AIJ guide for numerical prediction of wind loads on buildings

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ABSTRACT: This paper presents the activities of Architectural Institute of Japan (AIJ) concerning the computational wind engineering, especially focusing on the numerical prediction of wind loads on buildings. Also, the current CFD techniques, including LES and the modified RANS, are discussed and estimated for their practical use to the wind-resistant design of actual buildings.

KEYWORDS: LES, RANS, practical use of CFD, wind-resistant design

1 INTRODUCTION

Architectural Institute of Japan (AIJ), by establishing the working group\textsuperscript{*}, has investigated the applicability of CFD technique to the wind-resistant design of actual buildings and structures. Consequently the current state of accuracy by the numerical prediction is clarified and also, the guide for the appropriate numerical model and method is provided\textsuperscript{1}). This paper summarizes the activities of AIJ concerning estimation for various techniques in the computational wind engineering. Recent advancement of CFD technique makes it possible to predict the wind flows around a building and a structure under the conditions very close to the actual state. Therefore the practical use of CFD even for wind-resistant design becomes almost realized now. Here we deal with a low-rise (1:1:0.5) and a high-rise (1:1:4) buildings. LES and RANS are adopted for these problems. The computed wind force and pressure are estimated by comparison with the experimental data. Also we provide the wind loads on these buildings predicted by LES and RANS.

2 NUMERICAL PREDICTION OF WIND PRESSURES AND WIND FORCES ON BUILDINGS

2.1 Selection of numerical method

LES is the method which can simulate the unsteady grid-scale eddies using time marching approach. By using LES we can get the time series of wind pressures and wind forces. RANS is used to simulate the time-averaged flows and the unsteady flows in which large vortices generated periodically in the wake of buildings. LES can be used to predict wind loads both on cladding and structural frames. The use of RANS would be limited to estimating the time-averaged wind forces on buildings.

2.2 Numerical model

The standard $k$-$\epsilon$ model is commonly used model for RANS, but it has a drawback in simulating the flows around buildings. In these studies, modified $k$-$\epsilon$ models such as the MMK model\textsuperscript{2}) and

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the k-ε-φ model\(^3\) are applied to improve the drawback. The model coefficients of LES are obtained using the dynamic procedure in these studies. Inflow turbulence for LES is generated numerically using the quasi-periodic boundary condition\(^4\) in the stream-wise direction. To achieve the target mean velocity and turbulence intensity profiles, roughness blocks are arrayed on the surface to realize the surface roughness.

2.3 Prediction by RANS

Figure 2.1, 2.2 show the time-averaged pressure coefficients on the center section of a low-rise building. The standard k-ε model overestimates the pressure coefficients on the frontal surface. It is because that the turbulence energy is overproducing at the impinging flow and the approaching flow doesn’t separate from the leading edge the roof. The approaching flows of the modified k-ε models separate from the leading edge of the roof and the overestimation of the pressure in the frontal surface is improved and the pressure recovery on the roof is in good agreement with experiment.

2.4 Prediction by LES

The time-averaged pressure coefficients on the center section of the low-rise building are well predicted by LES compared with the experimental data\(^2\) (Figure 2.3). The discrepancy in the profiles of the mean inflow velocity (LES: \(a=0.33\), experiment: \(a=0.25\)) cause the overestimation of rms pressure coefficients of LES on the roof. Although LES is slightly overestimating the time-averaged pressure on the frontal surface of the high-rise building, the predictions are in good agreement with two wind tunnel experiments\(^6\), \(^7\) (Figure 2.4).

3 NUMERICAL PREDICTION OF WIND LOADS ON BUILDINGS

3.1 Estimation method of wind load

Estimation methods of the design wind loads on cladding or structural frames of buildings using CFD are introduced here.

(1) Wind load on cladding

Figure 3.1 shows the procedure of estimation of wind loads on cladding using CFD. To estimate the wind loads on cladding, the peak wind pressure coefficients must
be calculated from CFD results considering a size effect. The size effect can be evaluated by a filtering method or a spatial integration method. For this treatment, the time-history data of the fluctuating wind pressures obtained by LES are indispensable. So RANS cannot be used for this method. A factor for effect of fluctuating internal pressure can be obtained from AIJ recommendations.

![Figure 3.1 Procedure of estimation of wind loads on cladding using CFD](image)

(2) Wind load on structural frames

Figure 3.2 shows the procedure of estimation of wind loads on structural frames using CFD. There are three routes. First one uses the mean wind pressure data obtained by RANS. The maximum wind load is calculated by multiplying the gust effect factor obtained by AIJ recommendations to the mean wind load. This method is available only for estimation of the alongwind load. Second one is for conducting a dynamic response analysis such as a spectral modal analysis or a time-history response analysis using the time-history data of the fluctuating wind pressures obtained by LES. Last one uses a fluid-structure interaction analysis. This method can calculate the maximum wind load on structural frames directly.

![Figure 3.2 Procedure of estimation of wind loads on structural frames using CFD](image)

3.2 Wind load on low-rise building

To verify the adequacy of numerical prediction methods, the wind loads on the low-rise (1:1:0.5) building predicted by CFD are compared with those by the wind tunnel experiment and AIJ recommendations. As an example of the result, comparison of the wind loads on the structural frame at the center section of the low-rise building’s roof is shown in Figure 3.3. Each wind load is calculated by multiplying the gust effect factor obtained by AIJ recommendations to the mean wind load. The LES result is greater than the experimental result. This is because that the reproducibility of the inflow turbulence at the inflow boundary of LES is insufficient. If this influence is taken into account, the LES result reproduces the experiment results. About the modified k-ε models,
the k-\(\epsilon\)-\(\phi\) model reproduces well the experimental results, but the MMK model underestimates the experimental result. This is because that the reproduction of the flow separation from the leading edge of the roof is insufficient.

3.3 Wind load on high-rise building
To verify the adequacy of the numerical prediction methods, the wind loads on the high-rise (1:1:4) building predicted by CFD are compared with those by the wind tunnel experiment and AIJ recommendations. As an example of the result, comparison of the wind loads on the cladding of the high-rise building is shown in Figure 3.4. The LES results coincide well with the experimental results.

3.4 Habitability for wind-induced oscillation
Through the response analysis, peak accelerations of the building oscillation are obtained simultaneously. Then the habitability for the wind-induced oscillation can be evaluated comparing those values to AIJ guidelines.

4 CONCLUDING REMARKS
We carried out LES and RANS simulation for the low-rise (1:1:0.5) and the high-rise (1:1:4) buildings. The accuracy of both methods is discussed. The applicability of CFD technique to the estimation of wind loads on actual buildings is clarified. We should note that, in order to use CFD technique for the wind loads estimation, time-dependent analysis with sufficient accuracy in time such as LES is definitely required for the prediction of peak-type of quantities.

5 REFERENCES