Unsteady pressurization method to measure the airtightness of the building envelope.

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ABSTRACT: The unsteady pressurization method to measure the airtightness of the building envelope is studied. Recording the pressure decay in the building space provides the airtightness of the building envelope. The governing equations are derived and the air leakage is calculated

1 INTRODUCTION

The methods to calculate the airtightness of the building envelope are classified into two types based on the pressurization method used. One is steady pressurization, called the DC method, and the other is unsteady pressurization, called the AC method. Unsteady pressurization methods include the following.

- Decay method
- Pulse method
- Oscillation method

One of the merits of these methods is that the curve reflecting the response pressure change in the room gives the characteristic equation of the airtightness of the building envelope. In contrast, in a DC method the rate of air flow in or out the room must be measured under several different pressure, sequentially set, between the inside and the outside of the room. This takes so much time. Decay method will be conducted by establishing a pressure difference between inside and outside the room accomplished by pushing some amount of air into the room or pulling it out, and by stopping the airflow suddenly. The pulse method projects a short duration pulse pressure into the room. Both methods record the decay of the pressure difference. Ichihashi et al. (1985) & Nishioka (2000) studied Pulse method and applied it to the laboratory animal rooms. In this work, the theoretical bases were not illustrated. Sherman et al. (1979) developed Oscillation (AC) method. This needs so heavy equipment such as s piston oscillating. In this paper, the decay method is studied. The theoretical basis of the method is introduced and experimental tests are carried out.

2 BASIC EQUATIONS

Leakage can be determined by applying the mass balance equation. When there is a source releasing the rate of air M and the leakage Q in a room whose volume is V, the mass balance gives the following:

$$V\frac{d\boldsymbol{r}}{dt} = M - \boldsymbol{r}Q \qquad (1)$$

where ñ= density of the air.

The state of the air in the room is given as:

$$\boldsymbol{r} = \frac{G}{V} = \frac{P}{RT} \qquad (2)$$

where G= mass, P= pressure, T= temperature, and R= gas constant of the air in the room.

Differentiate Equation 1 under the assumption that the temperature is nearly constant:

$$\frac{d\boldsymbol{r}}{dt} = \frac{1}{RT}\frac{dP}{dt} \qquad (3)$$

Combining Equation 1 and 3 yields:

$$V\frac{dP}{dt} = RMT - PQ \qquad (4)$$

The pressure difference between the room and the atmosphere is very small compared with the pressure of the room and of the atmosphere. It can be assumed that these two pressures are constant and equal each other. Then: (P_a= atmospheric pressure)

$$P = P_a + \Delta p$$

$$\Delta p \prec P, P_a \because P \cong P_a (= \text{constant})$$

Using the above relations, Equation 4 is described as:

$$V\frac{d\Delta p}{dt} = RTM - P_a Q \qquad (5)$$

The rate of leakage Q is governed by the power law as the following:

$$Q = a\Delta p^{n} \tag{6}$$

Introducing the above Equation into Equation 4 gives the following:

$$V\frac{d\Delta p}{dt} = RTM - P_a a\Delta p^{n} \tag{7}$$

If the pressure change is steady state (i.e., if the left side of the above equation becomes zero) at the constant injection rate *M*, Equation 7 expresses the DC pressurization method. When *M* in Equation 7 is the pulse injection of the air, the solution of the equation gives the pressure decay of the room and is utilized with the Pulse method. When *M* is injected in a volume-oscillatory manner, the solution of Equation 7 presents the room pressure response synchronous to the injected air volume oscillation, and is used with the AC method. If *M*=0, the solution of Equation 7 at the initial condition of a given pressure P_0 gives the pressure decay from P_0 to zero.

If *n*=1, Equation 7 becomes linear and can be solved:

$$\Delta p = \frac{RTM}{P_a a}\left(1 - e^{-\frac{P_a a}{V}t}\right) \tag{8}$$

Generally *n* is not a unit, and Equation 7 cannot be solved analytically except when *RMT*=0.

3 PROCEDURE

Equation 7 can be solved analytically only when *M*=0 at initial value P_0. If *M*=0, Equation 7 becomes a linear equation and can be solved by separating the variables as follows:(Sherman: 1988)

$$\Delta p = p_0\left[1 - \frac{ap_a(1-n)t}{Vp_0^{1-n}}\right]^{\frac{1}{1-n}} \tag{9}$$

In practice, this can be done as follows: Some amount of air *M* is injected for a short duration. After the pressure in the room reaches a predetermined level, injection is stopped and the pressure drop should be recorded. The pressure decay data is fit to Equation 9, and the resultant value of the leakage parameters *n* and *a* of Equation 6 are obtained. Unfortunately, Equation 9 is not linear, and it is therefore not possible to determine an approximate expression of Equation 9 using least-square regression.

Instead, Equation 6 is approximated directly by the least-regression method using a given set of values calculated from the pressure decay curve. From Equation 4, the relationship between the pressure and the leakage at M=0 is obtained as follows:

$$Q = -\frac{Vd\Delta p}{P_a dt} \tag{10}$$

The derivative of the pressure with respect to time is approximated as:

$$\frac{d\Delta p}{dt} \cong \frac{\Delta p(t+\Delta t) - \Delta p(t)}{\Delta t} \tag{11}$$

Äp(*t*+*Ät*) and *Ä*p(*t*) are calculated from the measured decay curve. Combine Equation 11 with Equation 10, and obtain:

$$Q(t) = -\frac{V}{P_a}\frac{\Delta p(t+\Delta t) - \Delta p(t)}{\Delta t} \tag{12}$$

At the pressure difference between inside and outside of the room, *Ä*p(*t*), the leakage rate *Q(t)* is calculated by Equation 11. Several sets of values, (*Ä*p(t_1), *Q*(t_1)), (*Ä*p(t_2), *Q*(t_2)),…, (*Ä*p(t_n), *Q*(t_n)), calculated from Equation 11, give the leakage Equation 6 by least-squares regression. Although is tedious work to calculate this manually, it is rather easy by personal computer.

Figure 1 shows the schematic diagram of the experiment. The system consists of the airtight chamber (1000x1000x1000; plywood), the flow meter (contraction cone), and the blower. Test pieces are fixed on the opening (300x300) bored in the left sidewall of the chamber. Each test piece has a crack the size and shape of which are known. After the test piece is fixed, the blower is turned on to extract air from the chamber and decrease the pressure therein. Then the blower is turned off and the pressure change is recorded.

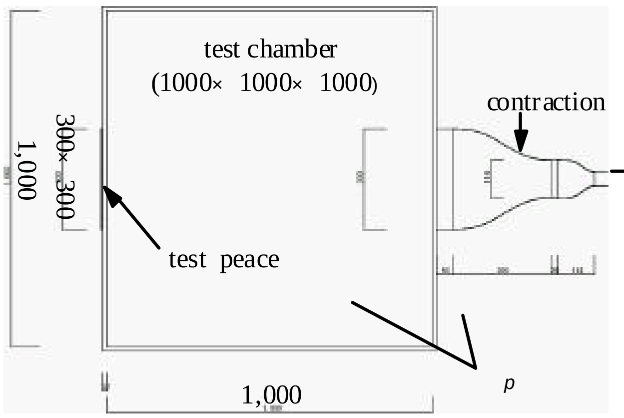
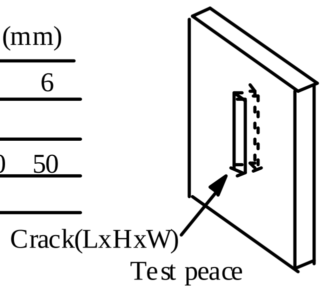


Figure 1 Test equipment

Table 1 Size of Cracks (mm)

	1	2	3	4	5	6
L	5					
H	5	10	20	30	40	50
W	5					



4 RESALUTS

Several kinds of crack are examined. Crack sizes are presented in Table 1. For several minutes the blower extracts air at 0.1m^3/h from the chamber, then is stopped to record the pressure change. Figure 2 shows the pressure change for each crack size.

The smaller the crack size, the greater the pressure difference increase

Figure 3 presents the leakage equation induced by

Table 3 Leakage parameters

	Case1	Case2	Case3	Case4	Case5	Case6
Crack	3x5	3x10	3x20	3x30	3x40	3x50
a(10^{-2})	1.58	1.75	1.48	1.66	1.65	1.69
n	0.90	0.89	0.96	0.96	0.97	0.98

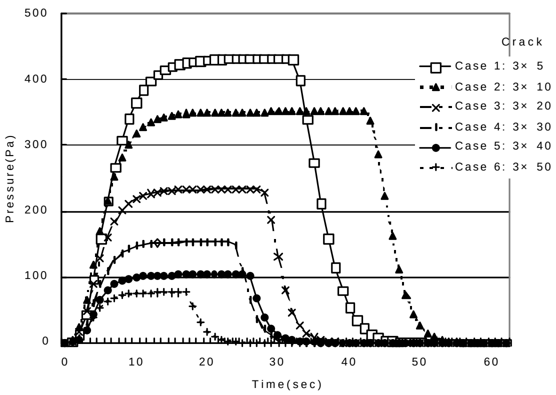


Figure 2 Pressure decay for several size of cracks

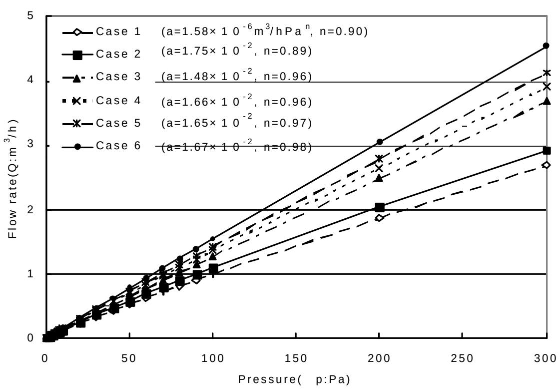


Figure 3 Leakage equations by experiment

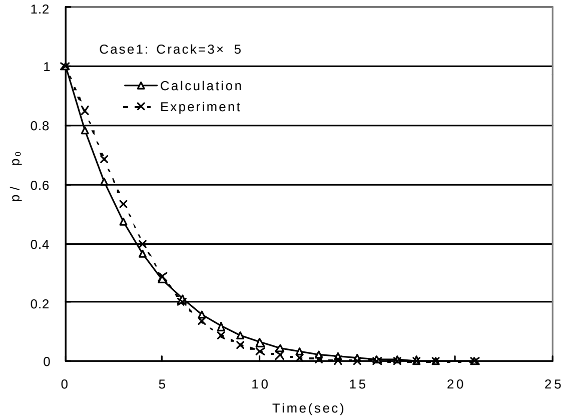


Figure 4 Pressure decay Case 1

fitting the measure data of pressure decay. The figure clearly shows that as the size of the crack increases, the rate of the leakage increases. The leakage parameters *a* and *n* found by using standard linear regression methods are shown in Table 2. Parameter *a* increases and parameter *n* decreases with crack size increase.

Figures 4 through Figure 9 illustrate a comparison between the calculated and the experimental values of pressure decay. The calculations are obtained from Equation 9 using the leakage parameters in Table 3.

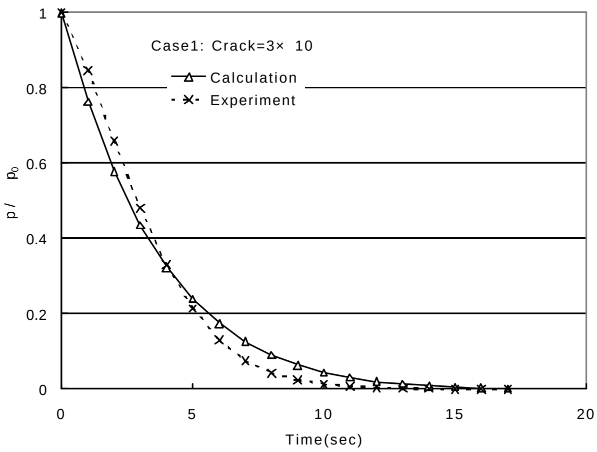


Figure 5 Pressure decay Case 2

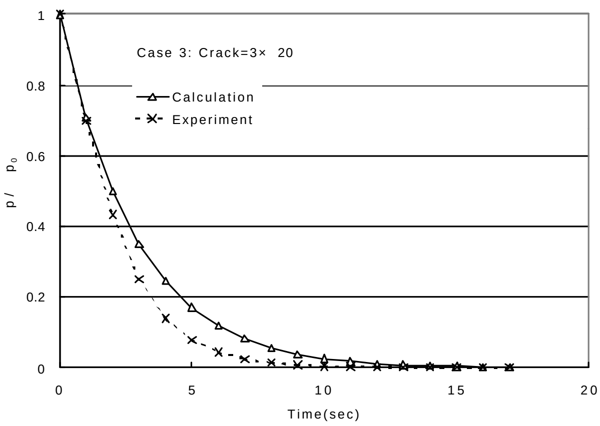


Figure 6 Pressure decay Case 3

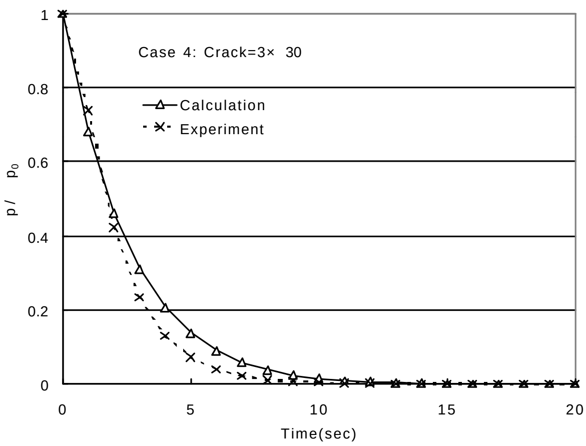


Figure 7 Pressure decay Case 4

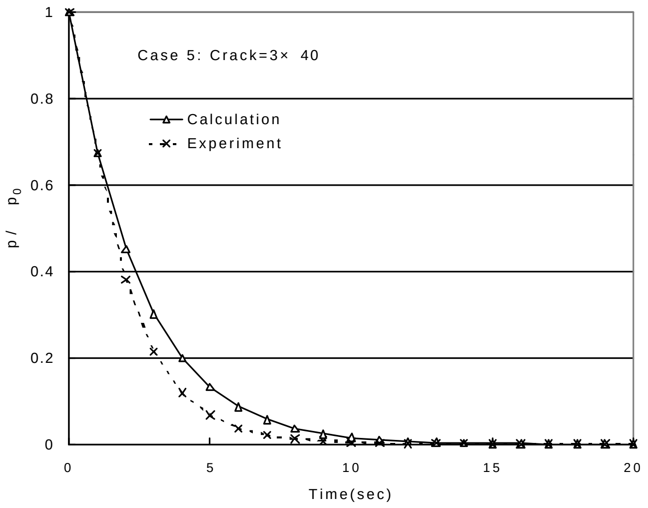


Figure 8 Pressure decay Case 5

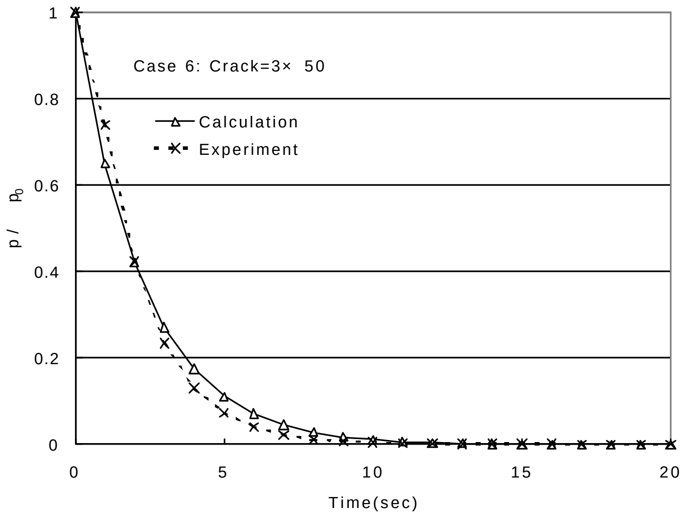


Figure 9 Pressure decay Case 6

5 CONCLUSION

Decay methods are used to calculate the air leakage through the building envelope. The decay equation is presented and the experiments were conducted in the test box. Five sizes of leakage cracks were measured with the test box, and the leakage equations of these cracks were established. The calculated pressure decay values were compared with those of the experiment. The respective values were in very good agree Thus, this method is proved to be practical and useful.

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