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WIND LOADS ON OPEN-TOPPED OIL STORAGE TANKS

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1 INTRODUCTION

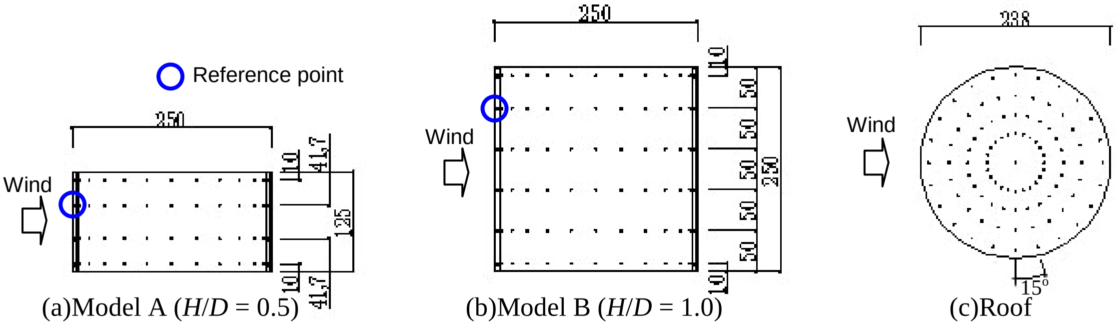
Wind loads and aerodynamic behavior of circular cylindrical structures, such as oil-storage tanks and silos, were studied extensively in the past (e.g. MacDonald et al. [1, 2], Holroyd [3], Uematsu and Yamada [4]). However, no study has been made of the dynamic wind forces based on simultaneous pressure measurements at many locations both on the external and internal surfaces of open-topped structures. In such structures, the wind load becomes the most critical when they are empty. The net wind forces should be evaluated by considering the correlation between the external and internal pressures.

In the present study, the characteristics of wind forces on open-topped oil-storage tanks are studied in a turbulent boundary layer. A conditional sampling technique and a POD (Proper Orthogonal Decomposition) analysis are employed to investigate the pressure field on the external and internal surfaces in more detail.

2 EXPERIMENTAL APPARATUS AND PROCEDURES

The wind-tunnel experiments are carried out in a turbulent boundary layer with a power law exponent (α) of approximately 0.15 for the mean wind velocity profile at Kajima Technical Research Institute. The geometric scale of wind-tunnel flow is approximately 1/400. The wind tunnel models are shown in Figure 1. The external diameter (D) is 250 mm. The aspect ratio (H/D) is 0.5 for Model A and 1.0 for Model B. The wall thickness is 6 mm. The pressure taps of 0.5 mm diameter are installed at a step of 15^o on the external surface and at a step of 30^o on the internal surface along each circumference. The roof height h_r can be varied from 0 to H. However, the present study focuses on the empty and full conditions, i.e. h_r = 0 and H. Ninety-seven pressure taps are installed on the roof. The wind pressures at all pressure taps are sampled at a rate of 1 kHz for approximately 33 sec simultaneously. The wind velocity U_H at the level of the wall height H is approximately 10 m/s for both models;

the corresponding Reynolds number Re (=$U_H D/\nu$, with ν being the kinematic viscosity of the air) is approximately 1.6×10^5. The Reynolds number regime is regarded as 'transcritical', based on McDonald et al. [1] and Uematsu and Koo [5].



(a)Model A (H/D = 0.5) (b)Model B (H/D = 1.0) (c)Roof

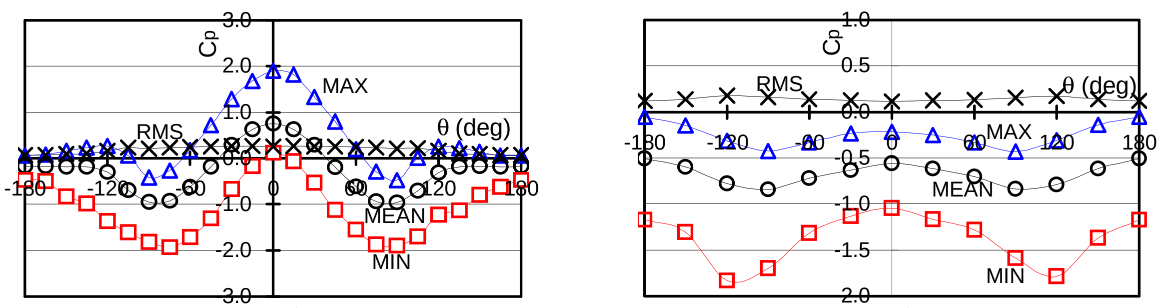
Figure 1: Wind-tunnel models and location of pressure taps

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Statistics of wind pressures

The mean, standard deviation (RMS), the maximum and minimum peak pressure coefficients (C_{pmean}, C_{prms}, C_{pmax}, C_{pmin}) at all pressure taps are computed. The same statistical values of the net wind force (pressure difference) coefficients C_f on the wall are also computed when h_r = 0. Since the internal pressures were measured at a step of 30° in the circumferential direction, the wind pressure coefficients at the mid points are interpolated by using the cubic spline function at each time step. The wind pressure and force coefficients are defined in terms of the dynamic pressure q_H of the approaching flow at the wall height H. Note that each statistical value is evaluated by the ensemble average of the results of several consecutive runs, each of which corresponds to 10 min in full scale.

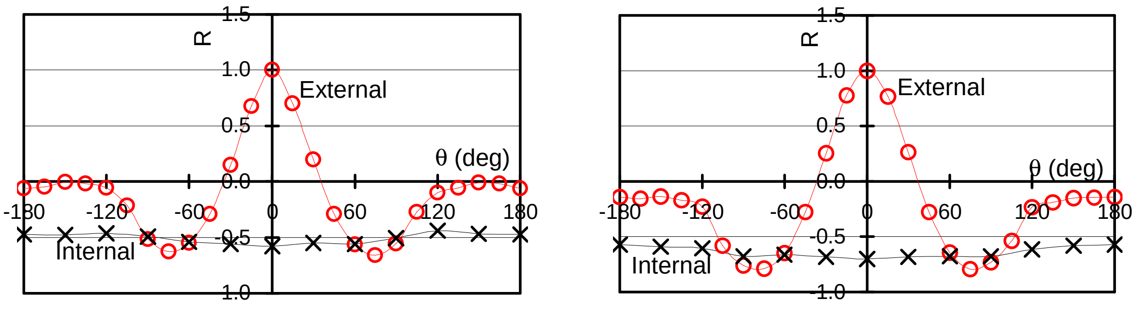
The maximum peak pressure coefficient is observed at a point of $z \approx 2/3H$ for Model A and $z \approx 4/5H$ for Model B on the windward generator (θ = 0°). The contours of C_{pmean}, C_{prms}, C_{pmax}, and C_{pmin}, not shown in the present paper, indicate that the statistical values of C_p change only significantly in the vertical direction (z). Figure 2 shows the circumferential distributions of the statistical values of C_p along a circumference at z = 2/3H for Model A. The distributions of C_{pmax} and C_{pmin} are similar to that of C_{pmean}. An instantaneous C_p-distribution can take place over a wide range from the C_{pmax}- to the C_{pmin}-curve.



(a) External surface (b) Internal surface

Figure 2: Circumferential distributions of the external and internal pressure coefficients at z = 2/3H (Model A)

Figure 3 shows the distribution of the correlation coefficients (R) between the wind pressures at the reference point (see Figure 1) and the other points. It is interesting to note that the distribution of R is similar in shape to that of C_{pmean}, particularly in the windward positive pressure region. In the negative pressure region, however, the magnitude of R is generally smaller than that of C_{pmean}. In the wake region, the value of R is fairly small in magnitude. The values of R for the internal pressures are nearly constant except for the top region.

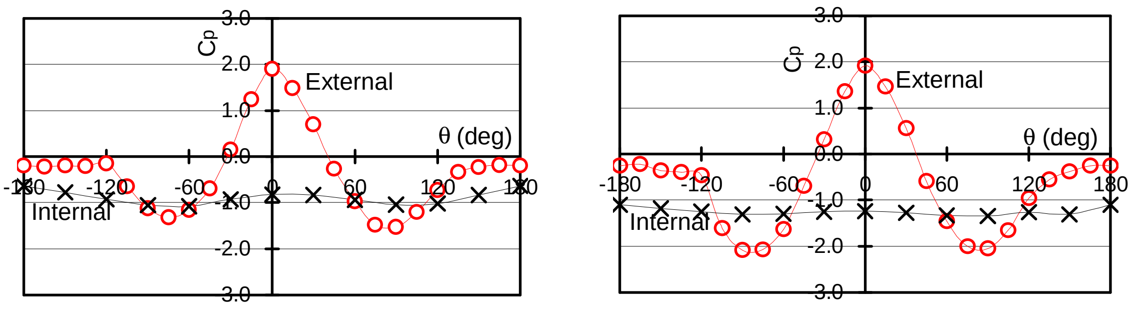


(a) Model A (z/H = 2/3) (b) Model B (z/H = 4/5)

Figure 3: Distribution of the correlation coefficients along the circumference

3.2 Conditional sampling

Uematsu and Uchiyama [6] indicated that the buckling behavior of thin cylindrical shells under wind loading is dependent on the extent of positive pressure as well as on the magnitude of the maximum pressure. Therefore, the pressure distribution at the instance when the external wind pressure at the reference point becomes the maximum peak value may be the most important from the viewpoint of structural stability of the wall, particularly for open-topped tanks. To investigate the structure of pressure field, a conditional sampling of wind pressure coefficients is carried out. Figure 4 shows sample results, in which the pressure coefficient distributions along a circumference at z = 2/3H (Model A) or 4/5H (Model B) is plotted. The distribution is similar in shape to that of C_{pmean}. However, the extent of positive pressure on the external surface is somewhat narrower than those of C_{pmean}. Furthermore, the value of external pressure coefficient in the wake region (θ>120°) is smaller in magnitude than that of C_{pmean}, when normalized by the values at the windward stagnation point (θ = 0°). The internal pressure coefficient is nearly constant over the whole circumference. The magnitude is larger for H/D = 1.0 than for H/D = 0.5.

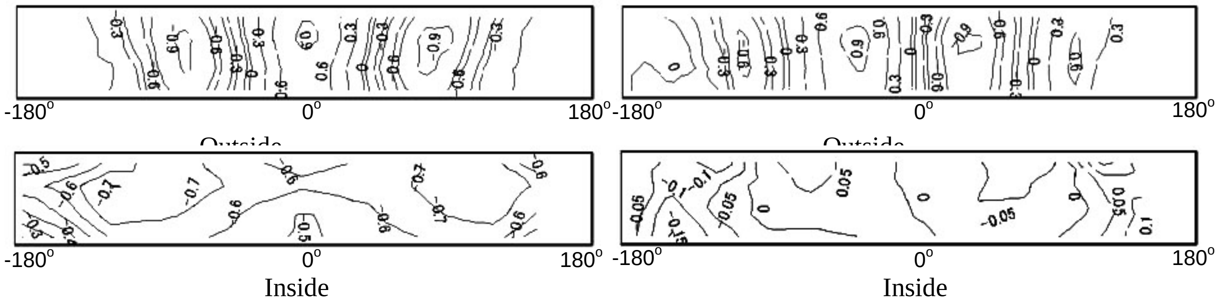


(a) Model A (z/H = 2/3) (b) Model B (z/H = 4/5)

Figure 4: Circumferential distribution of pressure coefficient at the instance when the external pressure at the reference point becomes the maximum peak value

3.3 POD analysis

Because the pressure field on open-topped oil storage tanks is highly random both in time and space, a POD analysis is employed to investigate the structure of pressure field in detail. In the analysis, the effect of difference in tributary area for pressure taps is considered (see Taniguchi et al. [7]). The results for Model A are shown in Figure 5. The normalized eigen values for the first and second modes are approximately 0.5 and 0.15, respectively. Based on a quasi-steady assumption, the first and second mode shapes are similar to those of $C_{p\mathrm{mean}}$ and $\partial C_{p\,\mathrm{mean}} / \partial\theta$, respectively. This is the case in the present experiment. However, the first mode shape is much similar to the pressure coefficient distribution obtained from the conditional sampling as well as to the distribution of the correlation coefficients.



(a) First mode (b) Second mode

Figure 5: Eigen modes of pressures on the external and internal surfaces (Model A)

4 CONCLUDING REMARKS

The characteristics of wind pressures acting on open-topped oil storage tanks have been investigated in the present study. The pressure coefficient distribution obtained from the conditional sampling is somewhat different from the $C_{p\mathrm{mean}}$-distribution; it is similar to the first mode shape obtained from the POD analysis and to the distribution of the correlation coefficients. Experimental and numerical studies on the deflection and buckling behavior of open-topped oil storage tanks under wind loading are now on going. Based on these studies, the wind loads for designing such structures will be proposed.

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