Wind Effects

New Frontier of Education and Research in Wind Engineering

Bulletin

Vol.16 November 2011

Wind Engineering Research Center
Graduate School of Engineering
Tokyo Polytechnic University

INDEX

Report on re-election of Prof. Tamura as president of IAWE

At the General Assembly of the International Association for Wind Engineering (IAWE) that was held during the 13th International Conference on Wind Engineering (ICWE13), Professor Y. Tamura was re-elected for a second term as President of IAWE.

Prof. Tamura's first term as President of IAWE started in 2007, when he was elected at the General Assembly held in Cairns during the 12th International Conference on Wind Engineering (ICWE12). Since then, he has taken a leadership role in promoting international co-operation among scientists, engineers and other professionals for advancement of knowledge in the broad field of wind engineering. One of his most important achievements during 2007-2011 was the establishment of an International Group (IG) to work on Wind-Related Disaster Risk Reduction (WRDRR). IAWE initiated this project together with GCOE-TPU (Global COE Program at Tokyo Polytechnic University), UN/ISDR (United Nations / International Strategy for Disaster Reduction) and other UN organizations and NGOs. Despite recognition of the critical need for cooperative actions in WRDRR activities among various professional organizations, there had been no notable collaborative efforts among the various groups in the past. While wind-related organizations like IAWE had been effectively working to develop technologies, codes and standards for wind hazard mitigation, there had been a dearth of coordinated activities with other international groups such as the UN and NGOs to bring these technologies to work for less fortunate communities in low-lying areas, which are often struck by devastating wind storms such as hurricanes/typhoons with attendant escalating loss of life and associated perils they bring to the region. The main task of IG-WRDRR was to establish linkages and to coordinate various communities, e.g., IAWE, to serve as inter-agency coordinators with a charter to work with international organizations involving agencies of the UN and involved NGOs, and to empower them with the responsibility to serve as a bridge between policy makers and agencies responsible for actually carrying out the DRR at the local community level.

The General Assembly of the IAWE was held at Room E103, the RAI International Exhibition & Congress Centre, in Amsterdam, the Netherlands from 19:00-22:30, Tuesday (12th July 2011). Prof. Y. Tamura was the sole nominee for president for the term 2011-2015. Thus, Prof. Y. Tamura was elected unopposed for a second term.

Report on 13th International Conference on Wind Engineering (ICWE13)

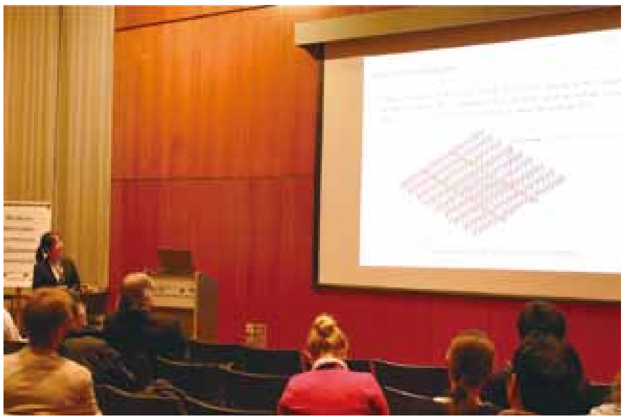
Date : July 10-15, 2011
Venue : RAI Convention Center, Amsterdam

The 13th International Conference on Wind Engineering (ICWE13) was held from July 10 to 15 at the RAI Convention Center in Amsterdam. About 500 papers were presented at the symposium, including keynote addresses, and there were about 580 participants, which was the largest number ever. The following papers were presented by members of the Tokyo Polytechnic University Global COE Program.

- Yukio Tamura, Shuyang Cao,"International Group for Wind-Related Disaster Risk Reduction (IG-WRDRR)"
- Masahiro Matsui, Yukio Tamura,"Real-time controlled

electromagnetic device with load cell for experimental study on windborne debris"

- Akihito Yoshida, Rei Okada, Yukio Tamura, Yoshiaki Hisada, "Establishment of response monitoring network for buildings using GPS technology"
- Rei Okada, Masahiro Matsui, Akihito Yoshida, Yukio Tamura, "Damage investigations of recent tornadoes in Japan and their publication on internet database"
- Le Thai Hoa, Yukio Tamura, Masaru Matsumoto, "Temporal-spectral correlation of wind fluctuations and buffeting forces using time-frequency analysis methods"
- Le Thai Hoa, Yukio Tamura, Masaru Matsumoto, "Multiple admittance function estimation using system identification techniques"
- Yong Chul Kim, Akihito Yoshida, Yukio Tamura, "Experimental investigation of surrounding roughness effects on wind pressures applied to low-rise building"
- Wonsul Kim, Yukio Tamura, Akihito Yoshida, "Interference effects on local peak pressures on two adjacent tall Buildings"
- Geetha Rajasekharan Sabareesh, Masahiro Matsui, Yukio Tamura, "Characteristics of internal pressure and resulting roof wind force in tornado-like flow"



- Sudha Radhika, Masahiro Matsui, Yukio Tamura, "Automated Detection of Tornado Damage to Building Structures from Aerial Imageries using Color Invariant Features"
- Zhibin Ding, Akihito Yoshida, Yukio Tamura, "Wind-induced dynamic behavior of a Monocoque steel chimney with ring stiffeners"
- Yi Hui, Akihito Yoshida, Wonsul Kim, Yukio Tamura, "Interference effect on local peak pressure between two high-rise buildings with different shapes"
- Ronwaldo Emmanuel R. Aquino, Yukio Tamura, "Damping based on EPP spring models of stick-slip surfaces"
- Jinxin Cao, Akihito Yoshida, Yukio Tamura, "Wind pressures on multi-level flat roof of medium-rise buildings"
- Bandi Eswara Kumar, YongChul Kim, Akihito Yoshida, Yukio Tamura, "Aerodynamic characteristics of triangular-section tall buildings with different helical angles"
- Proshit Kumar Saha, Akihito Yoshida, Yukio Tamura, "Study on wind loading on solar panel on a flat-roof building: Effects of locations and inclination angles"
- Katsumura A, Tamura Y, Nakamura O, "Application of Universal Equivalent Static Wind Load"
- Hideyuki Tanaka, Yukio Tamura, Kazuo Ohtake, Msayoshi Nakai, YongChul Kim, "Aerodynamic characteristics of tall building models with various unconventional configurations"
- Giorgio Barone, Giulio Cottone, Mario Di Paola, Yukio Tamura, "Wind loads spectrum generation by the 'H-fractional spectral moments' decomposition"
- Haeyoung Kim, Tetsuya Kitagawa, "Numerical investigation of wake galloping around two circular cylinders"
- Sivaraja Subramania Pillai, Ryuchiro Yoshie, "Experimental and numerical studies on convective heat transfer from various urban canopy configurations"
- Tingting Hu, Ryuichiro Yoshie, "Effects of building arrangement on ventilation performance in newly-built urban area"
- Guoyi Jiang, Ryuichiro Yoshie, Taichi Shirasawa, "Inflow turbulence generation techniques for LES in non-isothermal condition"
- Shinya Morikami, Masaaki Ohba, Kenji Tsukamoto, "Human-subject experiments on thermal sweating for evaporative cooling by fluctuating wind"

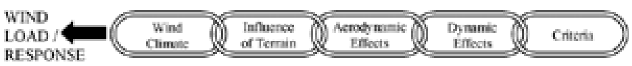
Announcement of the Alan G. Davenport Wind Loading Chain

Professor Alan Garnett Davenport (1932 – 2009)

On July 12, 2011 during ICWE-13 in Amsterdam, the General Assembly of the International Association of Wind Engineering (IAWE) unanimously approved the use of the term the "Alan G. Davenport Wind Loading Chain" for describing Alan Davenport's approach for evaluating wind loads and wind-induced responses for buildings and structures. Many of us remember Alan G. Davenport's name in connection with a number of specific technical aspects of wind engineering. These include his power law wind profiles; his spectrum of turbulence; his admittance and joint acceptance functions, which describe the spatial and temporal properties of turbulence as required in the evaluation of dynamic wind action; his gust effect factor; his pioneering use of wind tunnel model studies to chart the dynamic properties of buildings and structures; his statistical methods for predicting maximum values of extreme winds and their effects of wind on buildings and structures; and his criteria for judging the effects of wind on building occupants and pedestrians. Notwithstanding his influence on these and many other specific aspects of wind engineering, his greatest legacy is his rational approach or "chain of thought", which ties together these various concepts in the development of the methodology for evaluating the action of wind particular buildings and structures.

Professor Davenport's approach or chain of thought is described as follows:

THE ALAN G. DAVENPORT WIND LOADING CHAIN



Alan's approach recognizes that the wind loading on a particular building or structure is determined by the combined effects of the local wind climate, which must be described in statistical terms; the local wind exposure, which is determined by the terrain roughness and topography; the aerodynamic characteristics of the building shape; and the potential for load increases due to possible wind-induced resonant vibrations. He also recognized that clear criteria must be in place for judging the acceptability of the predicted loads and responses. These include the effects of wind on the integrity of the structural system and the exterior envelope and various serviceability considerations which influence performance and which determine habitability. The latter include the wind-induced drift, the effects of wind-induced motion on occupants and the usability of outdoor areas of the project, as well as its immediate surroundings.

In his papers Alan referred to this process for evaluating wind action as the wind loading chain. This was in recognition that the evaluation of wind loading and its effects relies on several interconnected considerations, each of which requires scrutiny and careful assessment. With analogy to a physical chain, the weakest link or component of the process determines the final outcome. Little is gained by embellishing strong links but much is lost by not paying attention to the weak ones.

Alan and others have written about this wind loading chain and have used this chain concept to describe and solve specific wind engineering problems. Perhaps the most lucid raison d'être for this "chain" was articulated by Alan himself in his Chapter 12 of the book entitled "Engineering Meteorology", edited by Eric Plate and published by Elsevier Scientific Publishing Company in 1982. This chain or multiplicative process for arriving at wind loads has been adopted in many building codes and standards. Not only is it effective for formulating the loads and responses to wind action, it is also a powerful model for evaluating the reliability of the final outcome. For example, the coefficient of variation of the predicted wind action to a good degree of approximation is equal to the square root of the sums of the squares of the coefficients of variation of each of the individual links. In the case of wind loads, the coefficient of variation (CV) can be approximated as follows

$$CV_{wind\ load} \approx \left(CV^2_{reference\ wind\ pressure} + CV^2_{wind\ exposure} + CV^2_{aerodynamic\ shape} + CV^2_{dynamic\ action}\right)^{1/2}$$

It is most fitting that the IAWE has decided to posthumously honor the late Alan G. Davenport by adding the "Alan G. Davenport Wind Loading Chain" to the wind engineering terminology. This is done in recognition of Alan's many contributions to the development of wind engineering. It is hoped that the usage of the term "Alan G. Davenport Wind Loading Chain" to describe the wind loading process, as Alan developed it, will keep both the man and his work in our memory.

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The proposal submitted to the IAWE to formally recognize the term "Alan G. Davenport Wind Loading Chain" for use by the wind engineering community was supported by the following colleagues at the BLWTL:

Horia Hangan, Director
Eric Ho, Director
Peter King, Director
Greg Kopp, Director
David Surry, Consulting Director
Barry Vickery, Consulting Director

Annual report of Global COE research projects

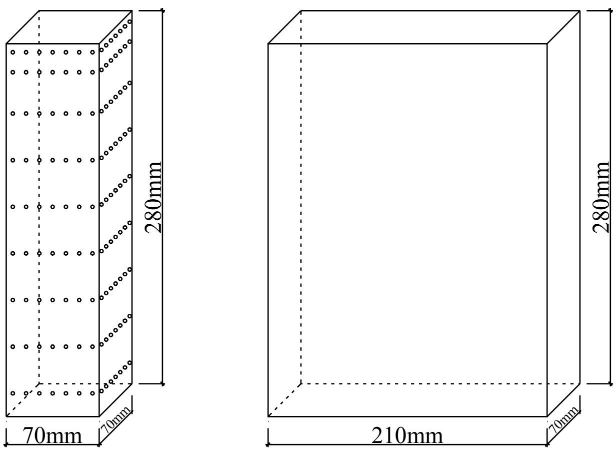
Project 1: Wind Hazard Mitigation

1) Effects on peak wind pressure and wind force for high-rise building due to surrounding buildings

Modern tall buildings are often built in groups in urban areas. Flow interference occurs and wind loads on each building are modified from their isolated single building situation. Catastrophic incidents may result if the interference effect on load has not been considered in design. Investigation of interference effect is complicated by the large number of variables needed to describe the broad set of possible situations–sizes and shapes of buildings, relative locations of adjacent building(s), wind directions, upstream terrain conditions and so on.

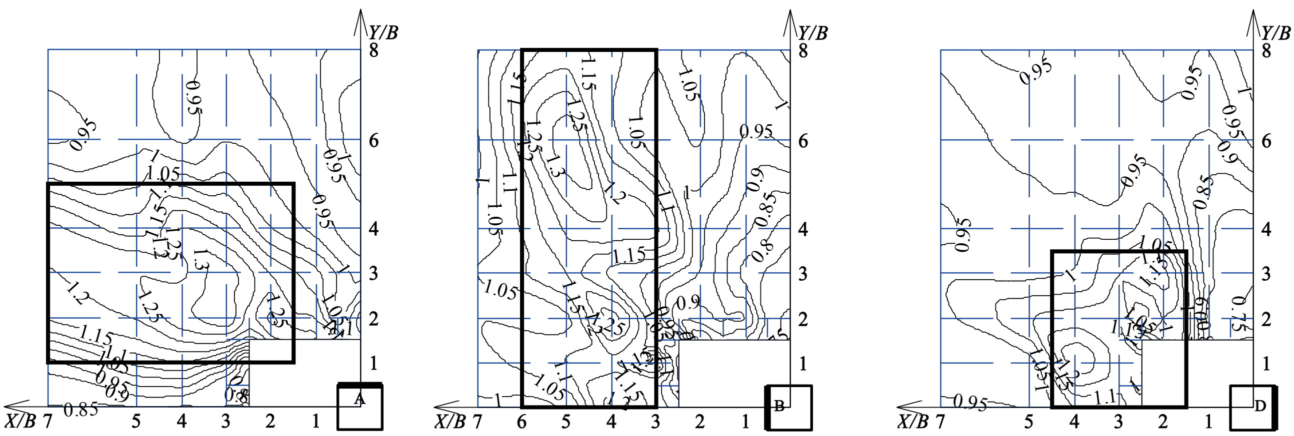
In this fiscal year, in order to obtain more general results, various side ratios of interfering building are used as principal and interfering buildings, and wind tunnel experiments were conducted. The experimental model, the experimental setup, and the contour of the interference factor are shown in the following figures.

Severe locations for interference factor and unfavorable wind directions are verified in this project.



(a)Principal building (b) Interfering building
Figure 1. Expetiment models

Figure 2. Expetimental setup in wind tunnel



(a) Face A (b) Face B (c) Face D

Figure 3. Contour of interference factor for negative peak pressure on wall A, B, and D

2) Wind-resistant performance test using test facilities for verifying cladding strength

In October 2010, a facility for verifying wind resistance of cladding (Pressure Chamber) was set in the TPU campus. In this fiscal year, the static and dynamic capabilities of the pressure chamber were confirmed. The ceiling system was then set in the pressure chamber as the specimen for the pilot test. In the test, the system was broken due to suction pressure, thus verifying its ‘strength’ and ‘mode of disintegration’.

Figure 4. Test facility (LEFT: Open-topped pressure chamber,RIGHT: Pressure adjustment mechanism)

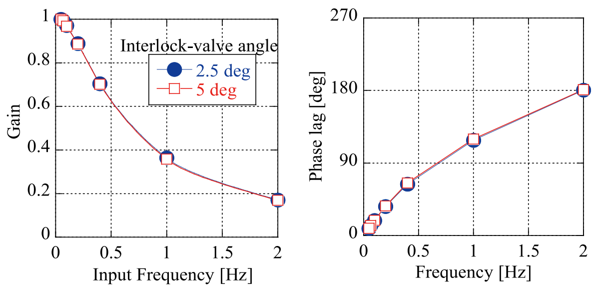
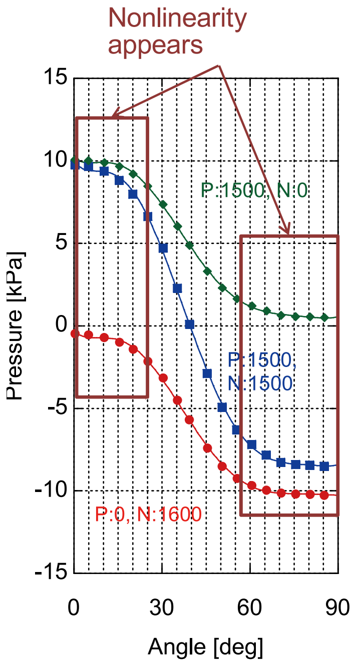


Figure 6. Gain and Phase lag of pressure chamber (2.5 deg and 5.0 deg)



Y = M0 + M1*x + ... M5*x^5 + M6*x^6	
M0	−0. 33486
M1	−0. 15049
M2	0. 020918
M3	−0. 0012008
M4	2. 4705e−05
M5	−2. 1773e−07
M6	7. 0435e−10
R	0. 99978

Y = M0 + M1*x + ... M5*x^5 + M6*x^6	
M0	9. 9602
M1	−0. 22359
M2	0. 031945
M3	−0. 0019329
M4	4. 0294e−05
M5	−3. 5697e−07
M6	1. 1597e−09
R	0. 99984

Y = M0 + M1*x + ... M5*x^5 + M6*x^6	
M0	10. 164
M1	−0. 11823
M2	0. 018523
M3	−0. 0011447
M4	2. 4529e−05
M5	−2. 2417e−07
M6	7. 5233e−10
R	0. 99986

Figure 5. Static relationship between angle of interlock valve and chamber pressure

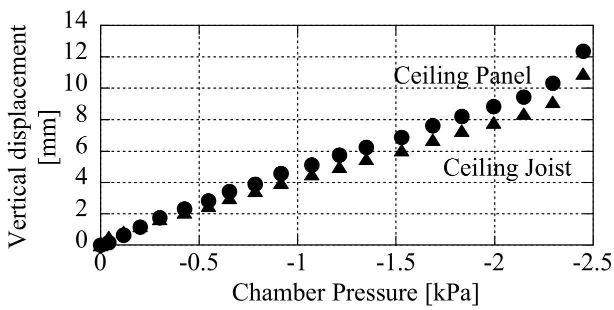
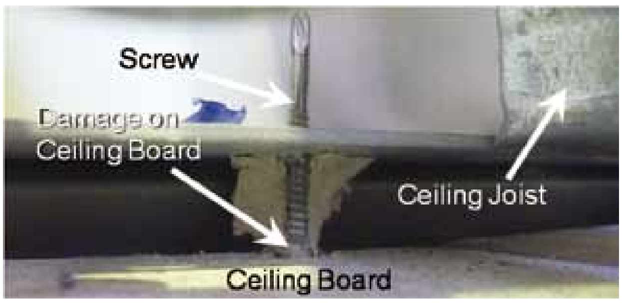
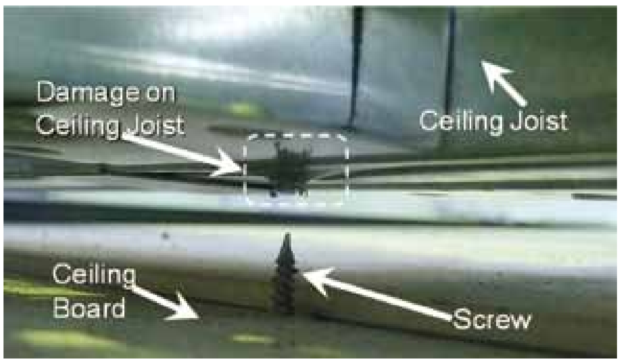


Figure 7. Vertical displacement of Ceiling Panel and Ceiling Joist



Damage to Ceiling board



Damage to Ceiling joist

Figure 8. 2 types of damage observed in strength test of ceiling system

3) Wind resistant capabilities for green-roof system

Green roofing systems, which have both economic and environmental benefits, are becoming more and more popular around the world. Previous studies on green roofing systems have focused on their costs and benefits, such as the effects on energy use and urban heat island, storm water management and air quality; but limited work has been done on the aerodynamic performances of green roofing systems. In this fiscal year, a tree-type green roofing system (intensive green roof) was simulated in a boundary layer wind tunnel and the wind force coefficients were measured using small-range strain-gauged force sensors specially designed for this study. Design parameters such as tree position, tree shape, wind direction and parapet height were considered. A drawing of the building, pictures of tree models, and, as an example output, the effects of parapet height, are shown in the following figures.

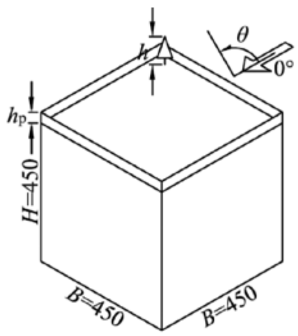
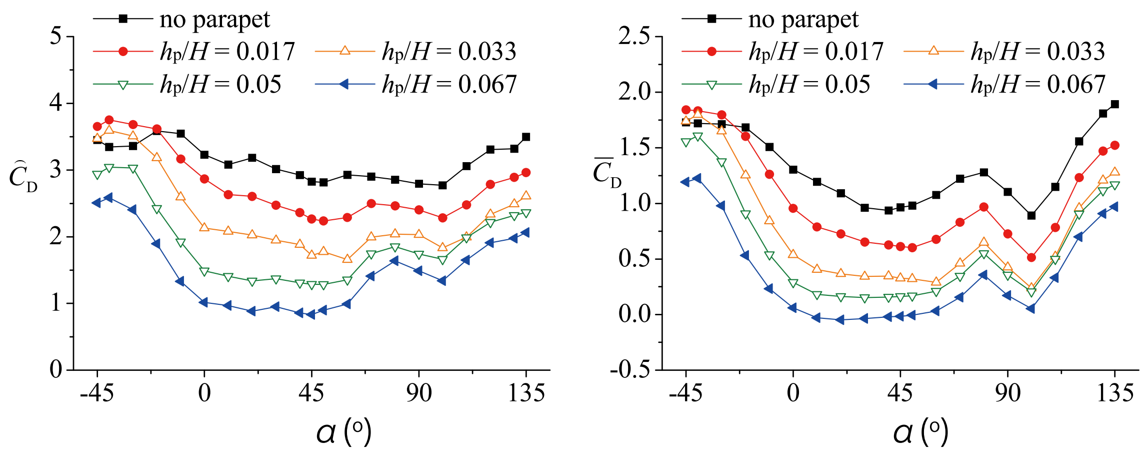


Figure 9. Dimensions of model of tree and building

Figure 10. Pictures of trees



(a)Mean value

(b) Peak value

Figure 11. Effect of parapet height (hp is parapet height)

4) Maintenance and management of modules in Virtual Engineering Organization (VORTEX-Winds)

The VORTEX-Winds [https://www.vortex-winds.org/] were released on the WWW in this fiscal year. The VORTEX-Winds is the EVO (Engineering Virtual Organization) in Wind Engineering field. It has been jointly developed off-line by the Tokyo Polytechnic University and University of Notre Dame. After releasing the EVO, the each content was modified based on the many opinions from users. The aerodynamic database is one of the modules in VORTEX-Winds. In this fiscal year, the contents which are related to surface pressure distributions of high-rise building considering the effects of adjacent building was established. It will be a new content of the database soon. On the other hand, in the damage database, the result of field investigation of damages due to the strong winds will be added. In this fiscal year, Global COE group conduct the damage investigation for 8 damaged areas due to strong winds.

These contents are released on the web with judgment of the expert committee of VORTEX-Winds.

Table 1 Parameters of contents related to interference effect of adjacent model

Test model	Dimensions(mm) $(B \times D \times H)$ $(B_i \times D_i \times H_i)$	Height Ratio $(H_r = H_i / H)$	Location of model	Wind direction
Principal model	70×70×280	1	1	0° – 355° (5° steps)
Adjacent (Interfering) model	70×70×140	0.5	37	0° – 355° (5° steps)
	70×70×196	0.7	4	0° – 355° (5° steps)
	70×70×280	1	37	0° – 355° (5° steps)
	70×70×420	1.5	37	0° – 355° (5° steps)
	70×70×560	2	4	0° – 355° (5° steps)

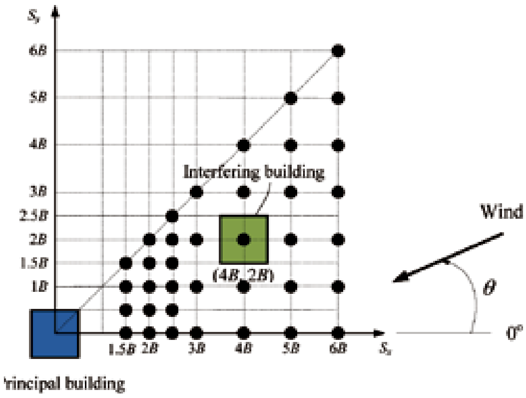


Figure 12. Definitions of adjacent model and wind direction

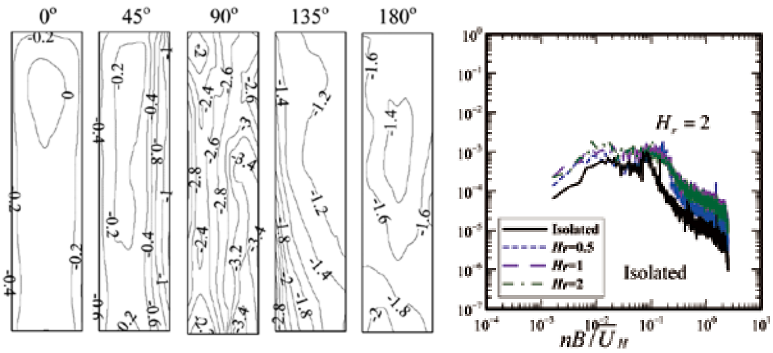


Figure 13. Example of contents (Pressure distributions and Power Spectrum of pressure)

Table 2 List of damage investigations in 2009 and 2010

2009			2010		
Prefecture	City	Date	Prefecture	City	Date
Gunma	Tatebayash	6/27	Niigata	Tainai	10/15
Chiba	Kujukuri	10/8	Akita	Katagami	10/17
Ibaragi	Tsuchiura	10/8	Chiba	Sanmu	11/1
Ibaragi	Ryugasaki	10/8	Akita	Happou	11/12
Akita	Noshiro	10/30	Ishikawa	Shika	11/29
			Fukui	Fukui	11/29
			Kanagawa	Kamakura	12/3
			Niigata	Joetsu	12/9

Figure 14. Example of Damage Distributions and Structures(Katagami city October, 2010)

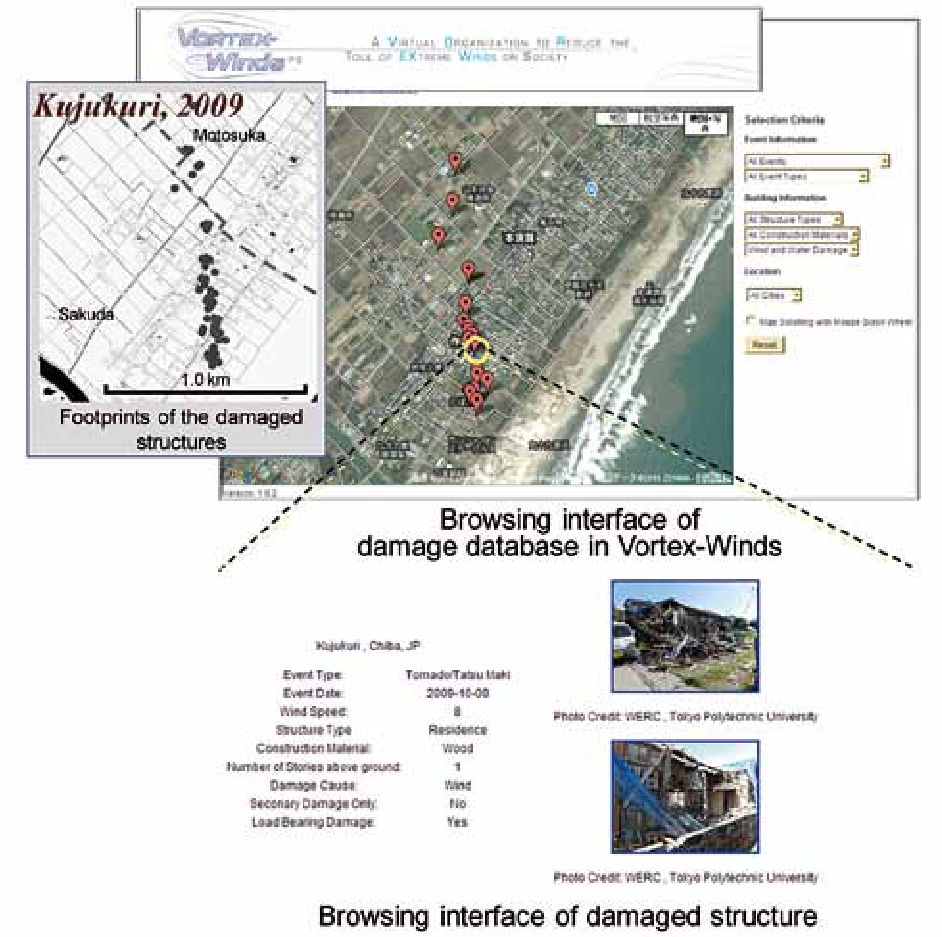


Figure 15. Browsing interface of damage database in VORTEX-Winds

Figure 16. Top page of Wind-wiki (4 fields related to wind engineering are included in this database.)

5) Development of knowledge database 'Wind-Wiki' in VORTEX-Winds

'Wind-Wiki' is one of the main contents of VORTEX-Winds. The user can search the meaning of the basic technical terms and concepts in the wind engineering field using this Wikipedia. It consists of 4 fields: Micrometeorology, Aerodynamics/Aeroelasticity, Structural dynamics, and experimental Methods. The infrastructure of Wind-Wiki has been completed. In this fiscal year, it was released on the website with some explanations of main technical terms. More contents will be added by researchers and it will be released on the WWW after the articles have been nreviewed by the expert committee on VORTEX-Winds.

Table 3 Contents of this table will be released on the WWW

Flow around Low-Rise Building	Extreme Wind Load Distributions
Flow around 3-Dimensional Circular Cylinder	Flow around Buildings in Urban Area
Dynamics of Ideal Fluid	Habitability to Wind-Induced Building Vibration
Flow Measurement Technique	Countermeasures for Strong Wind in Urban Area
Flow around 3-Dimensional Rectangular Prism	Wind observation [period, locations, and contents]
Flow around High-Rise Building	Wind Environmental Problems due to High-Rise Building Construction
Feature of Flow Field around 2D Structure	Discomfort by Wind Induced Motion
Feature of Flow Field around 3D Structure	Flow around Other 2-Dimensional Sectional Cylinder
Boundary layer and Reynolds number	Mean Wind Pressure Distribution of Rectangular Prism
Irrotational Flow and Complex Analysis	Fluctuating Wind Pressure of Rectangular Prism
Dynamics of Viscous Flow, -Navier-Stokes equation-	Design Wind Speed
Flow around Bridge Section Structure	Significance of Full-Scale Monitoring
Flow visualization around the structure	Full-Scale Measurement of Pressure
Pollution around Building	Edge Tone
Flow around Multiple 2-Dimensional Bluff Bodies Arranged in Tandem or In-Line	External Pressure Coefficient and Internal Pressure Coefficient
Generation of Drag Force	Temporal Fluctuation of Internal Pressure
Velocity Pressure and Wind Pressure Coefficient	Wind Directionality Factor
Temporal Fluctuation of Wind Pressure	Necessary Range of Topographic Model in Wind Tunnel
Spatial Scale of Pressure Fluctuation	Karman Vortex Street
Examples of Wind-Induced Oscillation on buildings	Flow around Sphere
Auxiliary Damping Devices	Flow around 2-Dimensional Inclined Circular Cylinder
Equivalent Static Wind Load	Full-Scale Measurement for Responses

Project 2: Natural/Cross ventilation

This project is aimed at development of a method of designing natural/cross ventilation for sustainable buildings utilizing natural wind, and also to establish a hybrid system for dehumidifying and cooling with natural draft and radiating heat compatible with the weather conditions of Asia-Pacific countries. The main research results obtained in the 2010 FY are reported as follows.

1) Human-subject experiments on thermal sweating for evaporative cooling by fluctuating wind

Based on experimental results using human subjects in 2009FY, the cooling breeze effect of fluctuating wind on perspiration evaporation by sweating was investigated in more detail for uniform flow and sinusoidal wind flow using a climate controllable wind tunnel. The fluctuating flow was produced by adjusting the frequency of the sinusoidal wave while keeping air temperature at 32 ºC, humidity at 70% and mean air velocity at 0.4 m/s.

Figure 1 shows skin temperatures on the forehead and forearms averaged for 4 subjects. The forehead skin temperature was kept constant at 35.5 ºC regardless of the spectral peak frequency of the wind velocity. However, the forearm skin temperature indicated an increasing tendency when the spectral peak frequency of wind velocity increased, where the correlation coefficient between forearm temperature and spectral peak frequency of wind velocity was 0.47.

Figure 2 gives the relation between spectral peak frequencies of sweat rate and wind velocity. In the range between 0.02Hz and 0.2Hz, the spectral peak frequency of sweat rate corresponded well with the spectral peak frequency of the sinusoidal wave flow. It is concluded that the sweating frequency has high correlation with wind velocity. In the frequency range above 0.3Hz, the perspiration meter could not accurately measure the sweat signals because its response was not quick enough.

Figure 3 shows the relation between heat loss of the whole body and spectral peak frequency of wind velocity. The evaporation of sweat secreted due to thermoregulatory control was defined as 6% of the maximum evaporative potential per unit area. The convective and radiative heat losses were kept constant regardless of spectral peak frequency of wind velocity because the wind velocity, air temperature and relative humidity were set constant in the experiment. For air temperature 32 ºC and relative humidity 70%, the evaporative heat loss was 40% higher than other heat losses. The evaporative heat loss indicated a decreasing tendency when the spectral peak frequency increased with a correlation coefficient of -0.77 and a significance level of 5%. Sweat evaporation was promoted at lower frequency of wind velocity compared to that at higher frequency.

Figure 4 shows the relation between skin wettedness and spectral peak frequency of wind velocity. Skin wettedness showed a decreasing tendency when the spectral peak frequency increased, with a correlation coefficient of 0.72 and a significance level of 5%. It is concluded that wind fluctuation affects sweat evaporation, and also the long wave component of natural wind plays an important role in the sweat evaporation process.

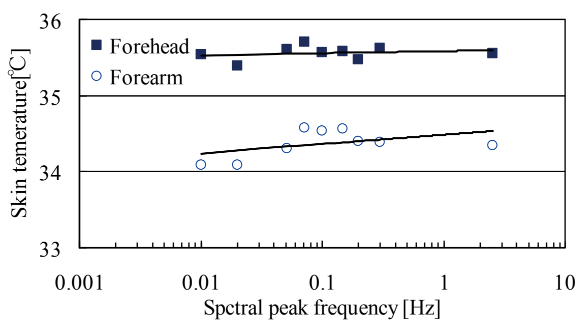


Figure 1. Relation between skin temperature and spectral peak frequency of wind velocity

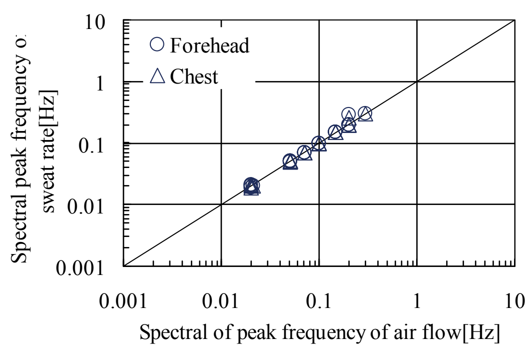


Figure 2. Relation between spectral peak requencies of sweat rate and wind velocity

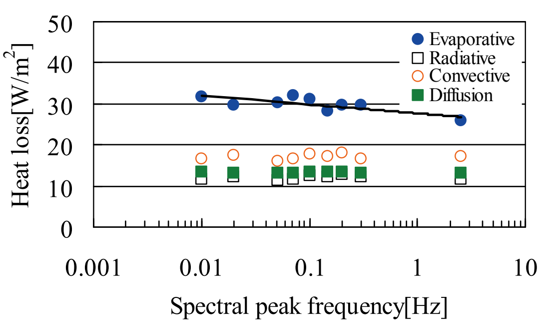


Figure 3. Relation between heat loss of whole body and spectral peak frequency of wind velocity

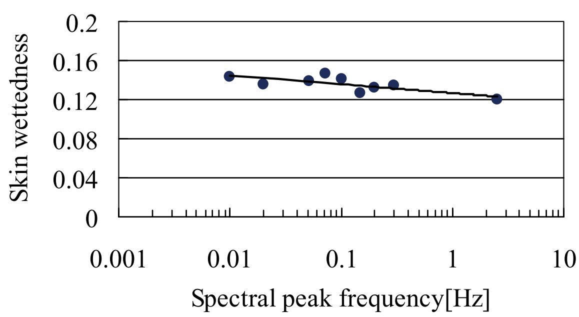


Figure 4. Relation between skin wettedness and spectral peak frequency of wind velocity

2) Development of Natural Ventilation System with Constant Air Volume

Rooms need ventilation when they are occupied, and this consumes a lot of energy. However, reliance on air-conditioning equipment increases running costs, so natural ventilation systems that are cheap to run and can also contribute to energy saving are now attracting attention. However, the amount of ventilation varies a lot depending on the wind conditions. Sliding shutters, called Amado in Japan, have various functions such as protection from the rain, protection against wind, crime prevention, heat insulation, sound isolation, maintenance of privacy, and so on. They are shut for crime prevention during the night, so cannot contribute to ventilation. Thus, there is a demand for a natural ventilation system that can take in a uniform amount of air regardless of wind conditions. In this research, a natural ventilation system using a constant air volume provided by natural wind is developed. This system and its mechanism are shown in picture 1 and Figure 5, respectively. Figure 6 shows the relationship between upstream wind speeds and the wind force on the wings caused by wind pressure depending on the angle of the wings. When the angle of the wings is fixed, the downstream wind speeds are proportional to the upstream wind speeds as shown in Figure 7. By adjusting the balance with a mass and a spring, the amount of ventilation is made almost uniform when the upstream wind speed is from 3 m/s to 5.5 m/s, as shown in Figure 8.

Picture 1 Developed natural ventilation system

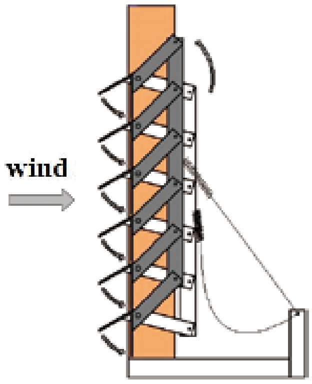


Figure 5. Mechanism of the natural ventilation system

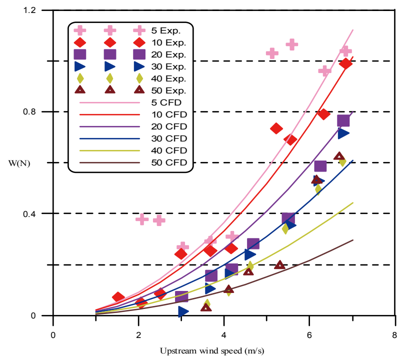


Figure 6. Wind force on wings

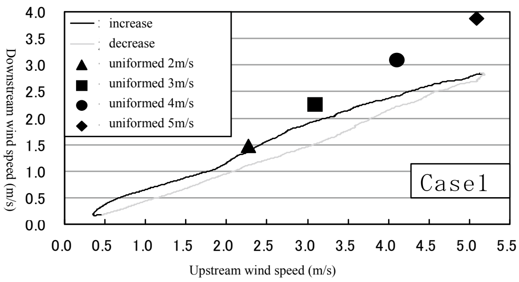


Figure 7. Relation between downstream wind speed and upstream wind speed

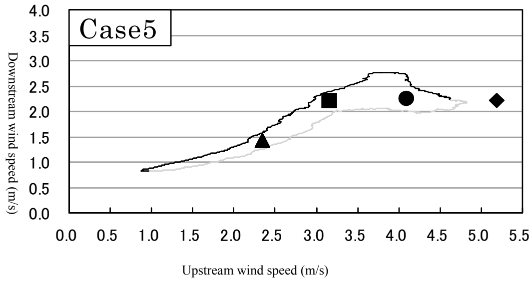


Figure 8. Amount of ventilation

Project 3: Outdoor Wind Environment

1) Experimental, computational studies on heat transfer from urban canopy and its dependence on urban parameters in developing a modified urban canopy model

The Weather Research Forecasting (WRF) model coupled with the Urban Canopy Model (UCM) is an effective tool for prediction of urban heat island phenomena. In UCM, the local convective heat transfer from the urban canopy and its dependence on urban parameters such as building coverage ratio and building height variations are not explicitly modeled. In the single layer Urban Canopy Model (Kusaka et al. 2001) in WRF, the heat transfer coefficient from canyon surfaces are evaluated from Jurges formula. In this formula, the local convective heat transfer coefficient from building walls and ground depends only on the velocity inside the canopy. However, this cannot be justified since other urban parameters also contribute to the heat transfer coefficient. Moreover, this model cannot distinguish the difference between convective heat transfer coefficients on different wall surfaces, i.e., windward, leeward and side walls.

Therefore, wind tunnel experiments and CFD simulations have been carried out to clarify this issue. Wind tunnel experiments were conducted to roughly grasp the dependence of urban parameters on bulk heat transfer from the urban canopy in a thermally stratified wind tunnel. However, it is not an easy task in wind tunnel experiments to evaluate local convective heat transfer coefficients, which vary on individual canyon surfaces such as building roofs, walls and ground. Thus, CFD simulation with a low Reynolds number k-ε model was conducted to evaluate the convective heat transfer on these surfaces. Calculated CFD results showed good agreement with experimental results. After this validation, the effects of urban canopy parameters on local convective heat transfer on individual surfaces were investigated by CFD simulation. Based on these results, the convective heat transfer coefficient and heat flux from the urban canopy will be modified with respect to the urban parameters, which will be incorporated into the UCM.

2) Reproduction of vertical profiles of wind velocity by WRF

To assess the pedestrian wind environment around tall buildings based on occurrence frequencies of wind velocities we need reliable statistical wind observation data from near their construction sites. However, wind observatories are not always located near construction sites. Even if they are, their observation heights are sometimes not high enough and the wind data are affected by surrounding buildings. Meso-scale simulation can be an alternative to direct observation. We intended to use the WRF (Weather Research and Forecasting Model), a meso-scale simulation model, to prepare standard wind data at high altitude for the assessment of the pedestrian wind environment. We also plan to use WRF for research on urban heat island phenomena, which is becoming serious in large cities in Japan. One effective countermeasure against heat island phenomena is to lead cool air of sea breeze into urban canopies. This strategy strongly depends on the vertical profile of wind velocity and the temperature of the sea breeze. Before doing these investigations using WRF, it is necessary to confirm how WRF can correctly regenerate the occurrence frequencies and vertical profiles of wind velocities. For this validation, observation data measured by Doppler Sodar in the Minami Senju district in Tokyo (Miyashita et al. 2002) were used. In order to well regenerate the vertical profile of wind velocity by WRF, it is considered that an appropriate surface roughness should be given to the WRF calculation. However, the default setting of WRF based on USGS (United States Geological Survey) expresses urban areas as only by one category and gives a uniform roughness length regardless of building densities and heights. Thus, we used GIS (Geographic Information System) data to appropriately classify urban land-use categories and to give roughness lengths to the WRF calculation. We conducted two cases of WRF calculations using the default setting (Case 1) and based on GIS-derived land-use categories and surface roughness lengths (Case 2). The calculated results were compared with the observation data measured by Doppler Soda at Minami Senju. The calculated probabilities of exceedance of wind velocity at high altitude (especially Case 2) corresponded very well with that of the observation. In addition, it was apparent that calculated vertical profiles of mean wind velocity of Case 2 were very close to those of the observation.

3) Inflow turbulence generation techniques for LES in non-isothermal condition

The importance of inflow turbulence for LES has been presented in some papers, and several techniques have been proposed for generating inflow turbulence for LES in a neutral boundary layer, but few studies have considered the non-isothermal case. As the non-isothermal condition is a very common atmospheric phenomenon, how to generate physically correct velocity as well as temperature fluctuations corresponding to this condition for LES is a very important issue. In this research, several methods including the precursor method and the recycling method were examined for inflow turbulence generations in both unstable and stable conditions. The results were compared with experimental data obtained from our experiments in a thermally stratified wind tunnel, and how to generate inflow turbulence efficiently in a non-isothermal boundary layer was investigated. The main conclusions of this investigation were as follows:

- The characteristics of the generated flow (mean profiles and fluctuation profiles) by precursor simulation agreed well with those of the wind tunnel experiment. Although it is the simplest way, it requires a long computational domain and long simulation time.
- In the recycling method, a short domain can be adopted to make turbulence develop. When Kataoka's method is used in the thermal field, the turbulence intensity can be adjusted by roughness ground arrangement, or by buoyancy effect and damping function adjustment. For the temperature field, giving a mean profile as the inflow condition of the driver region is the simplest way. Even when inflow temperature fluctuation was not given, temperature fluctuation developed as the flow proceeded downstream in a turbulent boundary layer, but a sufficient distance should be ensured for it to occur. The recycling procedure is not necessary for the temperature field.

Report on ISWE5 'Wind Hazard Resilient Cities: New Challenges'

Date : March 7-8, 2011
Venue : Hotel Sunroute Plaza Shinjuku, Japan

'The 5th International Symposium on Wind Effects on Buildings and Urban Environment' was held at Shinjuku, Tokyo on March 7-8, 2011. This symposium compsises part of the activities under the Global COE Program, MEXT, 'New Frontier of Education and Research in Wind Engineering'. It has a basic philosophy of 'Wind Hazard Resilient Cities: New Challenges'.

The primary purpose of this symposium is to provide an ideal venue for exchanging and sharing information through discussion, so that serious wind-related problems regarding wind hazard risk due to meteorological turbulence such as typhoons and tornadoes, urban air pollution and increase of environmental load can be solved. The forum aims at contributing to the development and construction of sustainable urban environments with a low energy built environment and hence to achieve wind hazard resilient cities.

This symposium is held with the cooperation of the Architectural Institute of Japan, Council on Tall Buildings and Urban Habitat, International Association for Wind Engineering, International Group for Wind-Related Disaster Risk Reduction, Japan Association for Wind Engineering, Japan Society of Atmospheric Environment, Japan Society of Civil Engineers, Meteorological Society of Japan, and The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan. The 141 participants came from 12 countries and the participants' opinions were questioned, resulting in useful intellectual exchange.

The following is a list of the 7 Invited presentations and 7 technical sessions.

Invited Lectures:

- The Era of Tall Buildings: History and Development: Sang Dae Kim (Korea University)
- Analysis on Weather Characteristic in Myanmar: Win Zaw (Ministry of Construction Myanmar)
- Monitoring, Simulation and Their Hybrid Approaches for Investigation of Wind Effects on Long-span Bridges: Hui Li (Harbin Institute of Technology)
- Issues with validation of urban flow and dispersion CFD models: Michael Schatzmann (The University of Hamburg)
- Wind Hazard Resilient Cities: New Challenges: Kishor. Mehta (Texas Tech University)
- Wind and Rain Induced Effects on Stay Cables and Typical Prisms: Yaojun Ge (Tongji University)
- Wind hazard in harbour areas: Giovanni Solari (University of Genoa)

Sessions:

- Urban disasters from the structural design perspective
- Hurricane-related wind risks
- Damage Detection Analysis using Satellite Image
- Challenges to couple engineering CFD and meteorological models for analyzing urban climate change
- Effects of Short-rise-time Gust on Structures
- Countermeasures for the disasters and Tornado-related issues
- Wind-Resistant Design

Public hearing on doctoral dissertation

Public hearings on doctoral dissertations were held at the Atsugi campus of TPU on February 12, 2011 and on July 30, 2011. On February 12, PhD candidates Mr. Tsuyoshi Kurita and Mr. Kaoru Takigasaki presented their doctoral dissertation drafts, and on July 30, Mr. Geetha Rajasekharan Sabareesh and Mr. Subramania Pillai Sivaraja presented theirs.

The summaries of their dissertations are as follows.

Experimental study on heat transport characteristics in heated urban canopy layer in case of weakly unstable atmospheric stability

Tsuyoshi Kurita

The rapid increase in the number and density of high-rise buildings in urban areas is weakening wind velocity, and a large amount of heat is being emitted due to energy consumption. These factors further accelerate air temperature increase inside an urban canopy layer. In Japan, where many large cities are located in warm climate regions, the increase in cooling load due to high air temperature in summer causes higher annual peaks of electric power consumption. It has thus become necessary to take effective countermeasures against heat island effect. To evaluate this effect, it is important to correctly understand the heat flow within an urban area and to elucidate the mechanisms of heat island phenomena. However, there is presently insufficient understanding of turbulent flow behaviors in urban spaces because of complicated mixing conditions of natural convection, forced convection and separation flow.

In Mr. Kurita's study, he investigated the effects of gross coverage building ratios and atmospheric stability on heat and momentum transport characteristics in a heated urban canopy layer for three types of models in a thermally stratified wind tunnel. Roughness lengths and bulk transport coefficients related to heat and momentum transport characteristics were obtained and compared to actual field results. Based on the experimental results, a new method for predicting bulk transport flux of sensible heat in a heated urban canopy layer under conditions of weakly unstable atmospheric stability was proposed and evaluated.

Multi-target identification for emission parameters of building materials by unsteady concentration measurement in airtight micro-cell-type chamber

Kaoru Takigasaki

In order to prevent indoor air pollution by VOC emitted from building materials, it is necessary to select suitable building materials with low VOC emissions, and to predict the VOC concentration level in rooms at the design stage. From this point of view, information on physical/chemical properties of building materials, such as VOC emission rate, effective diffusion coefficient and chemical content (initial concentration in building materials) is important for healthy indoor environmental design. The purpose of this study was to develop a concurrent determination method that can estimate multiple emission parameters, that is, emission rate, initial concentration and effective diffusion coefficient Dc in building materials, by a single unsteady concentration measurement. This study focused on the time history of VOC concentration in the gas phase that occurred when the target building material was covered with an airtight micro-cell. The VOC concentration in the micro-cell gradually increased and finally reached an equilibrium concentration. Under the condition of uniform distribution of initial concentration in building materials, the profile of VOC concentration in the micro-cell was determined by the order of the Dc value. A chart of the time history of VOC concentration as a function of Dc and thickness of building materials was prepared in advance by numerical analysis and then Dc was estimated by overlapping the measurement result with this chart. A chart of emission rate as a function of Dc and building material thickness was also prepared and a procedure for determining emission rate taking into account the consistency between the 20 L small chamber method with in- and out-flow and the micro-cell method under an airtight condition was proposed. The estimation results of Dc and emission rate by this method were reasonably consistent with the results of the conventional method.

Experimental investigation of external and internal pressures acting on building models in a tornado like flow

Geetha Rajasekharan Sabareesh

Tornado events involve very complex wind-structure interaction. They are characterized by unpredictability, short life span and danger, making real-time evaluation difficult. This necessitates analysis of tornado-wind loadings on buildings in laboratory situations.

With this objective, scaled building models were subjected to a stationery vortex created using the tornado simulator developed at the WERC, Tokyo Polytechnic University. Parameters that govern a tornado like flow, such as swirl ratio and aspect ratio, were in close agreement with those achievable as reported by previous researchers.

In the present investigation, the influence of factors such as building location relative to vortex centre, swirl ratio, and terrain roughness on the mean and peak pressures in a building model under tornado-like flow were evaluated. A set of empirical pressure coefficient values were proposed, which describes the nature of pressures on a building exposed to a tornado.

Post-tornado damage investigations revealed building roof and openings in buildings as two critical failure modes. Openings in buildings result in changes in internal pressures in response to ambient pressures. The effects of opening porosity, building location relative to vortex, terrain roughness and swirl ratio on measured internal pressures inside scaled building models were determined.

Net roof wind loads showed differences in a forced and free vortex regions depending on the opening configuration. A building with leakage experienced higher suction pressures on its roof compared to a building with a dominant opening, when located at the centre of a vortex. Terrain roughness and swirl ratio were also found to influence the net wind loads on a roof.

A numerical model based on acoustic theory was found viable for predicting internal pressures in tornado-like flow. The internal pressures and resulting wind loads on a roof were thus predicted for dominant openings located in other side walls of a building, for different building distances from the vortex centre.

Modeling of convective heat transfer coefficient for urban canopy surfaces by experimental and numerical simulation.

Subramania Pillai Sivaraja

The Weather Research Forecasting (WRF) model coupled with the Urban Canopy Model (UCM) is an effective tool for prediction of urban heat island phenomena. In UCM, the local convective heat transfer from the urban canopy and its dependence on urban parameters such as building coverage ratio and building height variations are not explicitly modeled. In the single layer UCM in WRF, the heat transfer coefficient from urban canyon surfaces are evaluated from Jurges formula. In this formula, the local convective heat transfer coefficient from building walls and ground depends only on the velocity inside the canopy. However, this cannot be justified since other urban parameters also contribute to the heat transfer coefficient. Moreover, this model cannot distinguish the difference between convective heat transfer coefficients on different wall surfaces, i.e., windward, leeward and side walls. Therefore, wind tunnel experiments and CFD simulations have been carried out to clarify this issue. Wind tunnel experiments were conducted to roughly grasp the dependence of urban parameters on bulk heat transfer from the urban canopy in a thermally stratified wind tunnel. However, it is not an easy task in wind tunnel experiments to evaluate local convective heat transfer coefficients, which vary on individual canyon surfaces such as building roof, windward wall, leeward wall, sidewall and ground. Thus, CFD simulation with a low-Reynolds-number k-ε model was conducted to evaluate the convective heat transfer coefficient on these surfaces. Calculated CFD results showed good agreement with experimental results. After this validation, the effects of urban canopy parameters on local convective heat transfer on individual surfaces were investigated by CFD simulation. The heat transfer coefficients from individual urban canyon surfaces like roof, ground, windward wall, leeward wall and side wall have been explicitly modeled with respect to the velocity inside the canopy, building coverage ratio, variations in building heights and thermal stratification inside the canopy. Based on these results, the convective heat transfer coefficient and heat flux from the urban canopy will be modified with respect to the urban parameters, which will be incorporated into the UCM, which in turn are expected to increase the prediction accuracy of the urban canopy model. The CHTC generalized for the wall surfaces in the urban canopy is for the CFD urban canopy case with the inflow profile as uniform flow. However, the real sea breeze leading to the urban canopy is not a uniform flow. For more accurate prediction of CHTC from real coastal urban canopy surfaces, CFD simulation of sea breeze leading to the urban canopy requires appropriate vertical profiles of the sea breeze at the inflow boundary. One promising way of finding the vertical profiles of velocity and temperature in real coastal urban area is meso-scale numerical simulation. The vertical patterns of velocity and temperature were classified using cluster analysis and the occurrence frequencies of the patterns were examined. From cluster analysis, a representative vertical profile of velocity and temperature was determined. The representative profiles of velocity and temperature will be given as inflow boundary condition for CFD simulation and the CHTC variation from the canyon surfaces will be examined in the near future.

PhD students, researchers and engineering designers in the wind engineering field participated in the public hearings. There was active and fruitful discussion between audience and presenter. After the public hearings, the final assessments on the doctoral dissertation were carried out by five examiners including one external examiner to ensure the quality of the dissertation. TPU awarded PhD degrees to Mr. Tsuyoshi Kurita and Mr. Kaoru Takigasaki in March, 2011, and to Mr. Pillai and Mr. Sabareesh in September 2011.

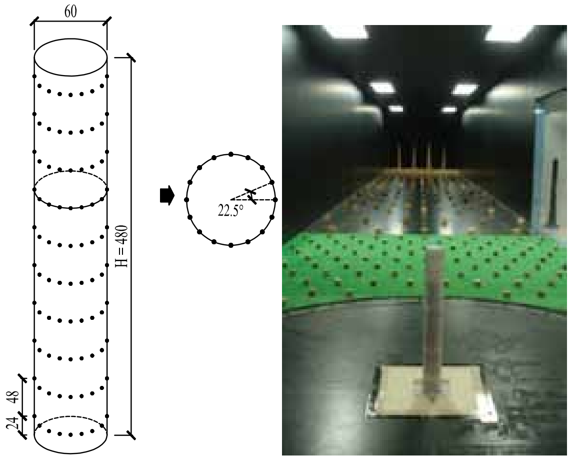
Effect of overall behaviors of Monocoque structure on stresses in members under fluctuating wind load

Zhibin Ding, Yukio Tamura, Akihito Yoshida

1. Introduction

In most standards or codes for wind loads (Architectural Institute of Japan, 2004; ASCE7-05, 2005), design wind load is divided into two parts: that on structural frames based on overall structural behavior and that on components/claddings based on the local behavior of structural members. However, it is impossible to distinguish between the structural frame and components/claddings for Monocoque structures, which support the structural load by using the object's exterior. Wind loading effects on the exterior walls depend not only on the overall bearing behavior but also on the local behavior of the shells. Current codes do not provide a means for determining the equivalent static wind load aimed at maximum loading effects for members of such structures.

The present work aimed at better understanding of wind loading effects on exterior walls of Monocoque structures. The internal stresses in the wall members were investigated by conducting time-history analysis using the finite element (FE) method, with special attention to the largest wind loading effects, including negative and positive peak member stresses. A method was proposed for estimating the contributions to the largest wind loading effects due to overall structural behavior.



(a) (b)

Figure 1. Wind pressure test model: (a) configuration of test model (unit: mm); (b) model in wind tunnel

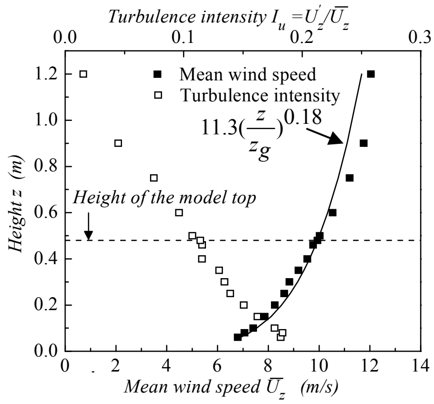


Figure 2. Mean wind speed and turbulence intensity profiles

2. Wind tunnel test

2.1. Experimental arrangements and procedures

Wind tunnel tests were conducted at the Tokyo Polytechnic University in Japan to measure the fluctuating wind pressures. A cylindrical model 0.48m in height and 0.06m in diameter was used, with 1/250 geometric scale, as shown in Figure 1. 160 wind pressure measurement points were arranged on the exterior of the model, 16 at each level at 22.5^{o} intervals. The power exponent of the vertical profile of mean wind speed was 0.18. The mean wind speed and the turbulence intensity at the height of the model were 9.9m/s and 11%, respectively. Measured longitudinal mean wind velocity and turbulence intensity profiles are shown in Figure 2.

2.2. Expanding fluctuating wind pressures

Because the locations of the nodes of the FE model did not coincide with those of the pressure taps on the experimental model, the fluctuating wind pressures at the nodes were simulated by using a proper orthogonal decomposition (POD) technique. A detailed discussion of this technique is presented in Tamura et al. (1997, 1999), for example. Table 1 gives the results of the normalized eigenvalues obtained from the POD analysis. The cumulative contribution up to the 50th mode is approximately 95%. Therefore, during the following analysis, the wind pressures at the nodes were simulated for the first 50 eigenmodes.

Table 1. Contribution of each mode from POD for Monocoque model

Mode	Contribution (%)	Cumulative Contribution
1st	28.21	28.21
2nd	8.61	36.82
3rd	7.30	44.12
…	…	…
20th	0.71	85.58
50th	0.16	94.79

3. Numerical analysis of wind loading effects

3.1. Analytical model

The prototype structure was a steel structure. ANSYS software was used for the FE modeling and analysis. The model was clamped at the bottom end while its top end was free. According to the geometric scale in the wind tunnel, 1:250, the height and the outside diameter were 120m and 15m, respectively, with a height-to-radius aspect ratio H/R= 16. The shell wall thickness, t=12mm, was set uniform with height. The mean wind speed at the top (H=120m) was set at 50m/s. The critical damping ratios for the first and second modes were set to 1% to calculate the two coefficients for the Raleigh damping equation. In the present study, the effects of aerodynamic damping and stiffness were not considered.

3.2. Estimating effects of overall behavior on member stresses

Firstly, the fluctuating wind pressures generated by POD were directly applied to the FE model and the dynamic wind load effects due to both overall and local behaviors were obtained. Then the tip time-history displacements obtained from a 10-lumped mass model system (Figure 4) under the overall fluctuating wind forces (Figure 3), assumed to represent the overall behavior of the structure, were applied to the FE model and the load effects were calculated considering only overall behavior. The effects of the overall behaviors on the member stresses were investigated by comparisons of the stress results from the above two round time-domain analyses.

It was assumed that there was no distortion on the cross sections when only overall behaviors were considered. The horizontal and rotational angular displacements of the lumped-mass system were transferred to the corresponding displacements of the nodes in the FE model.

3.3. Results and discussions

In the FE analysis, the global axes x, y, z were consistent with the axes defined earlier in Figure 4. In this case, σ_z represented the normal stress in the shell structure along the cylindrical axis, σ_y represented the stress in the circumferential direction and τ_{yz} represented the in-

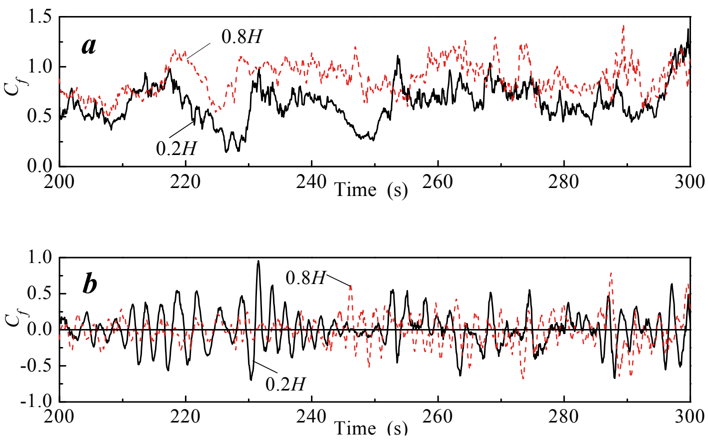


Figure 3. Overall wind force coefficients: (a) along-wind force coefficient; (b) across-wind force coefficient

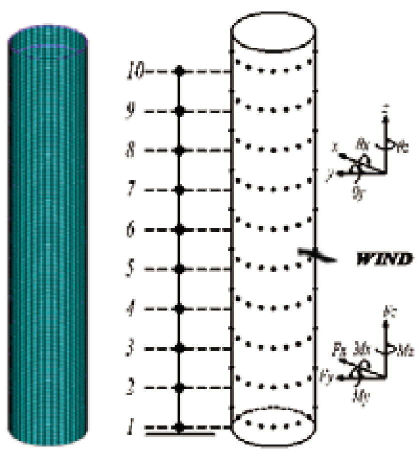


Figure 4. FE model and lumped-mass model system

plane shear stress in the shell structure. The area located at height 0.15H to 0.25H, at angles φ, -50°~50° from the windward meridian was chosen for discussion of the stress results. There were a total of 140 shell elements in this area.

The stresses in the elements became smaller when considering the overall behavior only, especially for the circumferential stress component. Because in this case only the bending behavior of the whole shell wall was considered, the bending moment and shear force were the main internal forces. Thus, the axial and shear stresses were the predominant loading effects when considering only the overall behaviors.

The other two stress components σ_y and τ_{yz} were smaller than the axial normal stress σ_z. Figure 5 shows the maximum axial tensile stresses and axial compression stresses separately in the order of the values. It can be clearly seen that considering only the overall behavior will underestimate the loading effects on the structural members. The effects of the overall behaviors on the member stresses are estimated by calculating the ratio between the largest wind load effects, $R_{max,\ overall}$ / $R_{max,\ real}$ and $R_{min,\ overall}$ /$R_{min,\ real}$. Here, $R_{max,\ overall}$ and $R_{min,\ overall}$ represent the maximum and minimum stresses under fluctuating wind load considering only overall behaviors for one element; $R_{max,\ real}$ and $R_{min,\ real}$ represent the maximum and minimum stresses under fluctuating wind load considering both overall behaviors and local behaviors. The ratios of the maximum axial normal stresses were about 65%~100%, while the ratios of the minimum axial normal stresses were about 60%~90%.

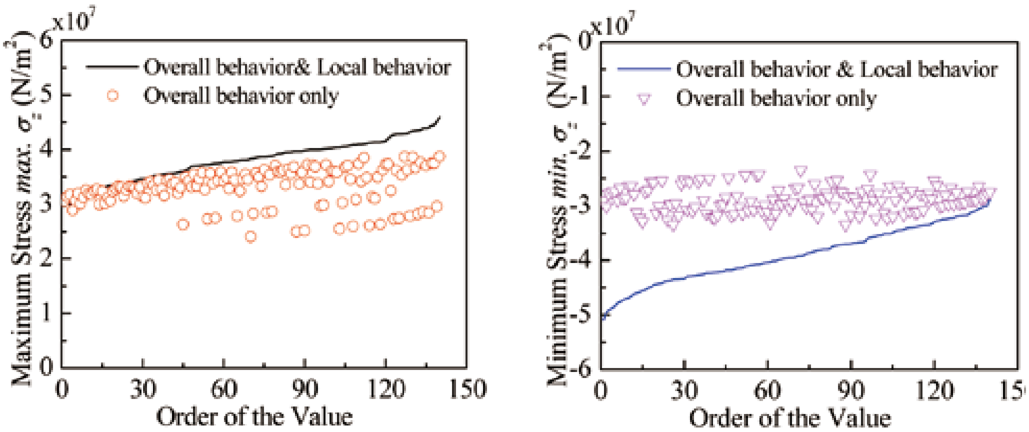


Figure 5. Comparison of maximum and minimum axial normal stresses according to order of values

4. Conclusion

Time-history displacements based on the overall behaviors and reconstructed fluctuating wind pressures were applied on to an FE model of a Monocoque structure. Considering only the overall behavior will underestimate the loading effects on the structural members, especially the circumferential stress component. The effects of the overall behaviors on the member stresses can be estimated by calculating the ratio between the largest wind load effects. For the elements chosen for discussion, the ratios of maximum axial normal stresses were about 65%~100%, while the ratios of minimum axial normal stresses were about 60%~90%. The error was more significant when the structural member was near the unfavorable area, where the member stresses were larger than others.

5. References

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Large Eddy Simulation of Gas Dispersion behind a High-rise Building in an Unstable Boundary Layer

Guoyi Jiang, Ryuichiro Yoshie, Kodai Katada

1. INTRODUCTION

Urban heat island phenomena and air pollution become serious problems in weak wind regions such as behind buildings and within street canyons, where buoyancy effect can not be neglected. In order to apply CFD techniques to estimation of ventilation and thermal and pollutant dispersion in urban areas, it is important to assess the performance of turbulence models adopted to simulate these phenomena. As the first step of this study, we carried out wind tunnel experiments and large eddy simulation (LES) of thermal and gas dispersion behind a high-rise building in an unstable non-isothermal turbulent flow. When simulating the turbulent atmospheric boundary layers using Large Eddy Simulation, a crucial issue is how to impose physically correct fluctuating inflow data. In a non-isothermal field, not only inflow velocity fluctuation but also temperature fluctuation is necessary. In this research, two inflow turbulence generation techniques (precursor method and recycling method) were investigated first. Then the turbulent inflow data generated by the precursor method was used for large eddy simulation of gas dispersion behind a high-rise building in an unstable turbulent boundary layer. The calculated results showed that LES results with inflow turbulence achieved good agreement with the experiment for the size of the recirculation region behind the building, especially for the lateral gas dispersion area, although the turbulent kinetic energy was a little overestimated in the top layer and in the wake region behind the building.

2. INFLOW TURBULENCE GENERATION FOR LES

When simulating turbulent atmospheric boundary layers using Large Eddy Simulation, a crucial issue is how to impose physically correct fluctuating inflow data. In a non-isothermal field, not only inflow velocity fluctuation but also temperature fluctuation is necessary. In this research, two inflow turbulence generation techniques were investigated.

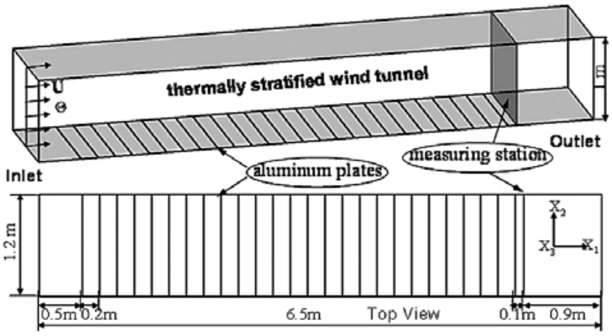
Firstly, we introduced a precursor method. In our wind tunnel experiment, the unstable turbulent boundary layer was generated by 26 very thin aluminum plates. In this precursor simulation, the whole wind tunnel (6.5 meters long) and all the aluminum plates (shown in Fig. 1a) were reproduced by LES using a buoyant solver. The plates were treated as having zero thickness in the simulation. The wind velocity and temperature distribution at the inlet of the wind tunnel were spatially uniform and turbulent intensity was very small (less than 1%), so a uniform velocity U=1.43 m/s and a uniform temperature Θ=9.4°C without turbulence were given to the inflow boundary of the pre-simulation. A zero gradient condition was used for the outlet boundary condition. A no-slip boundary condition was applied to the wall shear stress on the floor. As thermal boundary conditions, the surface temperature was 45.3°C and a heat conduction boundary condition was applied for the heat flux on the floor surface. The total mesh number used in the pre-simulation was $1042 \times 120 \times 79 = 9,878,160$. A unique time step Δt=0.001sec was used to make sure that the maximum courant number was less than 1 in all positions of the domain. The sampling plane to obtain fluctuating velocity and temperature data was set at 0.1m (11 times the aluminum plate height) downstream of the last aluminum plate.

Another method for generating inflow turbulence in a non-isothermal boundary layer using a recycling procedure was also investigated here. Tamura et al. (2003) proposed a method for dealing with the thermally stratified effect. In the driver region, velocity fluctuation was generated using Lund's method (Lund et al., 1998) for a rough wall, while temperature was treated as a passive scalar, and a mean temperature profile was given to the inflow condition of the driver region. The same concept was adopted here, but the velocity fluctuation was generated using Kataoka's method (Kataoka and Mizuno, 2002) with the roughness ground arrangement described by Nozawa and Tamura (2002). The roughness elements were exactly the same as those used in the wind tunnel experiment, but a short domain was adopted here.

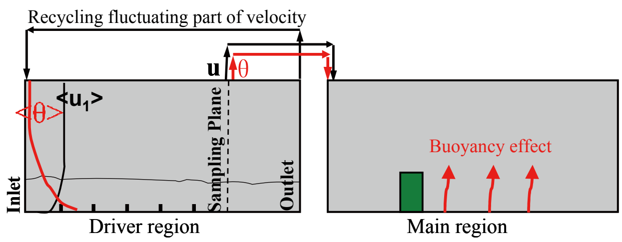
A mean velocity profile that came from the experimental measurement was prescribed for the inflow condition, and only the fluctuating part was recycled between outlet station and inlet station. The following damping function (Kataoka, 2008) was used to restrain development of the velocity fluctuation:

$$\phi(\eta)=\frac{1}{2}\{1-\tanh[\frac{8.0(\eta-1.0)}{-0.4\eta+0.82}]/\tanh(8.0)\} \quad (1)$$

where, $\eta = z/\delta$. δ is the boundary layer thickness (0.25m). Only a neutral boundary layer (NBL) was simulated in the driver region, the temperature was treated as a passive scalar, a mean temperature profile of the experiment was prescribed at the inflow boundary of the driver section, and we tried to use the fluctuating velocity field to generate a fluctuating temperature field. The computational arrangement for the recycling method is shown in Fig. 1(b).



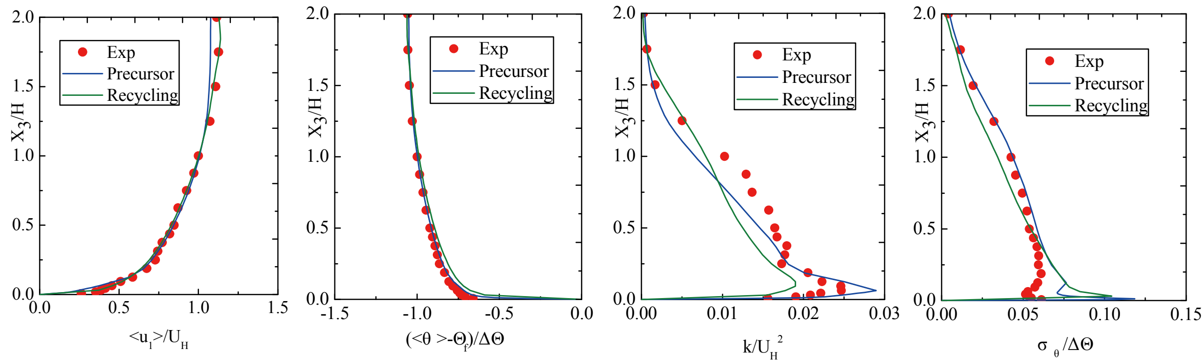
a. Precursor simulation domain and roughness elements arrangement



b. Recycling method

Figure 1. Inflow turbulence generation method:

Fig.2 shows the inflow characteristics generated by both the precursor method and the recycling method in the sampling position. The mean wind velocity, mean temperature, turbulent kinetic energy, and the r.m.s. value of temperature fluctuation agreed well with those of the experiment, and both methods can be used to generate turbulent inflow data for LES in a non-isothermal boundary. In this study, the turbulent inflow data generated by precursor simulation was used for large eddy simulation of gas dispersion behind a high-rise building in an unstable boundary layer.



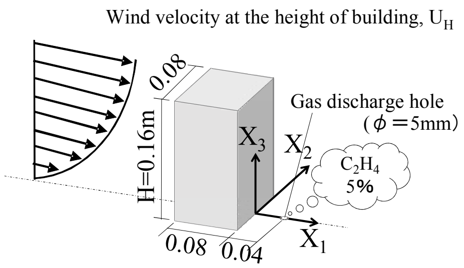
a. Mean stream-wise velocity b. Mean temperature c. Turbulent kinetic energy d. The r.m.s. value of temperature fluctuation

Figure 2. Inflow characteristics generated by precursor and recycling methods

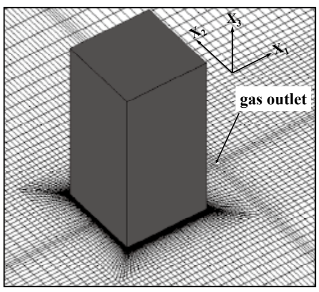
3. MAIN SIMULATION OF GAS DISPERSION BEHIND A HIGH-RISE BUILDING

Fig.3(a) shows the experimental setup. A building model ($0.08\times0.08\times0.16$ m^3) was placed in an unstable turbulent boundary layer. The experiment was conducted in a thermally stratified wind tunnel at Tokyo Polytechnic University. The surface temperature Θ_f of the wind tunnel floor was controlled uniformly at 45.3°C. Mean wind velocity and air temperature at the building height, U_H and Θ_H, were 1.37m/s and 11°C, respectively. The measured Richardson number was -0.3 near the boundary layer height. Tracer gas (5% C_2H_4: ethylene, 30°C) was released from a hole with diameterφ=5mm in the floor behind the building. The C_2H_4 gas flow rate was $9.17\times10^{-6}\times0.05m^3/s$ (0.05 means 5%).

For large eddy simulation of gas dispersion around the building, the standard Smagorinsky SGS model with Smagorinsky constant 0.12 was applied, and the Van Driest-type damping function was used to account for the near wall effect. In addition, the SGS Prandtl number and SGS Schmidt number were set to 0.7. An O-type grid around the building was used for LES as shown in Fig.3(b). The non-dimensional distances from the surfaces to the first fluid cells were below 1.0 for most regions. The fluctuating velocity and temperature data generated by the precursor simulation were used as the inflow boundary conditions. The physical time step was set to 0.0001sec to make the largest courant number less than 1. The time step and the grid arrangement in the X_2-X_3 section of the main simulation were different from those of the pre-simulation, so the data from the pre-simulation were linearly interpolated both temporally and spatially to match the time step and grids of the main simulation.

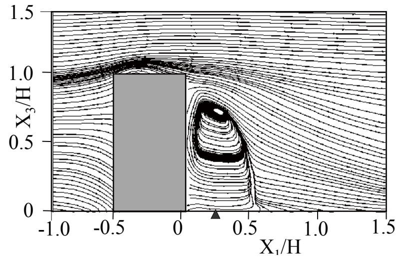


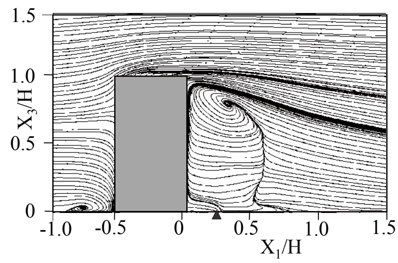
a. Experimental setup

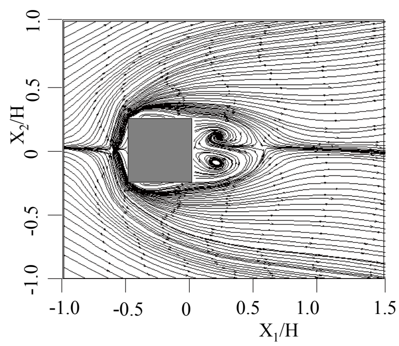


b. O-type grid around building

Figure 3. Model configuration


a. Exp (Vertical, $X_2/H=0$)


b. LES (Vertical, $X_2/H=0$)


c. Exp (Horizontal, $X_3/H=0.025$)

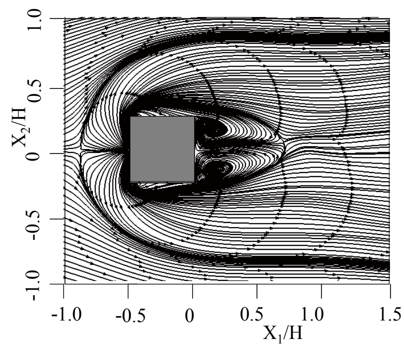
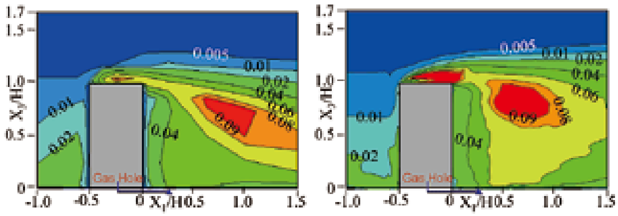

d. LES (Horizontal, $X_3/H=0.025$)

Figure 4. Distributions of streamlines by time averaged velocity

Fig.4 shows the streamlines by time averaged wind velocities in the vertical and horizontal planes. Both the recirculation region in the stream-wise direction and the affected region in the lateral direction, as well as the shapes of the streamlines of LES, are similar to those of the experiment.

Fig.5 shows the distributions of turbulent kinetic energy in the vertical section. The LES results show fairly good agreement with the experiment in front of the building, but the values are somewhat overestimated in the top layer, and also a little overestimated in the region behind the building.

The instantaneous iso-surface of the positive second invariant of velocity gradient Q=200 s^{-2} is shown in Fig.6. Due to the strong turbulence of the incoming flow, the momentum mixing in front of the building also becomes stronger. As a result, the horseshoe vortex in front of the building becomes unstable, and is not clearly seen in the figure. The flow separation at the edges of the front faces can be clearly observed.



a. Exp b. LES

Figure 5. Distributions of turbulent kinetic energy k/U_H^2

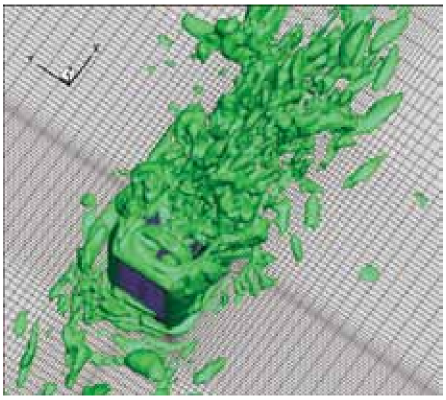
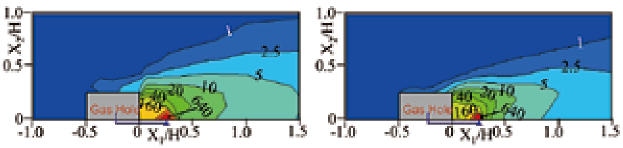


Figure 6. Instantaneous vortex structures (LES, Q=200 s^{-1})

Fig.7 shows the distributions of mean gas concentration in the horizontal direction. Because the periodic fluctuations due to vortex shedding were well reproduced in the large eddy simulation, the dispersion area in the horizontal direction becomes larger, which is similar to the experiment.



a. Exp b. LES

Figure 7. Horizontal distributions of mean concentration <c>/C_0 (X_3/H=0.025).

4. CONCLUSIONS

Wind tunnel experiments and large eddy simulation were carried out for thermal and gas dispersion behind a high-rise building in an unstable turbulent boundary layer. Two inflow turbulence generation techniques (precursor method and recycling method) were investigated first. The characteristics of the generated flow (mean profiles and fluctuation profiles) by both methods agreed well with those of the wind tunnel experiment. Then the turbulent inflow data generated by the precursor method were given to the inflow condition of the main domain to simulate the gas dispersion behind a high-rise building in an unstable boundary layer. The standard Smagorinsky SGS model with Van Driest damping function as the LES model was examined for the CFD calculation. The calculated results showed that the LES results with inflow turbulence achieved good agreement with the experiment for the size of the recirculation region behind the building, especially for the lateral gas dispersion area, although the turbulent kinetic energy was a little overestimated in the top layer and in the wake region behind the building.

ACKNOWLEDGMENT

This study was supported by the Ministry of Education, Culture, Sports, Science and Technology, Japan, through the Global Center of Excellence Program of Tokyo Polytechnic University.

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ISBN 978-4-902713-46-6