Pressure in a cavity of building-high double façade

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ABSTRACT: A numerical method is developed for estimating pressure in a cavity of a high double skin façade. The method is based on an extended Bernoulli’s theory, in which the pressure consists of friction loss and velocity pressure. The calculation consists of two stages. In the first stage, the pressure and the velocity by the friction loss in the cavity are calculated by the pressures at the openings of the double skin, which are given by the wind tunnel result for the normal single skin building. Then, velocity pressure is calculated by the velocity. By the comparison with the experimental results, the method can predict well the pressure in the cavity.

KEYWORDS: Double skin, Bernoulli’s theory, Friction loss, Velocity pressure, Numerical method, Wind tunnel experiment

1 INTRODUCTION
Recently, double skin glazing façades are becoming popular for modern buildings in Europe, U.S.A., Asia and other countries with new glass supporting systems. The façade can save not only energy for air-conditioning, but also can intake fresh air into a room. The double skin glazing systems are classified into two types. The first type is building high glazing system which is set outside of a building with a normal single skin glazing. Air vents from the bottom to the top of the building in a cavity between outside and inside skins. There is no horizontal dividers floor-by-floor as shown in Fig.1. The second type is story high glazing system in which air vents in a cavity in an each floor or an each window for various ways shown in Fig.1.

As the pressure in the cavity is as same as the pressure at the openings which is almost same as the external pressure on the outside skin in the case of the story high double skin, the pressure on the outside skin from the outside and the inside is balanced and the wind force on the outside skin is usually very small except near the corners. On the other hands, the pressures are normally different between top, side and bottom openings for the building high double skin, so the pressure in the cavity is different from a point to a point, which can induce the unbalance of the pressure on the outside skin from the outside and the inside, and then the relatively large wind force can act on the outside skin as is shown in Fig.2.

The numerical method to estimate the pressure in the cavity by pressure on a normal single skin is introduced in the paper and is compared with results obtained from the wind tunnel test. The method is based on an extended Bernoulli’s theory, in which the pressure consists of friction
loss and velocity pressure. The calculation consists of two stages. In the first stage, the pressure and the velocity by the friction loss in the cavity are calculated by the pressures at the openings of the double skin, which are given by the wind tunnel result for the normal single skin building (Chino 1993, Harris 1990). Then, velocity pressure is calculated by the velocity in the cavity. By the comparison with the experimental results, the method can predict well the pressure in the cavity except close to the openings.

2 THEORY

We divide the cavity into small regions shown in Fig. 3. The pressure and the velocity at the points \((i, j)\) and \((i, j-1)\) are expressed by \(p_{i,j}, p_{i,j-1}, v_{i,j}, v_{i,j-1}\), and an extended Bernoulli’s theory is applied to the flow from \((i, j)\) to \((i, j-1)\), then the following equation is given.

\[
p_{i,j} + \frac{1}{2} \rho v_{i,j}^2 + F = p_{i,j-1} + \frac{1}{2} \rho v_{i,j-1}^2
\]

(1)

where \(\rho, F\) are the air density and the friction loss between the points \((i, j)\) \((i, j-1)\).

Expressing the velocity from \((i, j)\) \((i, j-1)\) as \(v_{i,j-1}'\), the friction loss \(F\) is given by the equation (2).

\[
F = \text{sgn}(v_{i,j-1}')\frac{1}{2} \rho v_{i,j-1}'^2 k_{i,j-1} \Delta y = p_{i,j-1} - p_{i,j}
\]

(2)

where \(k_{i,j-1}, \Delta y\) are the friction loss coefficient and the distance between the points \((i, j)\) and \((i, j-1)\).

Substitute the equations (2) for (1), we get the equation (3).

\[
p_{i,j} + \frac{1}{2} \rho v_{i,j}^2 - p_{i,j} = p_{i,j-1} + \frac{1}{2} \rho v_{i,j-1}^2 - p_{i,j-1} = C
\]

(3)

So, the pressure at the point \((i, j)\) is given by

\[
p_{i,j} = p_{i,j} - \frac{1}{2} \rho v_{i,j}^2 + C
\]

(4)

Terms are divided by the velocity pressure of 0.5\(\rho V^2\), in which \(V\) is the velocity of the approaching flow.

\[
C_{p,i,j} = C'_{p,i,j} - \left(\frac{v_{i,j}}{V}\right)^2 + C'
\]

(5)

where \(C_{p,i,j}\) the pressure coefficient at the point \((i, j)\), \(C'_{p,i,j}\) the pressure coefficient by the friction loss and \(C'\) is the constant determined from the friction loss at the openings.

Assuming the velocity and the pressure at the openings are zero and \(P_o\), which is the pressure on the single skin at the openings, the following equation is given by,
\[ P_b = P_i + \frac{1}{2} \rho v_i^2 + k \frac{1}{2} \rho v_i^2 \quad (6) \]
where \( P_b, v_i \) are the pressure and the velocity at the second grid from the opening. The equation (6) is rewritten to the equation (7) in consideration of (4).

\[ P_b = p_i + k \frac{1}{2} \rho v_i^2 + C \quad (7) \]

Then,

\[ P_b - C - p_i = p_b - p_i = k \frac{1}{2} \rho v_i^2 \quad (8) \]

where \( p_b = P_b - C \) is the pressure at the opening given for the friction loss.

The velocity \( v_{i,j} \) at the point \((i, j)\) can be estimated by sum of flux into the point \((i, j)\) in x and y directions, then the velocities \( v_{k,i}, v_{j,i} \) at \((i, j)\) in x and y directions are given by the following equation.

\[ v_{k,i} = v'_{i-1,j} - v'_{i+1,j} \]
\[ v_{j,i} = v'_{i,j-1} - v'_{i,j+1} \quad (9) \]

On the other hands, the total flux into the point \((i, j)\) from the points of \((i, j-1), (i, j+1), (i-1, j) \) and \((i+1, j)\) is zero according to the mass conservation law.

\[ Q_{i,j-1} + Q_{i,j+1} + Q_{i-1,j} + Q_{i+1,j} = 0 \quad (10) \]

Taking into consideration of \( Q_{i,j-1} = v'_{i,j-1} \Delta x \) and the non-dimensional form of the equation (2)

\[ C'_{p,i} - C'_{p,j,i} = \sin(v'_{i,j-1}) \left( \frac{v'_{i,j-1}}{V} \right) k_{i,j-1} \Delta y \],
the following simultaneous equation is given for the calculation of \( C'_{p,j,i} \).

\[ \text{sgn} \left( C'_{p,i} - C'_{p,j,i} \right) \sqrt{ \frac{C'_{p,i} - C'_{p,j,i+1}}{k_{i,j-1} \Delta y} } + \text{sgn} \left( C'_{p,i} - C'_{p,j,i} \right) \sqrt{ \frac{C'_{p,i} - C'_{p,j+1,i}}{k_{i,j-1} \Delta y} } + \text{sgn} \left( C'_{p,i} - C'_{p,j,i-1} \right) \sqrt{ \frac{C'_{p,i} - C'_{p,j-1,i}}{k_{i,j+1} \Delta x} } = 0 \quad (11) \]

3 NUMERICAL PROCEDURE
The numerical calculation has been carried out by the following.
(1) The pressures at the openings for the single skin were used for the boundary condition. The velocities at the boundary were assumed as zeroes.
(2) The pressure induced by the friction loss is estimated by the equation (11).
(3) The velocity at the point \((i, j)\) is estimated by the equation (9) through the equation (2).
(4) The pressure at the point \((i, j)\) is calculated by the equation (4)
4 RESULTS

Fig. 4 shows the comparison of the pressure in the cavity between the experimental result and the calculations. The one grid inside region from the boundaries is shown in the figure, because the velocities are assumed zero in the calculation at the boundaries, which are the openings in the case. The cavity is divided into 13 x 17 grids. The friction loss coefficient of $k\Delta$ and the constant of $C'$ in the equation (5) are assumed as 1 and 0.07 respectively.

The pressure induced by the friction loss is also shown in the figure as Fig. 4 (b). The pressures are positive at the top and the bottom. On the other hands, the pressures are negative at the side ends. Therefore, air intakes into the cavity from the top and the bottom openings and comes out from the side openings. The direction of the flow is normal to the contour lines in Fig. (b). The pressure induced by the friction loss is positive in the most region of the cavity, and is different from the pressure in the cavity obtained by the experiment.

The sum of the pressure induced by the friction loss and the velocity pressure estimated by the velocity is calculated by the equation (6) and is shown in Fig. 4 (c). The distribution of the calculated cavity pressure is nearly the same as those of the experimental pressure expect the region close to the bottom opening, where the flow separates at the openings and accelerates to induce the large negative pressure.

5 CONCLUSIONS

The numerical method based on the extended Bernoulli’s theory is valuable to estimate the pressure in a cavity of double skin facades. The boundary conditions of the pressure at the openings are given by the pressure obtained from the experimental results of the normal single skin façade and the velocities at the openings are assumed as zeroes. The cavity pressure is expressed by the sum of the pressure induced by friction loss and the velocity pressure.

6 REFERENCES
