2003)

The Gaussian dilution model recommended in ASHRAE (2003) predicts worst-case dilution at roof-level, D_r, assuming that the plume has a Gaussian (bell-shaped) concentration profile in both the vertical and horizontal directions. The roof-level dilution for a plume at height, h, at a receptor distance, X, from the stack is given as:

$$D_r = 4\frac{U_H}{w_e}\frac{\sigma_y}{d_e}\frac{\sigma_z}{d_e}\exp\left[\frac{h^2}{2\sigma_z^2}\right] \qquad (1)$$

where U_H is the wind speed at the building height, d_e is stack diameter, w_e is the exhaust speed and σ_y and σ_z are the plume spreads in the horizontal and vertical directions, respectively. It should be noted that D_r is the predicted dilution on the plume centre-line. The height of plume above the roof or rooftop structure, h, is determined by

$$h = h_s + h_r - h_d \qquad (2)$$

where h_s is stack height, h_r is plume rise and h_d is the reduction in plume height due to entrainment into the stack wake during periods of strong winds. It should be noted that h_s is the height of the stack tip above the roof minus the height of rooftop obstacles (including their recirculation zones) that are in the path of the plume. Plume rise, which is assumed to occur instantaneously, is calculated using

$$h_r = 3\beta d_e\,(w_e/U_H) \qquad (3)$$

where β is the stack capping factor. The value of β is 1 for uncapped stacks and 0 for capped stacks. To account for the stack downwash caused by low exit velocities, when $w_e/U_H < 3.0$, a stack wake downwash adjustment h_d, which is defined as,

$$h_d = d_e\,(3.0 - \beta w_e/U_H) \qquad (4)$$

is recommended. For $w_e/U_H > 3.0$ there is no stack downwash ($h_d = 0$).

The horizontal and vertical plume spreads required in Eq. 1 are given by

$$\frac{\sigma_y}{d_e} = 0.071\left(\frac{t_{avg}}{2.0}\right)^{0.2}\frac{X}{d_e} + \frac{\sigma_o}{d_e} \qquad (5)$$

$$\frac{\sigma_z}{d_e} = 0.071\frac{X}{d_e} + \frac{\sigma_o}{d_e} \qquad (6)$$

where t_{avg} is the concentration averaging time in minutes, and σ_o is the initial source size that accounts for stack diameter and for dilution due to jet entrainment during plume rise:

$$\frac{\sigma_o}{d_e} = [0.125\beta\frac{w_e}{U_H} + 0.911\beta\left(\frac{w_e}{U_H}\right)^2 + 0.250]^{0.5} \qquad (7)$$

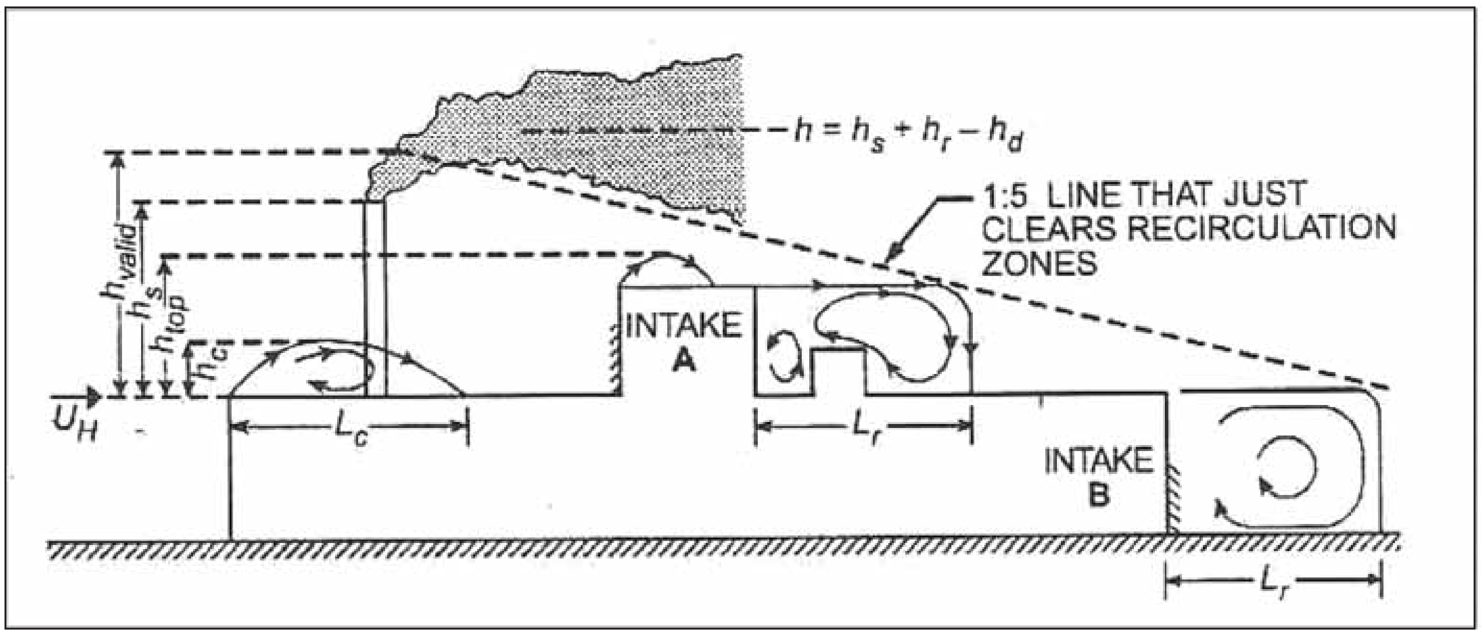
The Gaussian dilution model (Eq. 1) should not be used when the plume height, h, is less than the maximum height of the roof recirculation zones that are in the path of the plume. This critical height is referred to as h_{top} and is shown in the figure. For cases in which the plume height is greater than h_{top} but less than the height required to escape all critical recirculation zones (h_{valid} in the figure), the physical stack height should be set at 0 when calculating h [ASHRAE (2003)].

Design guidelines

The following provides a summary of various design guidelines formulated on the basis of results obtained in the author's laboratory:

Stack location: For open fetch situations, it is better to place the stack near the center of the roof. In this way, the leading edge recirculation zone is avoided, thus, maximizing plume rise. In addition, the required plume height to avoid contact with leeward wall receptors is minimized.

For the case of a taller building upwind of the emitting building, the center of the roof may not be the optimum stack location for receptors on the emitting building. Concentrations over most of the roof can be reduced by placing the stack near the leading edge. However, this stack location will result in higher concentrations on the leeward wall of the adjacent



building. Naturally, this depends on the distance between the two buildings.

Stack height: For open fetch situations, increasing the stack height from 1 m to 3 m reduces concentrations near the stack by approximately a factor of two. Far from the stack (X > 20 m), the effect is negligible. A stack height of at least 5 m is required to provide significant reduction of concentration at such distances. For an upwind adjacent building, small changes in stack height have little effect on concentration.

Stack exhaust speed: Increasing stack exhaust speed by a factor of 2.5 reduces concentrations near the stack by the same factor. For distant receptors (X>20 m), the effect of exhaust speed depends on the M-value (the ratio of exhaust speed to wind speed). In the low M range (1.5<M<4.5), which is typical of wind speeds exceeding 5 m/s, increasing exhaust speed may not be beneficial for distant receptors because the plume rise may not be sufficient to avoid them. On the other hand, for light wind conditions, doubling the exhaust speed may cause M to be high enough so that concentrations are reduced over the entire roof.

Placement of fresh air intakes: For an emitting low building in the wake of a taller building and wind coming from the direction of the taller building

-intakes on emitting building should be placed on its leeward wall if possible;

-intakes should not be placed on leeward wall of upwind building.

ASHRAE (2003) vs ASHRAE (1999) model: The ASHRAE (1999) dilution model is less conservative than the ASHRAE (2003) model and significantly better for distant samplers (X>30m).

For the typical design situation of low M cases (2.5<M<3.5), the ASHRAE (2003) dilution model appears to be overly conservative, especially for distant samplers - it underestimates dilution by a factor of 10 for receptors located more than 30 m from the stack. For high M cases (M~10), i.e. low wind speed, the ASHRAE (2003) dilution model is not conservative for samplers near the stack.

References

ASHRAE (1999) Chapter 43, "Building Air Intake and Exhaust Design", ASHRAE Applications Handbook, American Society of Heating, Refrig. and Air-Cond. Eng., Inc., Atlanta.

ASHRAE (2003) Chapter 44, "Building Air Intake and Exhaust Design", ASHRAE Applications Handbook, American Society of Heating, Refrig. and Air-Cond. Eng., Inc., Atlanta.

Saathoff P., Stathopoulos T., Lazure L and Peperkamp H. (2002), "The influence of rooftop structure on the dispersion of exhaust from a rooftop stack", ASHRAE Transactions, 108, part 2, pp. 1029-1038

Stathopoulos T., Lazure L, Saathoff, P. and Wei. X. (2002), "Dilution of exhaust from a roof top stack on a cubical building in an urban environment", Atmospheric Environment, 36, pp. 4577-4591.

Wilson, D.J. and Lamb, B., (1994), "Dispersion of exhaust gases from roof level stacks and vents on a laboratory building", Atmospheric Environment, 28, pp. 3099-3111.

Reports on Wind Disastaers in/around Japan

Tornado in Saga-prefecture

A deadly tornadic storm moved across Saga-city around 7:20AM, 27 June, 2004.

According to the Saga prefectural government, 15 persons were injured and 376 residential buildings, 6 educational buildings and 117 farming structures were damaged. 5 electric poles were broken and this led to power failures in 3500 houses' and non-operation of some traffic signals.

The Meteorological Agency observed cumulonimbus clouds passing over Saga-prefecture to the east-northeast on their radar around 7AM. The clouds reached Saga-city around 7:20AM and Tosu-city around 7:50AM. At 7:22AM 18.1m/s gust speed from north-northwest was

Figure 1. Major damage locations

recorded at Saga local meteorological observatory, located 4km north of the damaged area. A 2hPa pressure depression was observed at the same time. The damage and observation records indicated that the gusty winds were caused by a tornado of magnitude F2 on the Fujita scale.

Post disaster investigation was conducted on July 29 and 30 in communication with Prof. Junji Maeda (Kyushu University), Dr. Yosuo Okuda (Building Research Institute, BRI), Hitomitsu Kikitsu (BRI), Tomonori Murakami (BRI) and Sunao Ishida (National Institute for Land and Infrastructure Management, NILIM). Interview of local people was summarized as follows. The strong wind continued for 2 to 3 minutes. At one damaged house, the wind suddenly became strong, causing a loud noise, and its roof was blown off.

Damage was concentrated on the path of the tornado. No damage was seen away from its path. In a house 500m from the path, no noise was heard by residents. The damaged area, around 10km long by 200-500m wide, is illustrated in Figure 1. Most of the damage to houses and other buildings was to roofs. Windowpanes and outer walls were damaged as well.

(Masahiro Matsui)

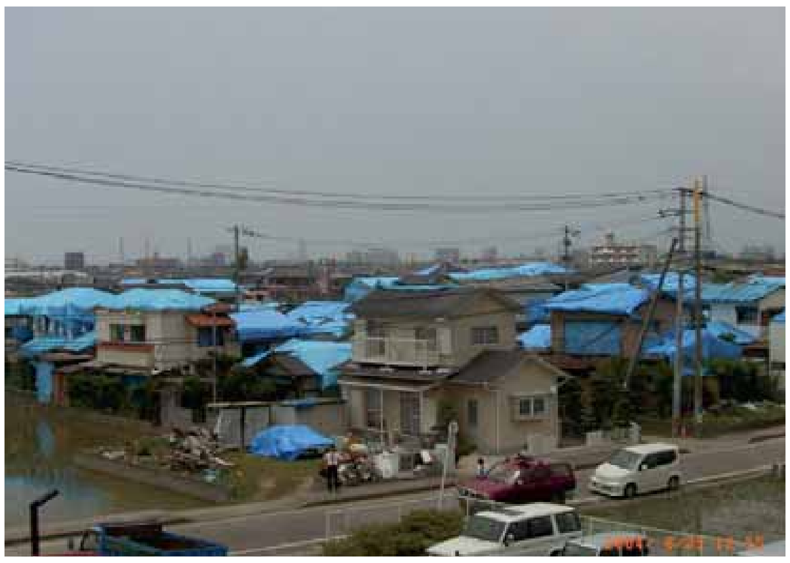


Photo 1. Major damages to roofs

Photo 2. A damaged roof frame

Photo 3. A collapsed wooden house

Wind damage at Ogawa-cho, Tochigi-prefecture, on June 29, 2004

Wind damage occurred at 20:15, June 29, 2004 around the Ogawa-cho area, in the south part of Tochigi-prefecture. There was no human damage. Wind damage and floods under floors of houses were reported by local media (Tochigi-TV). According to the town office, the most severe damage occurred within an 800m radius of the town office. This included broken electric power lines, which affected 130 houses for 4 hours from 8:30PM: damage to 36 houses, e.g. separation of roof cladding; breaking of 3 concrete block fences; and collapse of 21 trees. At Ogawa junior high school, a free-

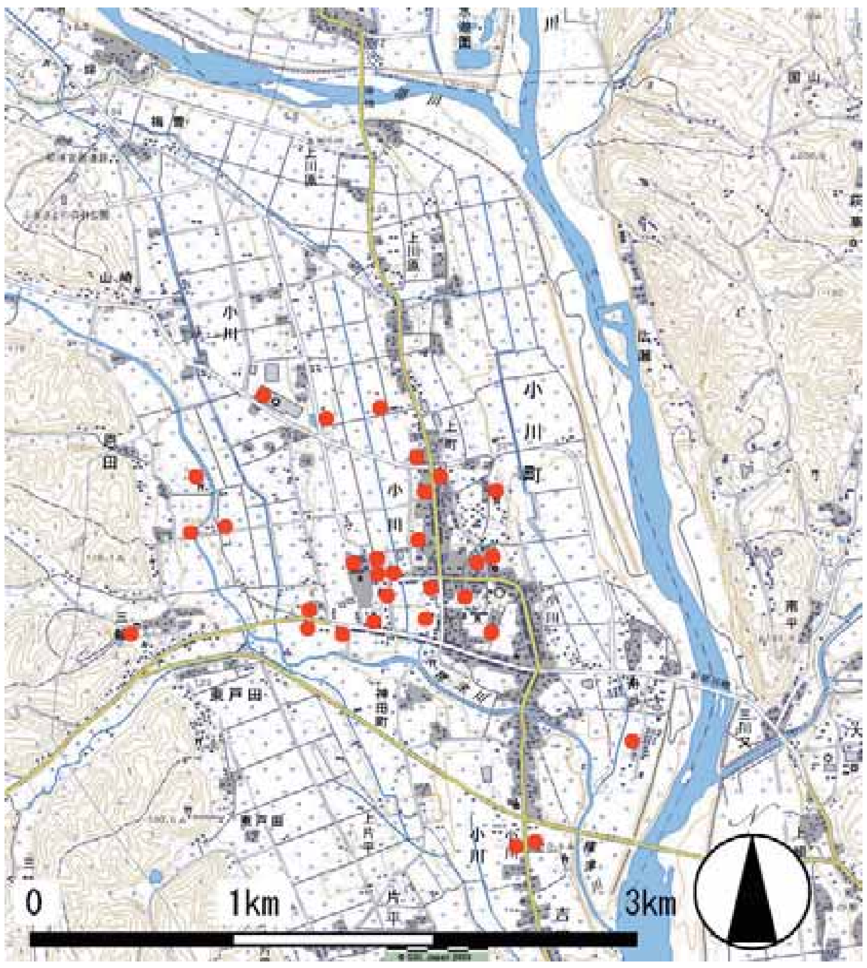


Figure 2. Locations of wind damage

standing canopy roof was broken and its corrugated iron roof sheet was blown 100m.

Utsunomiya local meteorological observatory indicated that this high wind was caused by a downburst evaluated at magnitude F0-F1 on the Fujita scale.

Post disaster investigation was conducted on July 1, 2004, and the damage was found to be not serious. The directions of blown-down trees and flying objects indicated that most of the damage was caused by west winds. Gusts continued for 5-6 minutes after a hailstorm. The hail-stones were about 2cm in diameter.

The authors would like to thank to all people at the site for their cooperation in the investigation. The map is based on one from the Geological Survey Institute of Japan. (Masahiro Matsui)

Photo 4. Broken trees in Onsen-shrine

Photo 5. Roof blown off stock shed

Photo 6 . Plant damaged by hail

News flash on wind damage caused by Typhoon No.13 (Rananim) in China

Typhoon No.13 landed at Shitang Town, Wenglin City of Zhejiang Province in southeast China on August 12, 2004. It passed through four areas called Taizhou, Wengzhou, Lishui and Quzhou for 13 hours with an estimated financial loss of about 18.2 billion RMB (Figure 3). It was a strong, large-scale typhoon with a central pressure at landing of 950Pa and 180km wide, with a wind speed of 24.5m/s to 28.4m/s. A maximum velocity of 58.7m/s was observed in the Taizhou area. The highest precipitation in history was recorded during this typhoon.

Totally, 164 persons died and 24 persons were missing. Collapse of buildings was the main reason for injury and death (see Table 1). When all or part of a roof was damaged by the strong wind, the brick wall lost support and collapsed. Besides the damage to house structures, damage to sloping roofs, cladding materials, plastic houses etc., was also severe.

This investigation was carried out with the cooperation from Prof. Ge Yaojun of Tongji University of China and Dr. Jin Xingyang of the Chinese Building Research Institute.

(Shuyang CAO)

Table 1. Reason for deaths

Reason	Death numder
Collapse of building	109
Boulder flow	28
Strong wind	9
Flood	12
Falling down of telegraph poles etc.	5
Others	1
Total	164

Figure 3. Course of Typhoon No.13


Photo 7. Broken steel roof


Photo 8. Damage to sloping roof


Photo 9. Collapse of stone wall of house

Wind induced damage caused by Typhoon No.18 (Songda)

Typhoon 0418 (Songda) was formed on August 28 at the Marshall Islands and developed its central pressure of 925hPa on September 5 near Okinawa Island. Then, after moving to the northeast, it landed at Nagasaki prefecture and with increasing speed it passed across the sea of Japan before reaching the west of Hokkaido (Figure 4).

This typhoon caused 45 humans killed, 1301 humans injured, 957 houses collapsed and 42,187 houses partially damaged. According to the General Insurance Association of Japan, insurance payments will amount to about 267.3 billion yen (2,429m USD). This is the third largest typhoon to hit Japan, following Typhoon No.19 in 1991 and Typhoon No.18 in 1999.

The numbers of damaged houses (collapsed or partially damaged) in the most severely affected prefectures were 229 in Hokkaido, 73 in Hiroshima Prefecture, 219 in Yamaguchi Prefecture, 50 in Fukuoka Prefecture and 171 in Kumamoto Prefecture.

(Masahiro Matsui and Shuyang CAO)

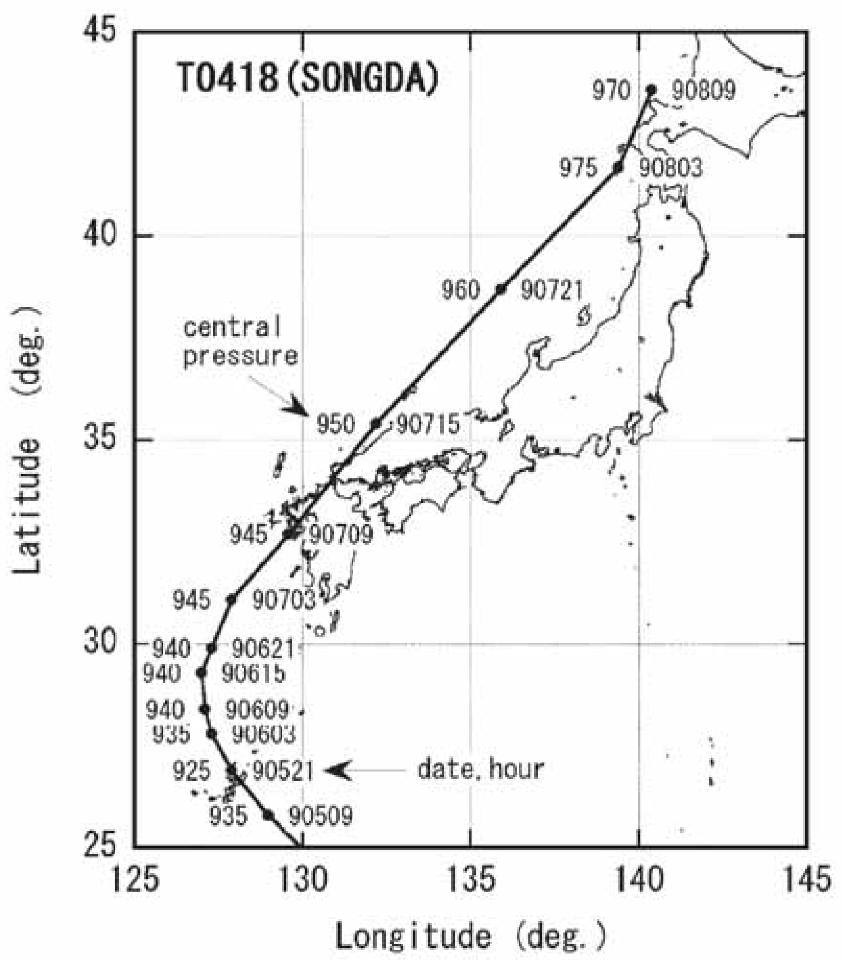


Figure 4 Typhoon No.18 (Songda)

Damage in Yamaguchi Prefecture

Kirara Dome received wind damage to the glass of its ceiling. 27 sheets were broken on the upwind side, among the total of 124 sheets broken, with a thickness of 20mm and with a film inside. Shade blinds were also broken in the Typhoon.

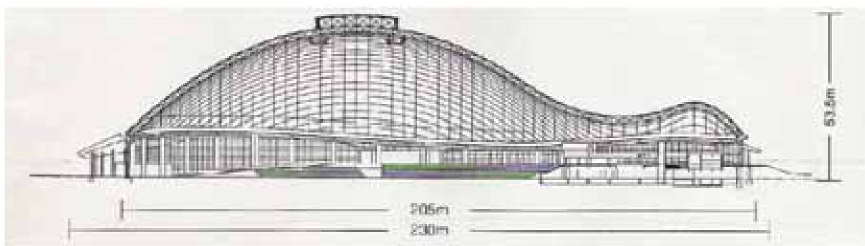


Figure 5. Kirara Dome

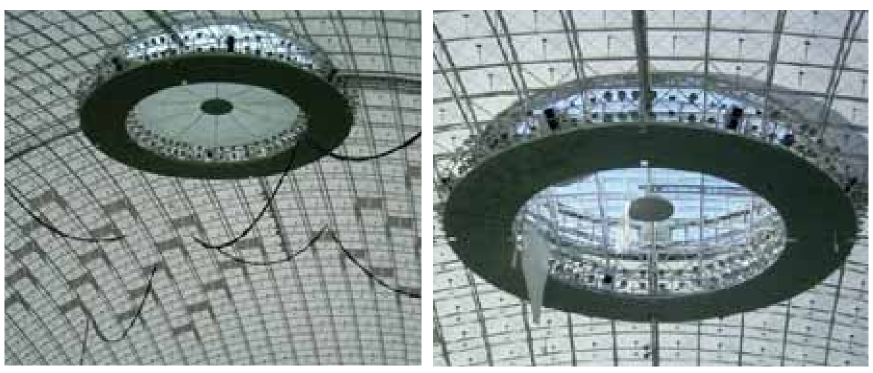


Photo 10. Damage to shading blind
(left: before damage; right: after damage)

Damage in Hiroshima Prefecture

In Hiroshima prefecture, the historical highest gust speed of 60.2m/s was recorded at the observatory at 14:20 on September 7, and the third highest wind speed of 33.3m/s was recorded at 14:40. Strong winds and high waves caused severe damage to Itsukushima Shrine at Miyajima-cho, Hiroshima prefecture, a World Heritage site. In Hiroshima-city, a lot of trees and electric power poles were blown down. This investigation was conducted with Associate Professor Takashi Maruyama (Disaster Prevention Research Institute, Kyoto University).

Photo 11. Damaged roof of corridor

Photo 12. Damaged traditional thatched roof

Photo 13. Separated roof tiles and damaged thatched roofs on leeward side

Damages in Hokkaido

Wind induced damage occurred over a wide area of Hokkaido. A 50.2m/s maximum gust was recorded at Sapporo-city (prefectural capital). Many street trees were blown down in the city. In the campus of Hokkaido University located at Sapporo-city, poplar trees lining streets and many elm trees were blown down. These blown-down trees caused some secondary damage.

In Otaru-city, damage occurred along the sea coast. Roofs and walls of Nishin-goten (historical wealthy fisherman's herring mansion), located at the top of a hill surrounded by the sea, were seriously damaged.

For the investigation in Hokkaido, we thank Professor Osamu Jo (Hokkaido University), Professor Huji Sakurai (Hokkai Gakuen University) and Professor Yasushi Uematsu (Tohoku University) for their cooperation.

Photo 14. Damage to roof tiles (Hokkaido University)

Photo 15. Blown-down popular trees (Hokkaido University)

Photo 16. Damage to Nishin-goten (Herring Mansion, Otaru-city)

Damage in Shizuoka Prefecture

Wind gust occurred at Fuji city, Shizuoka Prefecture, at 1:30 on September 8, 2004. Glass was broken, trees blew down, roof tiles blew off, etc., in a narrow area 1.5Km long (Figure 6). A total of 70 houses were partially damaged. Active cumulonimbus cloud was noticed in this area when the wind gust occurred. However, it has not been clarified whether the wind gust was caused by a tornado or a micro downburst.

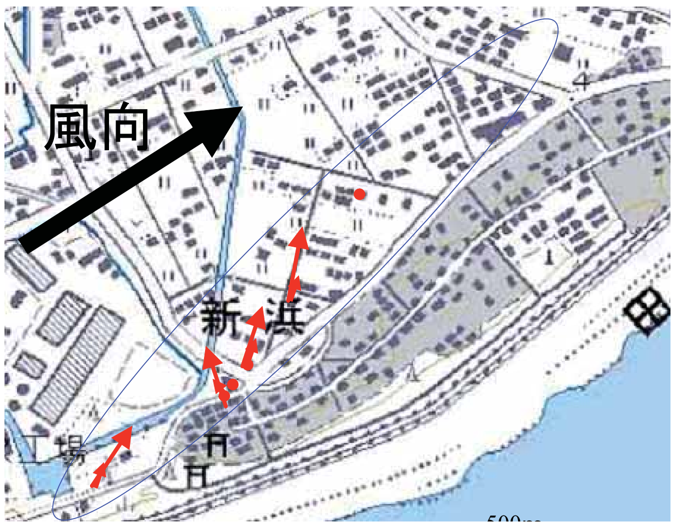


Figure 6. Damage situation (The vector shows the flying direction of the tilt)

Photo 17. Broken wall of a factory building

Tornado Damage at Toyohashi City, Aichi Prefecture, on September 29, 2004

Gust wind considered to be caused by a tornado occurred around 11:15 p.m. on September 29, 2004 in Toyohashi City, Aichi prefecture. 183 residences suffered damage (2 completely collapsed, 10 partially collapsed and 171 lightly damaged) .

In Toyohashi City, four tornados also occurred in 1999 and caused very serious damage (385 residences completely or partially destroyed). The areas where the tornado generated in 2004 were a several km away from the tornado birthplaces in 1999.

The tornado was generated when Typhoon No.21 moved to the northeast, from the Kinki district to the Hokuriku district. The average wind speed was about 6.9 m/s, the maximum instantaneous wind speed was 21.4 m/s, and the most frequent wind direction was south to southeast at a fire station near the tornado's birthplace.

A tornado was generated in Komatsubara town near the Pacific Ocean shore of Toyohashi City, and damage was seen over about 5km to near the Oiwa town. It is thought that the course of this tornado was mostly north, crossing the national road (Rout 1) and the track of the Tokaido Shinkansen.

As shown in Photo 18 and Photo 19, a lot of damage was caused by flying debris (roof tiles etc.) from windward structures (residences etc). In addition, a questionnaire will be performed as part of a future investigation, and this will be reported as soon as a result is settled.

(Akihito Yoshida)

Photo 18. Roof damage to a residential house

Photo 19. Cladding damage caused by flying debris

Research of turbulence structure flow over hills

Shuyang CAO
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(Former Research Associate of Tokyo Institute of Technology under the supervision of Prof. Tetsuro Tamura)

In complex terrain areas, wind velocity may accelerate and cause damages to structures. Accurate estimation of design wind speed at construction sites with geographical undulations is thus required to ensure wind resistant design. A large separation bubble becomes established on the lee side of a hill if the hill is steep enough. This influences wind related environmental problems such as pollutant dispersion and heat transportation also, thus requiring research of the turbulent structure and characteristics of flow over hills.

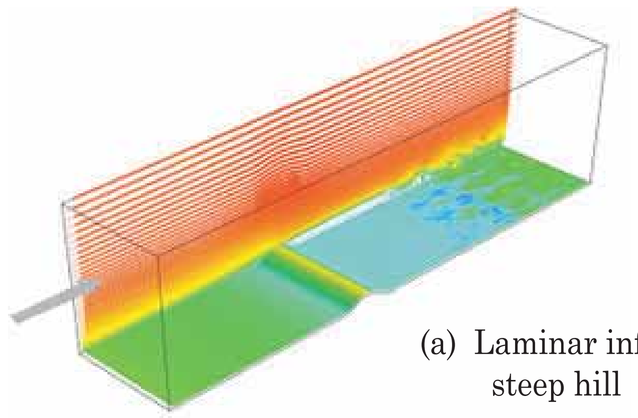
Flow over a hill is influenced by hill shape, inflow turbulence and surface roughness. For example, the critical angle for a stable separation to take place on a two dimensional hill decreases with increasing surface roughness. However, there remain problems on the physical mechanism of the interaction between inflow turbulence, the separated shear layer and surface roughness. In this research, we investigated systematically the effects of inflow turbulence, hill shape and surface roughness on the turbulent structure over a hill using numerical and experimental approaches.

DNS and LES that enable the time-dependent calculation of unsteady flows including large-scale vortices were carried out. Lund et al's method and Nozawa & Tamura's method were utilized to generate a turbulent boundary layer over smooth and rough walls as inflow turbulence. Experimental studies were also conducted to verify the numerical model.

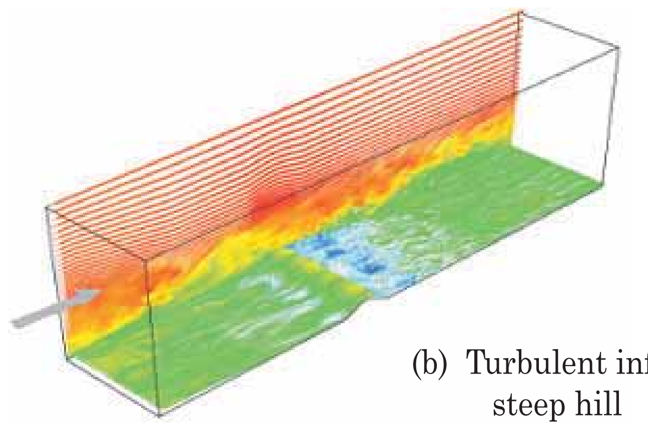
Figure 1 (a) and (b) compare the instantaneous flow field over a steep hill for laminar inflow and turbulent inflow. Because of the interaction between the separated shear and the inflow turbulence, entrainment of the separated shear layer is enhanced and the reattachment length is shortened when the inflow is turbulent. Figure 1(c) shows the instantaneous flow field over a low hill. A stable separation bubble is not formed, but instantaneous reversed flow is seen.

Figure 2 compares the time-averaged streamline over smooth and rough steep hills. The reattachment point shifts downstream when the surface is rough. This tendency is also seen in the experiment.

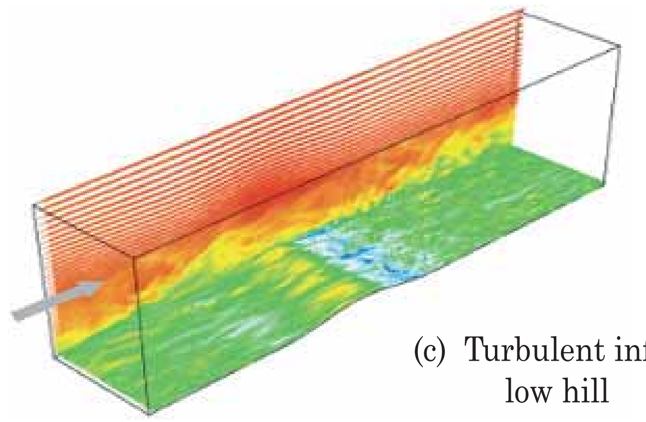
Figure 3 shows the speed-up ratio obtained in the experiment. A large speed-up ratio appears on the crest of the hill, and it is larger when the surface is rough. Figure 4 shows that the rms of the velocity fluctuation



(a) Laminar inflow steep hill



(b) Turbulent inflow steep hill

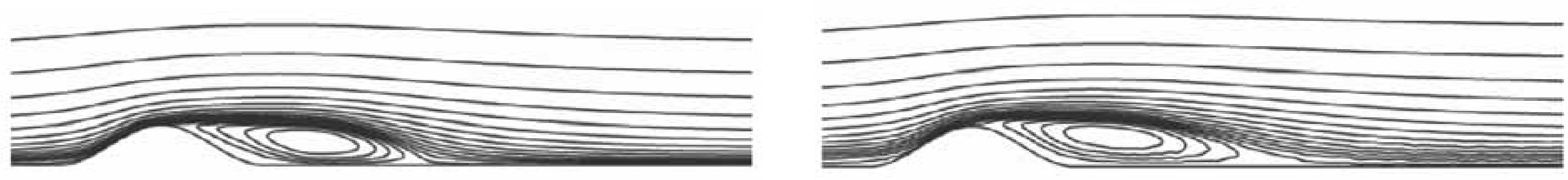


(c) Turbulent inflow low hill

Figure 1. Instantaneous flow field over hills

inside the separation bubble of the rough hill is smaller, and the position of maximum rms value is further downstream than on the smooth hill. Figure 5 shows the speed-up ratio under conditions of extreme roughness change (smooth hill in smooth flow, smooth hill in rough flow, rough hill in smooth flow and rough hill in rough flow). The speed-up ratio is larger in rough flow and roughness in the hill surface reduces the speed-up ratio.

This research was carried out when the author worked at the Environment Turbulence Lab (Prof. T. Tamura) of Tokyo Institute of Technology.



(a) smooth (b) rough

Figure 2. Time-averaged streamlines over smooth and rough hills

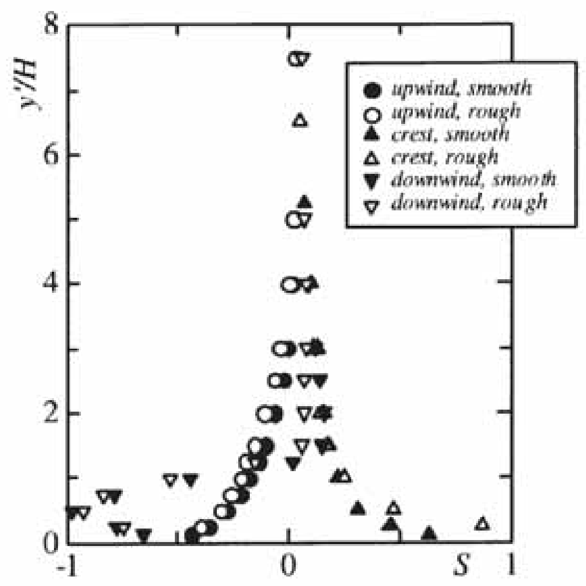


Figure 3. Speed-up ratio over hills

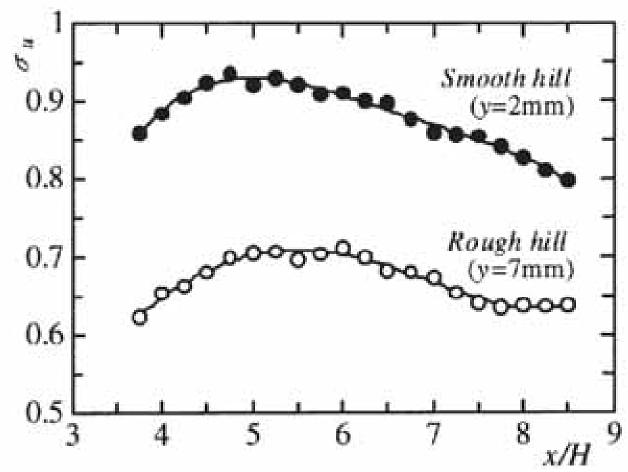


Figure 4. Downstream variation of rms value of velocity fluctuation

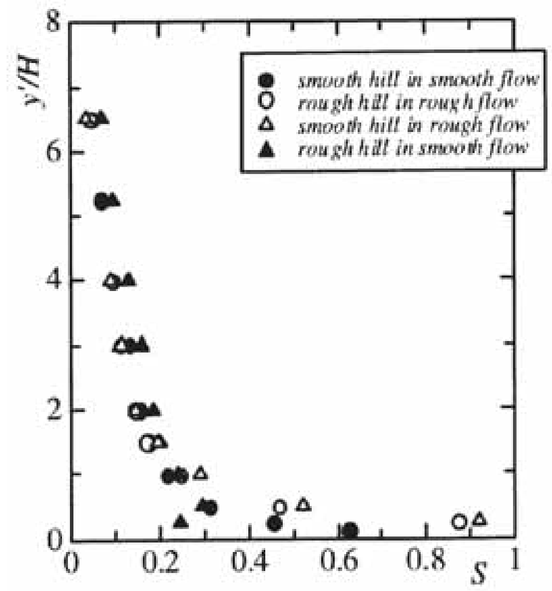


Figure 5. Speed-up ratio on the crest

Computer simulations of pedestrian wind environment around buildings and numerical studies of wind effects on cross-ventilation

Cheng-Hu Hu
COE Researcher

Pedestrian wind environment

The environmental quality of open spaces has a great impact on outdoor activities. Building form and layout can significantly affect the environmental quality of public spaces by inducing or diverting winds into streets and open spaces. This has been a priority in architectural design and urban planning. Figure 1 shows the flow pattern around two architectural proposals - Layout A and Layout B. The wind environments are evaluated for both of layouts.

Three criteria chosen for assessment of pedestrian comfort are flow pattern, comfort parameter (Figure 2) and windchill (Figure 3). The area of concern is a central open space embraced by buildings, as it is the designated area for the occupants of the buildings to undertake recreational activities, such as sitting, chatting and strolling. The results of numerical simulations show that "Layout B" is a better choice, as its design provides a good outdoor environment for pedestrians sitting or walking in the designated area.

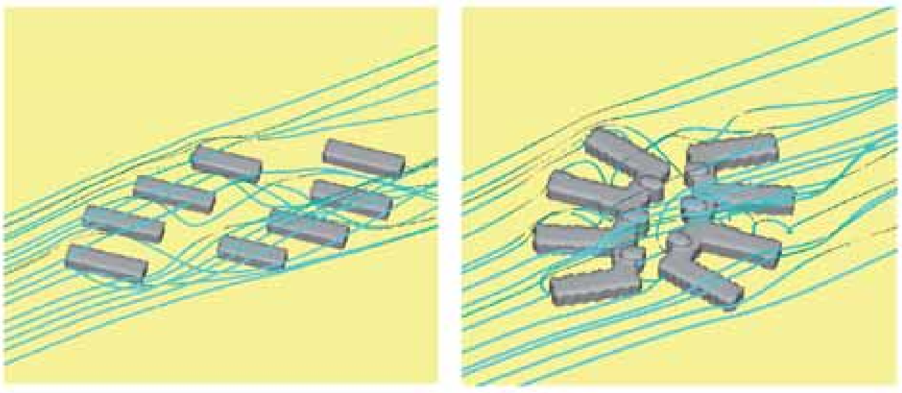


Figure 1. Flow patterns around buildings:
"layout A" (left) and "layout B" (right)

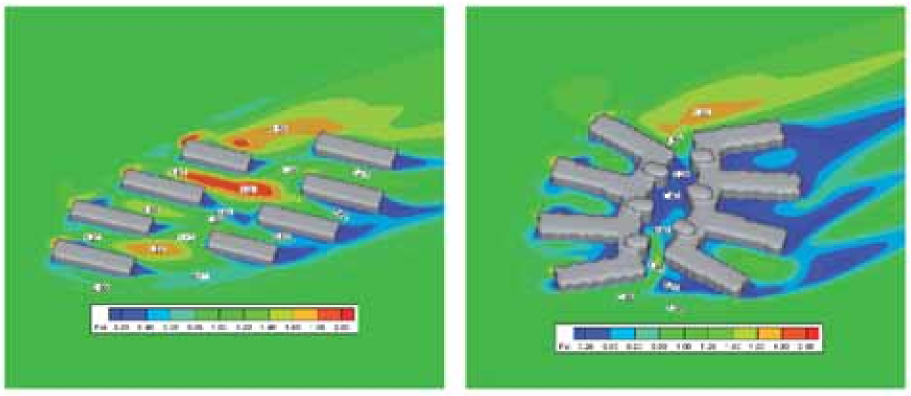


Figure 2. Contour of comfort parameter
"layout A" (left) and "layout B" (right)

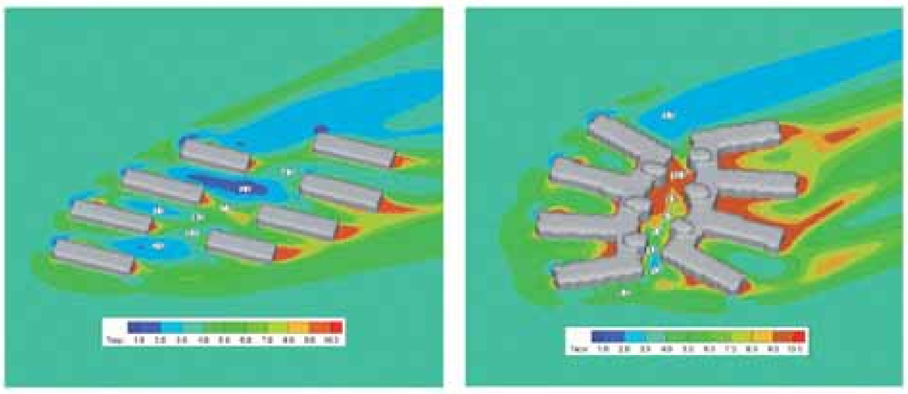


Figure 3. Windchill effects:
"layout A" (left) and "layout B" (right)

Cross-ventilation

Cross-ventilation is an environmentally-friendly strategy in architectural design. The wind around a building is the main source of energy providing the required momentum to drive the airflow in and out. The interactions between the flow field within and around the building are highly complex, as the flows are generally turbulent. This study was carried out to improve understanding of this complex flow field by means of numerical simulations. The CFD simulations apply the SST-kω model as the turbulence closure to solve the RANS equations, as the main interests are to investigate the mean values of the resolved flow field. From comparisons (Figure 4), the flow field simulated with the SST-kω model presents satisfactory results in terms of the patterns of velocity vectors and the distribution of turbulent kinetic energy within and around the model.

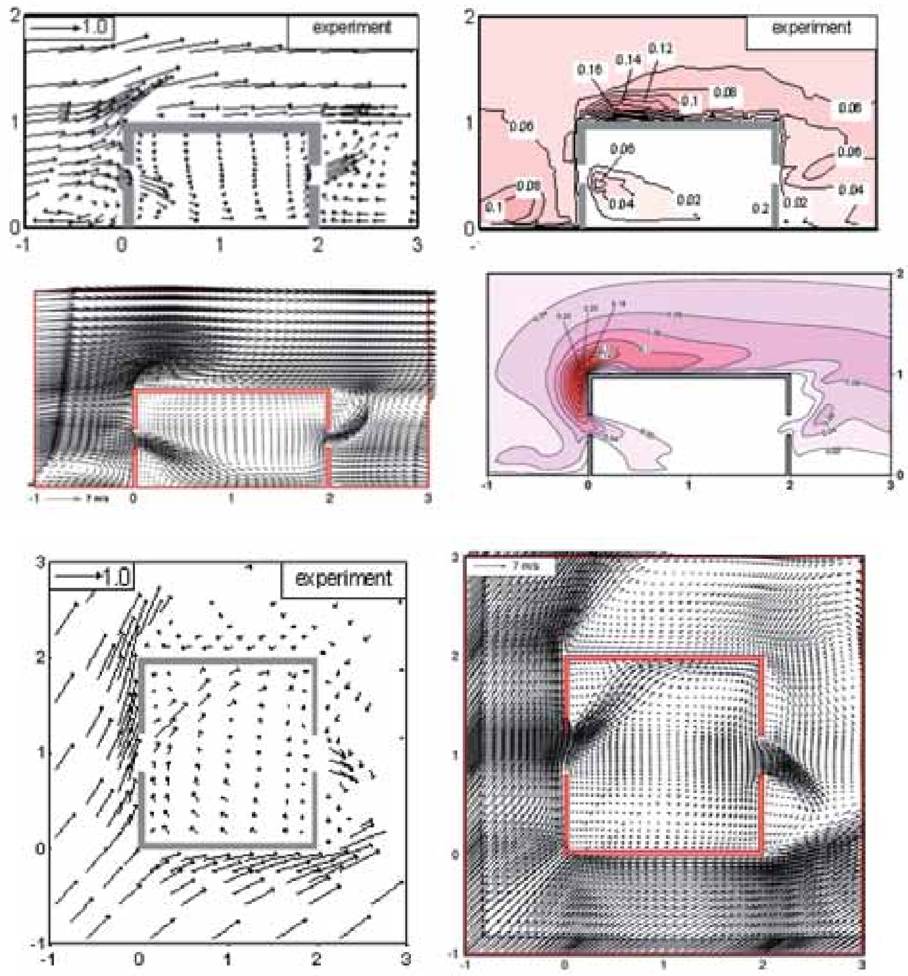


Figure 4. Comparisons between simulated flow field
and experimental results

The mechanism of cross-ventilated flow is preliminarily understood by observing the variations of velocity gradients and turbulent kinetic energy (Figure 5). The velocity gradients ($\partial U/\partial x$, $\partial W/\partial x$) increase at approximately the same rate when the flows approach the opening, but the U velocity decrease and the W velocity increases negatively. Therefore, the flows tend to enter the opening in a downward direction. More research is being undertaken to depict the effects of wind direction and the design of openings on a cross-ventilated building.

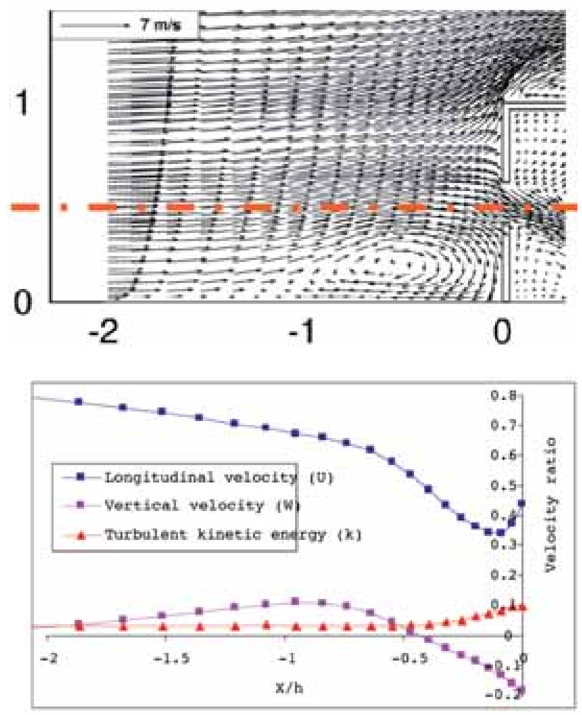


Figure 5. Variations of velocities (U, W) and turbulent
kinetic energy near the opening

COE Program TPU

Wind Effects on Buildings and Urban Environment

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