ESTIMATION OF WIND SPEED IN URBAN PEDESTRIAN SPACES ON THE BASIS OF LARGE-EDDY SIMULATION

Large-Eddy Simulation による都市歩道空間の風速予測

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The wind speeds in pedestrian spaces for staggered rectangular block arrays derived from large-eddy simulations are analyzed to model the urban pedestrian wind environment. The authors defined the area within 3 m of block walls as the pedestrian space and compared wind speeds in it under various geometric conditions. According to the result, the wind speeds in pedestrian spaces are influenced by the plan area ratio ($\lambda_p$) and block aspect ratio ($\alpha_r$). In addition, an exponential equation in terms of $\lambda_p$ and $\alpha_r$ can estimate the wind speed ratio well at the pedestrian level, especially for regions in front of blocks.

**Keywords:** Numerical simulation, Urban airflow, Pedestrian space, Wind speed ratio

1. INTRODUCTION

The airflow within urban canopies plays an important role in human comfort; hence, several criteria for acceptable wind speeds for pedestrians have been proposed. In addition, urban airflow dominates the transport phenomena of heat, vapor, and various pollutants between urban canyons and the atmosphere, affecting the urban air quality and thermal environment; thus, numerous studies have focused on the relation between urban geometry and airflow within urban street canyons. Considering recent rapid and massive urbanization in emerging countries, it is supposed that further knowledge for evaluating the urban wind environment for various urban geometries is important in providing effective guidelines for sustainable and comfortable cities.

Under these circumstances, wind tunnel experiments (WTE) have been conducted widely to investigate the geometry dependence of urban airflow. Hagishima et al. performed a series of WTE on the drag force acting on various types of rectangular block arrays and revealed that drag coefficients $\lambda_r$ exhibit a peak against block density due to the transition of the flow regime, namely isolated roughness flow, wake interference flow, and skimming flow (e.g., Meng et al.). Kubota et al. conducted multi-point measurements of the wind speed at the pedestrian level of block arrays representing real urban districts in Japan based on WTE. They clarified that the area-averaged mean wind speed ratio decreases linearly with increasing plan area ratio ($\lambda_p$, a ratio of total plan area of buildings to whole district area). They show that the wind speed becomes larger for middle- or high-rise residence districts than for low-rise ones.

In contrast, computational fluid dynamics (CFD) technique has gradually gained popularity and has greatly contributed to analysis of 3D turbulent flow structures around building arrays which are generally difficult to be measured by WTE alone. For example, Takebayashi et al. reported that urban ventilation is enhanced by the heterogeneity of building height based on Reynolds-averaged Navier-Stokes simulations (RANS). Razak et al. implemented large-eddy simulations (LES) of airflow over various types of block arrays...
and revealed that spatially averaged mean wind speed ratio at the pedestrian level can be described universally by a simple exponential function of frontal area ratio ($\lambda_f$, a ratio of frontal block area to unit district area).

Although simple relations between urban geometry and spatially averaged mean wind speeds given by these studies are useful, considering the high heterogeneity of mean wind distribution within urban streets (e.g., in Coccal et al.12), further detailed information about the spatial distribution of wind speed, especially in pedestrian spaces (the area close to a building wall), is needed in order to evaluate pedestrian thermal comfort.

Under these circumstances, the authors investigated mean wind speed ratios of pedestrian spaces for twelve types of urban building array based on the LES dataset derived by Razak et al.11) to examine how the pedestrian mean wind speed varies with urban geometric conditions. In addition, by coupling the analysis of LES data with the data of WTE, an equation of pedestrian wind speed, normalized by the value at the boundary layer height ($HBL$), is presented as a function of urban geometry.

2. LARGE-EDDY SIMULATION

The LES database of Razak et al.11) for rectangular block arrays is used for the analysis. They used the parallelized large-eddy simulation model (PALM) developed by Raasch et al.13), which consists of the continuity equation, incompressible Boussinesq equation with the 1.5th-order turbulent closure model proposed by Deardorff14), and the transport equation of subgrid-scale turbulence kinetic energy.

The LES computational domain is shown in Fig. 1. The coordinates ($x$, $y$, and $z$) and flow components ($u$, $v$, and $w$) are defined in the streamwise, spanwise, and vertical directions. 2 × 2 blocks are arranged in a domain of height 4$h$ ($h$ building height) for all cases. The grid resolution for $x$, $y$, and $z$ directions is $L/64$, where $L$ (25 m) is the scale of the building. The periodic condition is assumed for streamwise and lateral boundaries: thus, an infinite, uniform urban district is reproduced, and the flow is driven by a constant pressure gradient determined by the experimental results of Hagishima et al.6). In contrast, the free-slip condition is used at the top boundary, and the logarithmic law ($w_z = 0.01$m) is applied for solid wall surfaces. A time step $\Delta t$ in the range 0.025 s – 0.06 s is used, and the wind speed is recorded with a sampling frequency of 1 Hz for 16,000 seconds.

In this research, we utilized mean flow field data for the twelve types of uniform block arrays listed in Table 1 from the original database of 15 cases presented by Razak et al.11), and the spatio-temporal average of wind speed in pedestrian spaces was normalized by that at a reference height of 2$m$; thereby, $V_p/V_a$ is estimated. The geometry of the block arrays is characterized by two parameters, namely block aspect ratio ($\alpha_v$) and plan area ratio ($\lambda_v$). $\alpha_v$ is the ratio of frontal area to roof area of a block; thus, it indicates the slenderness of blocks.

The arrays are named according to the pattern “STA-B,” in which “ST” indicates a staggered array, and “A” and “B” refer to values of $\alpha_v$ and $\lambda_v$. For example, a staggered array with $\alpha_v$ of 1 and $\lambda_v$ of 25% is called ST1_25. We chose arrays consisting of blocks with five different $\alpha_v$ conditions, as shown in Fig. 2, for the analysis.
Since roughness Reynolds number \(Re^t = u_*x_0/v\), where \(u_*\) is the friction velocity, \(x_0\) is the roughness length assumed to be about 10% of canopy height according to Grimmond and Oke\(^{15}\), and \(v\) is kinematic viscosity, in the LES ranges between \(1.1 \times 10^4\) and \(4.0 \times 10^4\), the flow distribution pattern is independent of Reynolds number according to Snyder and Castro\(^{16}\); therefore, the simulation result can be interpreted for an arbitrary length scale. Notably, Razak et al.\(^{11}\) confirmed that the vertical profiles of wind speed for \(z<2h\) derived from LES show good agreement with that of the wind tunnel experiment of Cheng and Castro\(^{17}\) in which the block height was 20 mm and the roughness was repeated along the 150\(h\) long fetch. This means that there is a scale similarity of the mean flow profile for \(0<z<2h\) when the block layout is the same and the boundary layer is fully developed: thus, they could regard the wind speed at \(z = 0.05h, 0.1h, \) and \(0.25h\) as the data at a pedestrian level of 1.5 m in urban streets consisting of ten-, five-, and two-story buildings, respectively. In the same manner, we interpret data for the region within \(d = 0.1h, 0.2h, \) and \(0.5h\) (where \(d\) is distance from a block wall) as those of a pedestrian space with a width of 3 m around ten-, five-, and two-story buildings. Fig. 3 and Table 2 show how the relative dimensions of a pedestrian space vary with different assumed building heights. Furthermore, the pedestrian space for this analysis is classified into three areas: front, side, and behind, as shown in Fig. 4.

### 3. WIND TUNNEL EXPERIMENT

Since a periodic boundary condition is assumed on streamwise boundaries in the computational domain and the flow is driven by the constant pressure gradient in the current LES, the boundary layer height simulated eventually becomes identical to the domain height. In other words, the vertical wind profile simulated in the whole computational domain is fully adjusted to the geometry condition of the underlying block array; hence, the universal wind speed ratio, which is the pedestrian wind speed normalized by a reference value at a position where the effect of the block array geometry is negligible based on our LES data, is difficult to estimate.

To overcome this difficulty, we conducted a WTE using block arrays with similar geometry to those used in the previously mentioned LES. We measured mean wind profiles over the arrays at a position of about 130\(h\) downstream from the leading edge, and estimated wind speed ratios \(V_{aw}/V_{hil}\), which is determined with reference to the wind speed value at the height of the boundary layer generated by the block array. By coupling the WTE data of \(V_{aw}/V_{hil}\) with the LES estimates of \(V_f/V_{hil}\), the wind speed ratio \(V_f/V_{hil}\) can be estimated.

Fig. 5 shows the schematic outline of the experiment. The wind tunnel has a working section of 1 m \(\times\) 1.5 m \(\times\) 8 m, and the test section with the fetch is covered by a block array. The streamwise wind speed is measured by a split-film hot wire anemometer (Dantec, R55) with a frequency of 1000 Hz over a duration of 32 seconds. Table 3 shows geometrical conditions for block arrays used in the experiment. The mean wind speed is measured at 35 different altitudes and 19 points in the \(y\) plane to obtain the spatially averaged wind speed profile.

Fig. 6 shows the profiles of skewness and mean streamwise velocity over the ST1 array (\(\lambda_f = 17.4\%\)). Mean wind speed gradually increases with height and becomes almost constant at around a height of 7.5\(h\). On the other hand, a sharp negative peak of skewness can be found at a height of 7.5\(h\); this is a well-known feature of wind profiles over rough surfaces in wind tunnels and is generally consistent with the upper boundary of the outer layer (see Raupach\(^{19}\)). Hence we treat the height of a negative peak of skewness as the boundary layer height, similarly to Hagishima et al.\(^{6}\), and calculated \(V_{aw}/V_{hil}\). Fig. 7 shows the estimated result for each array, ranging between 0.5 and 0.7. Ideally, the WTE should be conducted in exactly the same conditions of \(\lambda_f\) used in the LES; however, considering the fact that \(V_{aw}/V_{hil}\) shown in Fig. 7 is relatively constant against \(\lambda_f\) it is supposed that linear interpolation provides adequate

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**Table 1** Block arrays used in numerical simulations.

<table>
<thead>
<tr>
<th>Arrays</th>
<th>(a_0)</th>
<th>(\lambda_f)%</th>
<th>(L_x)</th>
<th>(L_y)</th>
<th>(L_z)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST0.3_44</td>
<td>0.33</td>
<td>44.4</td>
<td>9.0L</td>
<td>9.0L</td>
<td>4.0L</td>
</tr>
<tr>
<td>ST0.5_44</td>
<td>0.5</td>
<td>44.4</td>
<td>6.0L</td>
<td>6.0L</td>
<td>4.0L</td>
</tr>
<tr>
<td>ST1_4</td>
<td>1.0</td>
<td>4.4</td>
<td>9.5L</td>
<td>9.5L</td>
<td>4.0L</td>
</tr>
<tr>
<td>ST1_8</td>
<td>8.2</td>
<td>7.0L</td>
<td>7.0L</td>
<td>4.0L</td>
<td></td>
</tr>
<tr>
<td>ST1_16</td>
<td>16.0</td>
<td>5.0L</td>
<td>5.0L</td>
<td>4.0L</td>
<td></td>
</tr>
<tr>
<td>ST1_25</td>
<td>25.0</td>
<td>4.0L</td>
<td>4.0L</td>
<td>4.0L</td>
<td></td>
</tr>
<tr>
<td>ST1_33</td>
<td>32.7</td>
<td>3.5L</td>
<td>3.5L</td>
<td>4.0L</td>
<td></td>
</tr>
<tr>
<td>ST1_44</td>
<td>44.4</td>
<td>3.0L</td>
<td>3.0L</td>
<td>4.0L</td>
<td></td>
</tr>
<tr>
<td>ST1.5_16</td>
<td>16.0</td>
<td>5.0L</td>
<td>5.0L</td>
<td>6.0L</td>
<td></td>
</tr>
<tr>
<td>ST1.5_33</td>
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<td>32.7</td>
<td>3.5L</td>
<td>3.5L</td>
<td>6.0L</td>
</tr>
<tr>
<td>ST1.5_44</td>
<td>44.4</td>
<td>3.0L</td>
<td>3.0L</td>
<td>6.0L</td>
<td></td>
</tr>
<tr>
<td>ST3_16</td>
<td>3.0</td>
<td>16.0</td>
<td>5.0L</td>
<td>5.0L</td>
<td>12L</td>
</tr>
</tbody>
</table>

\(\lambda_f\): block aspect ratio, \(\lambda_p\): plan area ratio, \(L_x, L_y, L_z\): domain size for \(x, y\) and \(x\) direction, \(L\): building scale (= 25 m), STA_B (A, B: values of \(a_0, \lambda_f\)).

**Table 2** Relative dimension of the pedestrian space.

<table>
<thead>
<tr>
<th>Building height</th>
<th>(d/h)</th>
<th>(z/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-story</td>
<td>0.1</td>
<td>0.05</td>
</tr>
<tr>
<td>5-story</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>2-story</td>
<td>0.5</td>
<td>0.25</td>
</tr>
</tbody>
</table>

**Table 3** Conditions of plan area ratio for block arrays used in wind tunnel experiments.

<table>
<thead>
<tr>
<th>Cases</th>
<th>(\lambda_f)%</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST0.3</td>
<td>4.3, 9.8, 17.4, 39.1, 69.4</td>
</tr>
<tr>
<td>ST0.5</td>
<td>4.3, 7.7, 17.4, 39.1</td>
</tr>
<tr>
<td>ST1</td>
<td>7.7, 17.4, 30.9</td>
</tr>
<tr>
<td>ST3</td>
<td>4.4, 16.0</td>
</tr>
</tbody>
</table>
estimation of $V_{20}/V_{BLH}$ for the conditions of $\lambda_p$ used in the LES.

4. RESULT

4.1 Mean flow distribution within a pedestrian space

Plan and side views of the distribution of normalized wind speed for ST1.25 are shown in Fig. 8 with pedestrian regions under the assumption of ten- and two-story building heights. Notable characteristics of the side area can be found in the plan view (Fig. 8a); when the buildings are regarded as ten-stories high, only the weak-flow regions near block walls are included in the side area, whereas high-speed regions parallel to the main stream also correspond to the side area in the two-story case. Similarly, the area ratio for weak-flow and high-speed regions included in the area behind the building varies depending on the assumption of building height. On the other hand, as shown in Fig. 8b, there is strong circulation near the ground surface in the front area.

Fig. 9 shows horizontal distributions of the normalized wind speed for arrays with the same plan area ratio of $p = 44\%$ and different block aspect ratios of $p = 0.3$ and $p = 1.5$ (ST0.3_44 and ST1.5_44). The wind speed is considerably reduced at the pedestrian level of ST1.5_44 due to the sheltering effect of densely packed blocks and the street width of only $1/3h$, while it is kept relatively large in the shallow canopy of ST0.3_44 because the flow obstruction effect of short blocks with relatively wide spacing ($3/2h$) is weak. These contrasting flow fields show that the block aspect ratio significantly affects the wind speed at the pedestrian level.

4.2 Mean wind profiles in a pedestrian space

Vertical distributions of spatio-temporally averaged wind speed in three pedestrian spaces normalized by values at $1h$ are shown in Fig. 10 for six types of block arrays with the same block aspect ratio of $\alpha_b = 1$ and with a height of ten stories. The area-averaged data for the whole street area including both pedestrian spaces and roadways given in Razak et al. is also included for a comparison. In the “whole” area, wind speed decreases monotonically with increasing $\lambda_p$ because the smaller amount of upper air can be introduced near the pedestrian level when building density increases. However, the profiles of each pedestrian space show different tendencies, and this implies difficulty in estimating pedestrian wind speed from the area-averaged “whole” data. For example, S-shaped profiles can be seen in the front area data for all arrays except for ST1.44 due to circulation near the floor surface which accelerates wind speed. On the other hand, in the side and behind-building areas the wind speed distributions for each array are nearly the same because these regions of ten-story building arrays are within the wake region; therefore, wind speed is always small regardless of the block density.
Next, vertical distributions of mean wind speed for arrays with the same plan area ratio of \( \alpha = 44\% \), as shown in Fig. 11, are addressed. Similar to the previous section, in the “whole” area increasing \( \alpha \) results in reduced wind speed in the canopy layer because the canyon becomes deeper and the upper air cannot reach the pedestrian level. In contrast, one can see a different tendency in each pedestrian area: again, \( S \)-shaped and linear profiles appear in the front areas for lower and higher block aspect ratio arrays, respectively. One possible reason for this tendency is the flow structure around slender blocks: in higher block aspect ratio arrays, strong circulation is generated less frequently in comparison with flattened blocks with low aspect ratio, and the flow tends to be more streamlined and easily follows block wall surfaces.

In summary, wind speed distributions in pedestrian spaces are remarkably different depending on two geometry parameters: plan area ratio and block aspect ratio.

### 4.3 The relation between pedestrian wind speed and geometric parameters

Wind speed ratios at the pedestrian level in a pedestrian space around ten-story building arrays for various front area ratios are summarized in Fig. 12. A solid line indicates estimation based on eq. (1), proposed by Razak et al.\(^{11}\), which predicts the area-averaged mean wind speed data of the whole street area at the pedestrian height by using \( \alpha \):

\[
\frac{V_d}{V_h} = 2.5 \, \alpha^{-0.8}.
\]

(1)

There are obvious discrepancies between the current LES result and values estimated using Eq. (1) except for the front area, which shows fairly good agreement. Meanwhile, we find that the wind speed ratios of the front and behind-building areas for arrays with
smaller block aspect ratios (ST0.3, 44 and ST0.5, 44) are relatively large in comparison with those of other arrays, which indicates that \( \lambda_c \) cannot universally explain pedestrian wind speed ratios for short block arrays.

Considering this fact, we propose an improved estimation equation for pedestrian wind speed on the basis of Eq. (1) as follows:

\[
\frac{V_p}{V_{2h}} = c \alpha_0^a \lambda_c^k
\]

Empirical constants \( a, b, \) and \( c \) are summarized in Table 4 with coefficients of determination. Moreover, a comparison between LES results and estimated values based on eq. (2) is shown in Fig. 13. The dashed line indicates \( Y=X \), the dotted line represents the error range of ±20%, and the color of each plot denotes block height.

The estimation shows fair agreement with LES results in the front area regardless of the assumption of building size (ten-, five-, and two-story buildings). Furthermore, the coefficient of determination for the “whole” area is increased from 0.56 to 0.93 compared to Razak et al.\(^{11}\). On the other hand, plots are scattered according to block height in the side and behind-building areas. These tendencies can be explained as follows: under the assumption of ten-story buildings, as shown in Fig. 8a, a pedestrian space is relatively small compared to the street width and most of the street is inside the weak-flow region of side and behind-building areas (indicated as dark-color regions). On the other hand, when the building height is assumed to be two-story, the pedestrian space is relatively wide: thus, the high-speed region of side and behind-building areas, which corresponds to the light-color region in Fig. 8a, is included in the pedestrian space. In short, since the dimensions of a pedestrian space relative to roadway size change with building height, it is difficult...
to predict wind speed in the pedestrian region for arbitrary building size by using Eq. (2).

4.4 Wind speed ratio defined by velocity at boundary layer height

The estimation equation described in section 4.3 can be modified by using wind tunnel experimental data to express the wind speed ratio normalized by a value at boundary layer height as follows:

\[ V_p/V_{BLH} = c \alpha_p \lambda_p \exp(k) \]  \tag{3}

Constants \( a, \ b, \) and \( c \) were determined based on the least-squares method. Fig. 14 and Table 5 show the results. Since the reference value \( V_{BLH} \) is less dependent with respect to the geometry of block arrays compared with \( V_{2h} \), Eq. (3) is presumed to provide more general guidance.

5. CONCLUSIONS

The LES database of the airflow over uniform, staggered block arrays with different plan area ratios performed by Razak et al.\textsuperscript{11}) is analyzed to clarify the relationship between mean wind speed in pedestrian spaces and urban geometry parameters. The authors defined a pedestrian space as a region within 3 m of block walls, classified it into three areas (front, side, and behind-building), and calculated spatially averaged mean wind speeds in each area. In addition, a series of wind tunnel experiments was conducted to estimate wind speed ratios between pedestrian height and boundary layer height, and results were combined with the LES data. According to the result, the vertical profiles of normalized mean wind speed in pedestrian spaces differ according to the following conditions: block height, block aspect ratio, plan area ratio, and regions within the pedestrian space (front, side, or behind-building). In addition, the wind speed at pedestrian level in each area can be estimated by an exponential equation in terms of block aspect ratio and plan area ratio. Especially in the front area, estimated values show good agreement with LES results. However, in the side and the behind-building areas there are some discrepancies between estimated values and LES results, depending on the assumption of the building height, owing to coexistence of weak-flow and high-speed zones in the pedestrian regions.

Since these findings are based on LES for a staggered layout, further improvements for estimating the pedestrian wind environment under various other urban geometry conditions will be our future work.

Acknowledgements

This work is supported by JSPS KAKENHI Grant Numbers 25820282 and 25289196. We are deeply indebted to Mr. Yuji Imabayashi for his efforts in the wind tunnel experiment.

Appendix

The vertical profiles of turbulence intensity of the current LES with those over cubical, staggered arrays with two \( \lambda_p \) conditions obtained in the WTE are shown in Fig. A1 for reference. These indicate the acceptable agreement between the LES and the WTE.
REFERENCES


Fig. A1 Vertical profiles of turbulence intensity ($\sigma_u/\bar{u}_z$)
和文要約

都市における建物群周辺の気流場は歩行者の温熱快適性や污染物質拡散など、都市居住者の健康や快適性に大きな影響を与える。そのため、建物群の粗密や高さばらつき等の都市の幾何条件と気流性状の関係について従来多くの研究が行われてきた。特に、Razakら（Building and Environment vol. 59, 2013）は高さばらつきの有無や粗度のスレンダランス、建蔽率等の条件を変化させた実体積積密度千鳥配列の周辺気流場についてのlarge-eddy simulation（LES）を行い、地上1.5mにおける時空間平均風速比が粗度面積密度とあらゆるパラメータによる普及的な指数関数で表現できることを明らかにしている。しかし、都市キャピティーの地上付近風速は水平面内に大きな分布を有することに加え、歩行者への風の影響評価のためにはより詳細な解析が必要される。これを受けて本研究では、都市歩行空間の速度場を都市幾何形状から予測することを目的として、RazakらによるLESを用いた数値計算結果を活用し、建物周囲の風速に対する解析を行った。加えて、数値計算と同様の粗度を用いて風洞実験を行い、この結果と数値計算結果を組み合わせることで、步行者高さと境界層高さの風速比を導出した。

本研究では並列計算に最適化された汎用LESコードPALM（Parallelized large-eddy simulation model）を使用し、Razakらによる千鳥配列粗度群に関する数値計算結果を用いてキャピティー風速を解析している。PALMでは、連続の式、非圧縮Navier-Stokes方程式、SGS-TKE予想方程式を基礎方程式とし、SGS乱流フラックスにはDeardorffのモード（Boundary-Layer Meteorology vol. 18, 1980）を適用している。

対象とする粗度群は粗度高さが均一な12配列とした。各配列の幾何条件は建蔽率とおよび粗度アスペクト比で決定されたものである。なお、建蔽率を粗度面積密度と粗度面積密度の比で、建蔽率を粗度面積密度としたものである。粗度面積密度と気流に対する立積密度の比であり、粗度の気流に対するスレンダランスを意味する。

計算ドメインは、2×2街区、高さ4h（h：粗度高さ）および解析領域は建蔽率8%および粗度アスペクト比0.25によって決定され、なお、数値計算における解像度は64×192となっている。水平方向境界面はcyclic条件を使用し、定圧力勾配によって流れが制御される。なお、数値計算における計算時間は10のオーダーでありレイノルズ数値は10^4のオーダーである。さらにレイノルズ数依存性は十分に小さいと考えられる。よって、計算結果を任意の幾何スケールに読み替えることが可能となる。本研究では、歩道の幅を3mと仮定し、建物壁面から0.1h、0.2h、0.5hにおけるデータが10, 5, 2街区建物群の歩道空間に相当すると仮定する。なお、歩道領域の中でも速度分布には大きな偏りが存在するため、歩道空間を風向に対し、front, side, behindという領域に細分化し、それぞれで個別に風速の抽出を行った。

歩道領域ごとに各配列における風速の鉛直分布形状の比を示した結果によると、front, side, behind各領域の分布形状はそれぞれ異なる。加えて、sensitivity testの結果から、歩道空間風速の分布形状は粗度アスペクト比と建蔽率の双方に強く影響を受ける事が明らかになった。

次いで、以上の結果を踏まえて、10, 5, 2街区での步行者高さにおける0.05h, 0.1h, 0.25hの風速と参調高さ2hの風速比、V/wVの予測を試みた。本研究では、Razakらが説明変数とした粗度面積密度αの粗度アスペクト比の積であることに着目し、V/wV = c α a bという一般化式を仮定して実験定数a, b, cを最小二乗法によって同定した。

なお、数値計算ではcyclic境界条件を採用しているため、自ずと、得られる速度プロファイルはモーダーの全領域に亘り解析対象の粗度配列にadjustしたもののである。そのため、歩行者間の速度を、粗度形状に依存しない参調速度で無次元化する事が困難となる。そこで、より一般的な風速比を求めるため別途、対象とした粗度配列をほぼ同じ条件にて粗度高さ2hの約130倍のフェッチを確保した風洞実験を行った。これらによって高さ2hの風速と境界層高さの風速比（V/wV）の比を算出した。これの結果を粗度計算によって求めめた風速比、V/wVを組み合わせることよりより一般的な風速比であるV/wVを推定した。その結果、front領域で決定係数は0.81, side, behind領域では0.73, 0.72という良好な予測精度を得たが、side, behind領域では、粗度建物群の影響を受けてブロック化に至らきりが確認された。これは、両領域が、想定する建物高さにより歩道に相当する領域が壁面近傍の低風速領域に収まっている場合もあれば、それぞれ主風向に平行な街路のチャンネル流や風下側の建物群との気流場のinteractionに起因する高速度領域を含む場合もあるため、高さ情報を含まない2つの予測式でこれに説明することが困難であったのだと考えられる。

（2014年7月10日受稿受理、2014年12月18日採用決定）