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Wind Loads for Agrovoltaic systems

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SUMMARY:
Wind tunnel tests were performed on 1/50 scaled models of agrovoltaic systems to evaluate wind loads as well as to suggest design wind force/moment coefficients for modules and their supporting structures.

Keywords: agrovoltaic, solar, wind tunnel

1. INTRODUCTION

With the necessity of renewable energy, solar energy has been playing an essential role and different type of solar system has been introduced all over the world. One of them is agrovoltaic system, which is constructed over the crop field and enables to cohabitation of agriculture and photovoltaics for the same land. This is introduced in Japan in 2013 and since then, the number of agrovoltaic system installation has been increased. The situation is the same for other countries and different types of supporting structures have been emerged depending on countries due to different regulations, climate, types of activities underneath the modules (agriculture, farming) and so on. While the rapid growth of this system is favoured, design requirements of the system have not been established, resulting in failures due to strong wind and poor designing.

There are mainly 2 types of supporting systems in Japan, independently arranged module system (Figure 1, left) and array system (Figure 1, right). This study focuses the first one which is the most common type in Japan. Compared to ground-mounted PV systems, this type of structure has higher height, wide column span (both for the access of agricultural machinery), and has to be simple structure (to be removed easily when the permitted period ends). These may affect wind loads acting on the system and different design for supporting structure from the one for ground-mounted PVs are necessary. Hence, wind tunnel tests on such system were performed to investigate these points.

2. WIND TUNNEL TEST

2.1. Agrovoltaic system model

Wind loads on agrovoltaic systems were measured by performing wind tunnel tests with models at a scale of 1/50. Figure 2 shows the sectional views of one of the agrovoltaic systems.

Figure 3 shows the module layouts. Not all modules on the supporting system have pressure taps and modules with pressure taps are not allocated as symmetrical. Hence, pressure were measured for wind direction, θ, of 0°-355° at 5° interval. The parameters considered are module tilt (α=10° and 30°) and row spacing, L/S (0.43 and 0.86), where S is on-center row spacing. The size of the module is 1 m (=chord, L) × 1.6 m and each contains 4 pressure taps on its upper and lower surfaces, respectively.

Figure 1. Common agrovoltaic supporting systems in Japan

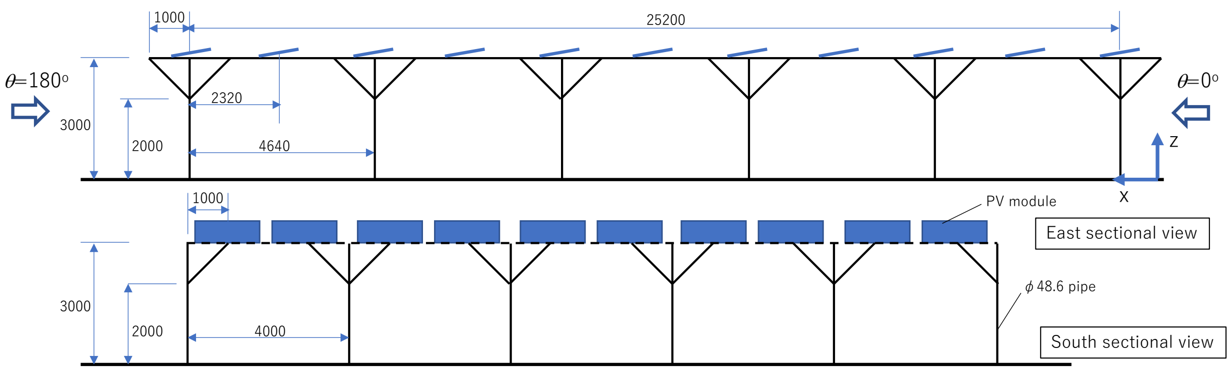

Figure 2. Plan and sectional view of agrovoltaic system considered in the present study (L/S=0.43)

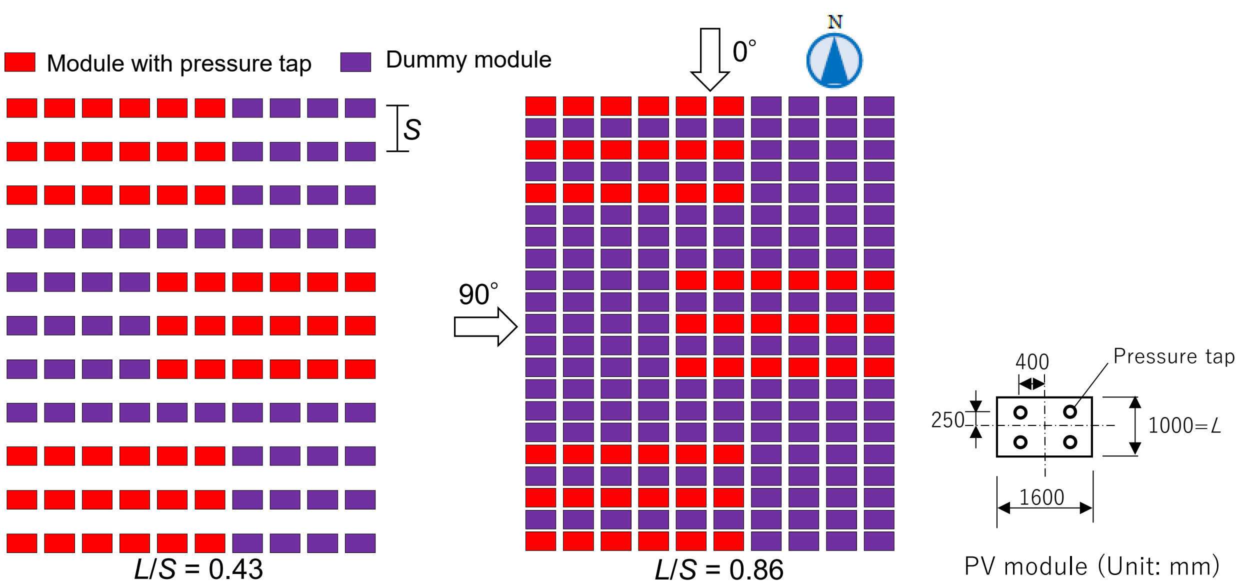

Figure 3. Layout of modules

2.2. Boundary Layer Simulations

Tests were performed in the open-circuit wind tunnel at Taisei Advanced Center of Technology, Taisei Corporation. The boundary layer simulations were designed to mimic roughness terrain II, defined in the AIJ Recommendations for Loads and Buildings of the Architectural Institute of Japan (AIJ Recommendations, 2015). The mean streamwise wind speed and turbulence intensity profiles together with those defined in the AIJ recommendations for this terrain are shown in Figure 4(a). Both correspond well with those ones in the AIJ recommendations. The power spectrum of the streamwise velocity fluctuations at 100 mm, $S_u(f)$ is calculated and is presented with Karman-type velocity spectrum in Figure 4(b). The agreement between the measured and target spectra is adequate at all frequency ranges, which assures that the flow simulation and hence the obtained wind pressure coefficient are adequate for the further discussion.

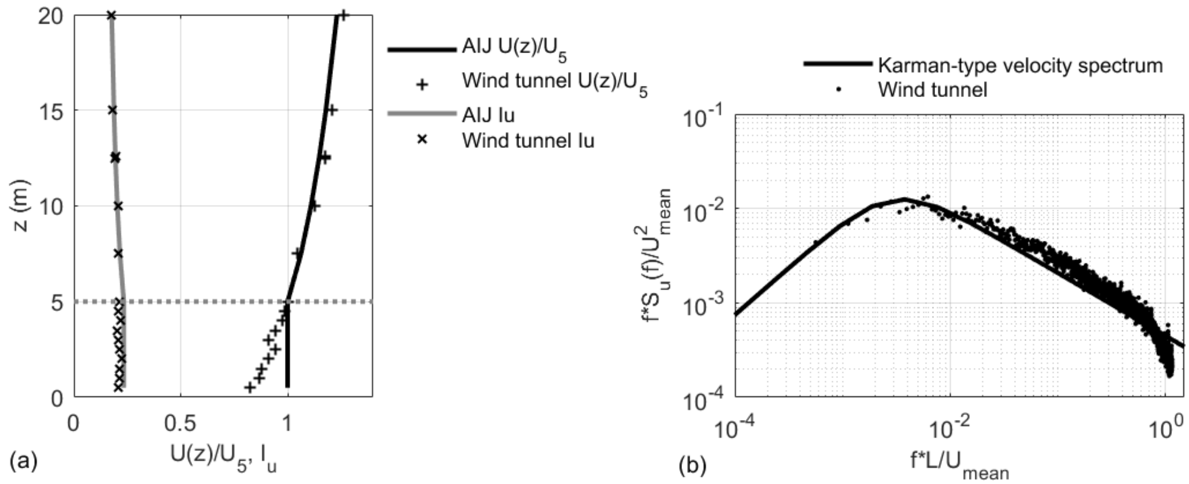

Figure 4. (a) The measured mean wind speed and streamwise turbulence intensity profiles, and (b) the longitudinal wind spectra at 100 mm

2.3. Pressure Measurements

Pressure on modules were sampled with a nominal wind tunnel speed of 8.3-8.5 m/s at lower module height, h (=60 mm) for sample length of 218 sec with a sampling rate of 600Hz. With an assumed velocity scale of 1/3.5 and a geometric scale of 1/50, the time scale becomes 1/14, resulting in a 218 sec measurement time corresponding to around 50 min in full-scale. Measured surface pressure, P, were converted into pressure coefficient, C_{pe}, and were referenced to dynamic pressure at h using a mean velocity profile, expressed by Eq. (1).

$$C_{pe} = (P_e - P_s)/q_h \tag{1}$$

where $P_e(t)$ is the external wind pressure measured on module, P_s is the static pressure at the reference height, and q_h is the wind velocity pressure at h.

3. RESULTS

3.1. Comparison with previous studies

The comparison with the results on ground-mount PV systems was performed to ensure the adequacy of the obtain C_p data. The wind tunnel results from Kopp et al. (2012) and CFD results from Jubayer and Hangan (2016) are employed. Table 1 presents experimental/CDF analysis parameters relevant to the results of comparison shown in Figure 5 where mean net wind force coefficients, C_{p_net}, acting on a solar table are compared. The horizontal axis is the dimensionless distance from the first row (x_1 is the distance from the first row centre to each table and H is the upper module height). Based on Jubayer and Hangan (2016), flow separation occurs at the windward edge of the first row and rows behind it are completely in the wake of it, which results in a large difference in mean C_{p_net} between the first and the rest of the rows. This can be seen in both wind directions in all studies. Although the magnitude of mean C_{p_net} varies among studies, this is reasonable considering the difference in parameters listed in Table 1. Hence, based on this result, the obtained C_p data are adequate to proceed further analysis.

Table 1. Summary of relevant parameters in each study

	Present	Kopp et al.	Jubayer & Hangan
table span × L (m)	19.6 × 1	19.8 × 1	21.92 × 2.47
Module tilt	10°, 30°	20°	25°
L/S	0.43, 0.86	0.6	0.63
H (m, FS)	3.17 (α=10°), 3.5 (α=30°)	0.5	1.65
Roughness terrain	Terrain II	O.C. (z_0=0.03m)	O.C. (z_0=0.03m)
# of measurement point/table	40 (upper), 40 (lower)	36 (upper), 10 (lower)	100 grids
Model scale	1/50	1/30	1/1

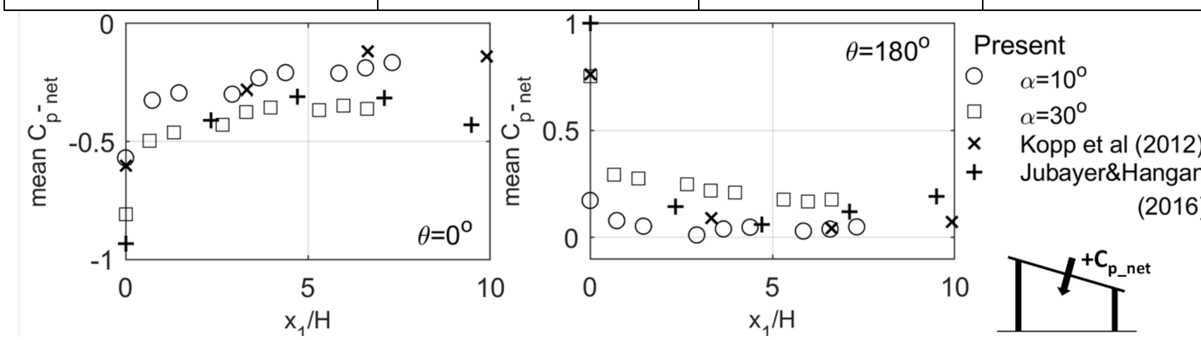

Figure 5. Mean net wind pressure coefficient on a solar table (for β = 35%)

4. CONCLUSIONS

The experimental setup for wind tunnel tests with agrovoltaic systems as well as the preliminary test results are reported. The full paper will present further results from testing and suggested design wind force/moment coefficients for module and supporting structure.

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