IS-2

Experiment and Evaluation of Building Drainage System and Low Water-Consumption Sanitary Facilities in Taiwan

Dr Wen-Hung, Lu (Architecture & Building Research Institute, M.O.I.)
Professor Cheng-Li Cheng (National Taiwan University of Science and Technology, NTUST)
Ms Chia-Ju Yen (National Taiwan University of Science and Technology, NTUST)

1. INTRODUCTION

The drainage system within a building affects the healthiness and comfort of our living environment greatly. Improper sanitary equipments and vertical drainage stack design can easily affect the performance of the drainage pipes. In effect, the sanitary equipments can no longer contain the trap and therefore diseases, such as SARS that took place not so long ago, can transmit along the pipes to different parts of the building. We can no longer ignore the hidden problems related to the performance of architectural drainage system. The performance of air pressure distribution in drainage system, trap seal water strength, and waste soluds transport in horizontal pipe line, what are widely used in Taiwan, needed to be confirmed step by step. As the previous research shown in the International SARS Symposium, the function of drainage system in a building should be permitted, especially the influence from the discharge in a drainage stack. (Julius, 2004) This paper showed the researches on the healthy issues of buildings which recently proceeded in Taiwan.

2. THEORETICAL REVIEWS

Appliance discharges to a vertical drain stack may be described as an unsteady or time dependent flow. The appliance discharge flow form contributes to this flow condition (Swaffield and Cambell, 1995). An actual vertical drainage stack discharge has a complex phenomenon and may consist of triple phase flow features incorporating solids, liquids and air. Airflow in the drainage stack is promoted by through-flow mixing and the friction interaction between falling water and air. This mechanism causes negative pressure in the upper floors and positive pressure in the lower floors in the building vertical drainage system. Figure 1 illustrates the flow state and modified interaction. The main parameters, air pressure, airflow rate and the resistance coefficients, are the essential factors for the air pressure distribution model in a vertical drainage stack.

The National Plumbing Code (NPC) guidelines from the US were used to set the permitted flow rate for drainage system regulations (Wyly and Eaton, 1961). Following initial HASS 203 work from Japan in the 1970s, the steady flow condition method was merged as the reference provision and evaluation technique. Hence, a series of researches on the steady flow method with reference to building drainage networks were conducted. An air pressure distribution prediction model for drainage stacks in high-rise (108m), (Cheng et al., 1996) and medium-height (30m) experiment towers (Ohtsuka, 1988a; Ohtsuka, 1988b) was developed in Japan in 1985. Considerable progress has been made in predicting the air pressure distribution within a vertical drainage stack.

According to the vertical drainage flow stack feature from the theoretical reviews, the drainage stack profile was divided into four zones, shown in the following diagram, Figure 2. Each zone is individually
modeled due to the corresponding characteristics. The air pressure distribution, which reveals the time average air pressure data with steady flow condition, does not involve instantaneous air pressure fluctuations in vertical drainage flow. The features of each zone are described in the following.

As an empirical approach of our previous researches, the experimental parameters have been firstly determined. According to the arranged calculation procedure, the drag coefficients of each zones (ξA, ξB, ξD) may be calculated, then the air pressures distribution of each zones can be determined. (Cheng and Lu, 2005)

Figure 1 Vertical drainage features and inverted model mechanism

Figure 2 Air pressure distribution zone profile in a drainage stack

3. EXPERIMENT AND INITIAL RESULTS

3.1 2-pipes Stack Drainage System Experimental Device of NTUST

At the first, in order to conduct a calculation system and verify the prediction model, this paper following the previous study performed an experiment upon a full-scale drainage experimental tower, which is adhered to a real building of 40 m height can simulate a drainage system within a medium-height apartment houses around 12 floors height. Following the results of the previous investigation and experiment of single drainage stack, the device had been modified to a 2-pipes stack drainage system for conducting the empirical parameter and evaluation method of air pressure distribution in a vertical drainage stack. (Lu et al., 2004) The experimental devices are shown in Figure 3. The diameter of the vent stack pipe was φ75mm, and the relief vent pipe was φ50mm. Hence, the vent loops in 2-pipes stack drainage system can be dominated. When all the ball valves closed, it can simulate as a single stack drainage system (Type O). All types of the drainage and vent loop are shown in Figure 4.
3.2 Experimental Tower and Devices of ABRI

Another experiments were performed on an experimental tower 16.5 m in height at ABRI. There are 5 floors, 3 kinds of drainage system, 4 sets of moving unit bath (UB), and the water supply system in this experimental tower. Figure 5 showed the layout and views of this experimental tower. The experimental device details and drainage system were shown in Figure 6. The diameter of the stack pipe was $\varphi 100$mm, the building drain pipe was $\varphi 125$mm, the horizontal fixture drain branch (branch pipe) was $\varphi 75$mm, the vent stack pipe of 2-pipes system was $\varphi 75$mm, and the relief vent pipe was $\varphi 50$mm. The stack pipe was connected to the drainage pipe using a typical joint to view the hydraulic jump effect. The drainage pipe was set straight and opened to the air. As the initial results of 3 kinds of experimental drainage system shown, the air pressure distribution of single stack system is following the previous theory.

On the other hand, the waste solids transport in a horizontal pipe strongly influences the performance of building drainage system. The device of waste solids transport is also constructed in this experimental tower. The pipe network can combine with the drainage system, including toilets, branch pipe, vertical stack, and the water supply system. Beside the device of the tower, there is also a branch pipe system for the sub-item of this research, shown as Figure 7.

Figure 3 Schematic diagram of 2-pipes drainage experimental tower of NTUST

Figure 4 Ventilation configurations of the combination types of 2-pipes building drainage system

Figure 5 The layout of the lower experimental tower of ABRI

Figure 6 The position of discharge and testing sample insert of seal water strength

Figure 7 The position of discharge and testing sample insert of seal water strength
4. Determination of the experiments and analysis

4.1 Determination of Prediction Method of Air Pressure of 2-pipes Stack Drainage System

Following the prediction model to predict air pressure distribution of single drainage stack system (Lu et al., 2002), this section focuses on the prediction method of air pressure of 2-pipes stack drainage system for different vent loop types. As the experimental results shown in Figure 8, the difference of the values of air pressure relates to the air flow circuit. The total air pressure difference value ($P_t = P_A + P_B + P_D$) and the peak negative pressure value ($P_{p-neg} = P_A + P_B$), can be set as components for air pressure reduction tendency analysis in stack. Figure 9 illustrates the air pressure reduction ratio of 2-pipes vertical drainage and vent stack system to single vertical drainage stack system.

The air pressure distribution of single drainage stack system should be predicted in the beginning. According to the tendency of air pressure reduction ratio, the values of air pressure difference relate to the air flow circuit. Following the reproduction of the prediction theory and the established device of single stack drainage experimental tower and by the prediction results of air pressure distribution in a single stack drainage system, the air pressure of 2-pipe stack drainage system could be calculated through pressure reduction ratio between single and 2-pipe stack drainage system. Comparison of measured air pressure distribution in the stack with the predicted results can be conducted to verify the accuracy of the prediction model.

---

Figure 7 The layout of horizontal drainage pipes for waste solids transport of ABRI's experimental tower

Figure 8 Profile of the relation of air pressure difference in a drainage stack

Figure 9 Profile of the air pressure difference between $T_0$ and $T_n$
pressure distribution results reveal that air pressure difference reduction ratio depends on different vent loop types. Hence, an effective design of drainage and vent loop would reduce the peak value of the air pressure in drainage stack and prevent the destruction of water trap seal.

Herein, the verification of this prediction method using experimental data, reproduction of the performance in the boundary conditions for these experimental device types (168 water discharge test patterns for each vent loop type, including discharge floors from 6F to 12F and water flow rates from 1.0 to 4.0 l/s) will thus emphasized. The air pressure values for $P_h$, $P_{\text{neg}}$, $P_A$, $P_B$ and $P_D$ in 2-pipe stack drainage depending on the vent loop type to verify the reliability of this prediction model can be reproduced. These results reveal that the calculation procedure can approximately be used to reproduce the experimental data for air pressure in 2-pipe stack drainage system for each vent loop type, and the deviations were acceptable under the designed experimental conditions. Figure 10 to Figure 14 Therefore, the methodology of air pressure prediction for 2-pipes stack drainage systems are determined under steady and sequential discharge conditions.

![Figure 10 Verification of $P_1$ (T5), results calculated via Type 0](image)

![Figure 11 Verification of $P_B$ (T5), results calculated via Type 0](image)

![Figure 12 Verification of $P_{\text{neg}}$(T5), results calculated via Type 0](image)

![Figure 13 Comparison profile of Type 1 (discharge from 10F)](image)

![Figure 14 Comparison profile of Type 5 (discharge from 10F)](image)

**4.2 Evaluation on the Trap Seal Water Performance of Floor Drains**

Secondly, this research developed a testing process within single stack system to confirm the trap seal water strength. Four points of air pressure were measured on floors 2-5 of each individual system, respectively. Therefore, the testing sample had been inserted at the branch pipe of 2F (positive pressure zone) and 4F (negative pressure zone). The water was discharged from 5F and continuous, and the flow
rate increased per 0.1 l/s until the trap seal water losing its function, shown as Figure 6. By the structure of previous drain samples, this research also developed 8 drain models designed for the experiments. The designed trap seal water depth was between 15 mm with 80 mm. Therefore, the effective depth of trap seal water was between 10 mm with 60 mm, shown in Table 1.

Table 1 Dimension of the experimental models of designed floor drain[8][9]

<table>
<thead>
<tr>
<th>Type of floor drain</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net weight of total seal water (g)</td>
<td>36.3</td>
<td>89.2</td>
<td>176.1</td>
<td>166.5</td>
<td>186.5</td>
<td>320</td>
<td>131.7</td>
<td>35.8</td>
</tr>
<tr>
<td>Weight of effective seal water (g)</td>
<td>24.1</td>
<td>42.2</td>
<td>80.9</td>
<td>118.5</td>
<td>92.7</td>
<td>88.8</td>
<td>60.3</td>
<td>12.6</td>
</tr>
<tr>
<td>Depth of effective seal water (mm)</td>
<td>10</td>
<td>20</td>
<td>40</td>
<td>60</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>10</td>
</tr>
</tbody>
</table>

Following the previous process, the trap seal water strength of each designed drain model had been tested in single stack system of the lower experimental tower individually. The results of trap seal water strength of model B indicates that the effective trap seal water losing in negative pressure zone was under the discharge flow rate 2.7 l/s, and the sample side air pressure was about −10.1 mmAq. In positive pressure zone, trap seal water was losing under the discharge flow rate 2.6 l/s, and the sample side air pressure was about −1.8 mmAq due to the resonance effect of trap seal water vibration. At the same time, by the initial results of trap seal water vaporizing rate, this research had also analyzed the relation between vaporizing rates with opening area of drain samples as Figure 15 and Equation (1) shown. The vaporizing rate (VpR) depended on the opening area of drain. While the weight of effective trap seal water and the vaporizing rate been measured, the time of seal water natural vaporizing until trap function losing could be calculated by Equation (2).

\[ VpR = 0.0029 \times A \]  
\[ T(Vp) = \frac{W_i}{VpR} \]

VpR : natural vaporizing rate of trap seal water (g/Hr)  
A : opening area of floor drains for vaporizing (mm²)  
W_i : weight of effective seal water ensuring the trap seal function (g)  
T(Vp) : time of seal water natural vaporizing until trap function losing (Hr)

By the initial results of trap seal water strength of drain models, this research had also analyzed relation between strength with their effective trap seal water depths as Figure 16 to Figure 17, and Equation (3) to Equation (4) shown. The trap seal water strength (Ssw) depended on the effective seal water depth of drain. Because of the resonance effect, the trap seal water strength of positive pressure zone was different from that of negative pressure zone. Following the regression equation, the strength of trap seal water until trap function losing could be calculated by their effective seal water depth.

\[ Ssw (N) = -0.6058 \times Dsw \]  
\[ Ssw (P) = -0.1114 \times Dsw \]

Ssw (N) : strength of seal water (negative pressure zone) (mmAq)  
Ssw (P) : strength of seal water (positive pressure zone) (mmAq)  
Dsw : depth of effective seal water (mm)
4.3 Evaluation of Waste Solids Transport in Horizontal Pipes of Building Drainage System

Taiwan has been listed on the lacking of water country by the United Nations. During the period of waterless conditions, the saving water policies has adopted not only by new buildings but also office building and residence house in generally. Obviously, using the lower volume closet had proved effectively. But that may cause other difficulty of ordure and waste solids transport performance in drainage system when decreasing flush volume twice as much. This section focuses on the lower volume closet waste transport performance and the regulation, which was used for 30 years, revised to lead into the lower volume closet. Consequently, this research has gotten preliminary results as below. The amount of the lower volume closet has increase enormously by government/manufacturer saving water policy and the user’s aware. The agenda of flush volume reduce which may cause the problem in drainage. The performance of distance influence by pipe caliber, pipe slope, flushes volume and so on. In main drain, the waste solid transport distance of the lower volume closet is 2.6 (±0.66) meters which 4 meters below than general water closet. In offset drain, the distance of the lower volume closet is 10.8 (±1.5) meters. The effect of pipe slope is more than pipe diameter. The regulation was suggested to set up the suitable range of pipe distance and slope. The measured results of waste solids transport in the main drain by general water closet and lower volume water closet are shown as Figure 18 and Figure 19.
5. DISCUSSION

First of all, there are 2 full-scaled experimental towers established following the tendency of building drainage system to simulate actual water discharge here in Taiwan. Following the single stack prediction theory, an experimental pipe system was modified to provide empirical parameters and model verification at NTUST. The first section focused on an empirical approach to air pressure prediction in 2-pipes vertical drainage and vent stacks system, which is widely used in Taiwan. Depending on the vent loop types connecting drainage to vent stacks, five types of drainage and vent stack system were designed for simulation. By the experiment and the comparisons results, a prediction method for air pressure distribution in 2-pipes stack drainage system was developed. The air pressure in 2-pipes vertical drainage stack of each vent loop type from the predicted air pressure distribution of single drainage stack could be reproduced. Verification on the reproduction results revealed that the prediction model was acceptable under the designed experimental conditions.

And the next, in order to determine the performance of each floor drain, we study the vaporizing rate of the trap seal water and the seal water strength by the experimental tower established at ABRI. There developed several kinds of floor drain in this research. Meanwhile, the tendency of seal water vaporizing rate and the relation between seal water depth and strength had been confirmed. At the same time, part of the performance testing methods and processes for the sanitary, such as floor drain, had been confirmed. With the results of the experiments and investigation, we had deliberated proper methods and standard process that suit our technical developments and sanitary testing for architectural drainage systems.

Using the lower volume closet may cause other difficulty of ordure and waste solids transport performance in drainage system when decreasing flush volume twice as much. The amount of the lower volume closet has increase enormously by government/manufacturer saving water policy and the user’s aware in Taiwan. The agenda of flush volume reduce which may cause the problem in drainage. The performance of waste solid transport influence by pipe caliber, pipe slope, flushes volume and so on.

6. Conclusions

The most important function of the building drainage system is to ensure proper drainage and to keep a clean and sanitary condition for human's life. The gravity drainage system without any energy supply is commonly used in building all over the world, and the trap with simple structure is also preferred to set as a critical part for most of sanitary facilities because of its easy elimination of stench and vermin. An actual discharge of a drainage pipe has a complex phenomenon and may consist of water, air and solids.
The main proposes of this research is to study the drainage theory system and to introduce the experimental system at NTUST and ABRI in Taiwan. Meanwhile, parts of the performance evaluation methods for building drainage system are developed. And these methods had finally been confirmed, that can be applied to the drainage design work.

In the near future, a basic theory system of building drainage design could be offered, and that would promote the building quality and better domestic living. More studies including appliance discharges with unsteady flow and multiple water discharge points must be conducted to provide practical information and reference for future building regulation.

Nomenclature

\[\begin{align*}
\text{Ah} & : \text{length from the top of stack vent pipe to the discharge height (m)} \\
P_A & : \text{pressure of A zone} \\
P_B & : \text{pressure of B zone} \\
P_D & : \text{pressure of D zone} \\
\gamma & : \text{specific weight of air (kgf/m}^3) \\
V_x & : \text{velocity of air flow at stack vent (m/s)} \\
Q_A & : \text{air flow rate in stack vent (m}^3\text{/s)} \\
Ssw(N) & : \text{strength of seal water (negative pressure zone)} \\
Ssw(P) & : \text{strength of seal water (positive pressure zone)} \\
Dsw & : \text{depth of effective seal water (mm)} \\
Wi & : \text{maximum weight of seal water ensuring the trap seal function (g)} \\
T(Vp) & : \text{time of seal water natural vaporizing until trap function losing (Hr)} \\
Q_s & : \text{water flow rate (V/s)} \\
\xi_A & : \text{drag coefficient of A zone} \\
\xi_B & : \text{drag coefficient of B zone} \\
\xi_D & : \text{drag coefficient of D Zone} \\
CB & : \text{constant pressure gradient (mmAq/m)} \\
g & : \text{acceleration of gravity (m/s}^2) \\
FL & : \text{Discharge floor height (m)} \\
L & : \text{Length scale of the B zone (m)} \\
C_L & : \text{Constant of L} \\
VpR & : \text{rate of seal water natural vaporizing (g/Hr)} \\
A & : \text{opening area of floor drains for vaporizing possible (mm}^2) \\
\end{align*}\]

REFERENCES

3. Julius Ballanco, 2004, "Floor Drain Trap Seal Protection", DVD of the International SARS Symposium, Disk #2, part 1


Main author presentation

Lu Wen-Hung is an associate researcher of the Architecture & Building Research Institute, Ministry of the Interior, R.O.C. Dr Lu graduated with a PhD from the National Taiwan University of Science and Technology, and his research focuses on drainage systems for buildings, and energy conservation in the specification of building materials.

Cheng-Li Cheng is the Professor at National Taiwan University of Science and Technology, Department of Architecture. He is a researcher and published widely on a range of water supply and drainage in building. Currently he also acts as referee of Taiwan Green Building Evaluation Committee and Nation Building Code Review Committee.

Chia-Ju Yen is a Ph.D student majoring in drainage system at National Taiwan University of Science and Technology, Department of Architecture. She is also interested in sustainable building.