Numerical Analysis of Induced Siphonage in P Trap

Kyosuke Sakaue (*MEIJI Univ., Japan*)

K. Fujimura, T. Miotsuaga

1. Introduction

Trap with seal water

◇**Purpose of Trap:** Seal water in trap plays a crucial role in preventing foul-smelling toxic gas in drainage pipes from entering indoors.

◇**Design Condition:** It is a design condition of drainage systems to prevent the seal break.

Seal break Phenomenon

◆**Induced sihonage**: Important of the phenomena associated with seal loss. It is that seal water rapidly in response to air pressure fluctuation in drain and gets lost. → Dynamic phenomenon

Design method (Prevention method for seal break)

◇**Premise:** Static proportional relationship between discharge flow rate, air pressure and seal loss is the premise of design methods.

◇**Methods:** ① Relaxation of Air pressure in drain → Secure air flow in drain:

○Method of determining pipe diameter, ○Installation of vet pipes

② Definition of seal strength: ○Minimum seal depth

◆ **Review premise:** Static relationship sould be reconsidered into dynamic relationship.

In this study the authors derived a motion equation for seal water fluctuations in response to pressure fluctuations in P trap, and analyzed the validity of the equation based on pressure and seal water fluctuation data collected from a discharge experiment conducted in a 15-story experimental tower.

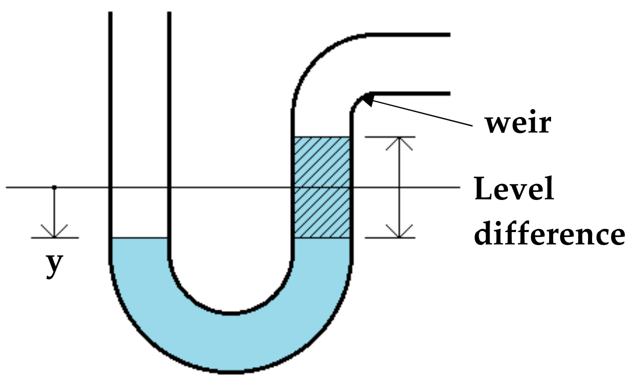
2. Motion equation for seal water fluctuation

Free vibration

The law of conservation of momentum can be applied to seal water vibration, is shown as eq. (1). As shown in Figure 1, the falling mass of water that amounts to the water levels between the trap legs constitutes the power of resistance.

The eq. (1) represents the motion equation for seal water fluctuations where the water level is y and damping coefficient is c. The damping coefficient c is determined from the eq. (3) with critical damping coefficient c_c and damping ratio ζ.

The damping ratio ζ is obtained from logarithmic decrement σ in the eq. (4).



$$\rho A L d^2 y/dt^2 + c\,dy/dt + 2\rho A g\, y = 0 \quad (1)$$

$$c_c = 2((\rho A L)\cdot(2\rho A g))^{1/2} \quad (2)$$

$$c = \zeta \cdot c_c \quad (3)$$

$$\zeta = \sigma/2\pi \quad (4)$$

$$f = ((2\rho A g)/(\rho A L)/(2\pi))^{1/2} \quad (5)$$

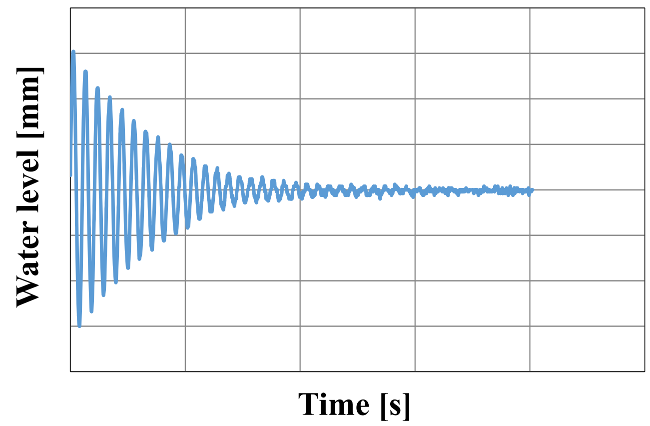


Fig. 1 Model of seal water fluctuation

Fig. 2 Free vibration (Experiment)

3. Numerical analysis of motion equation

Forced vibration

Fluctuations of seal water in trap is a forced vibration phenomenon that changes in response to air

$$\rho A L d^2 y/dt^2 + c dy/dt + 2\rho A g\, y - AP\ 0 \qquad (6)$$

Numerical analysis of motion equation

Seal loss occurs when the top of seal water in the outlet leg overflows the weir of a trap. When this happens, the mass of seal water is reduced and it must be dealt with as an **unsteady phenomenon**.

As a general solution cannot be obtained for an unsteady phenomenon, the numerical calculation method must be applied. We applied the **Runge-Kutta** method as a numerical calculation method, and used **EXCEL VBA**.

The damping coefficient c of 0.076 obtained from the preliminary experiment was applied and seal water fluctuation was simulated using air pressure fluctuations data from the experiment.

3. Numerical analysis of motion equation

Time-step

Time-step plays an important role in attaining accuracy in analysis. Therefore, appropriate time-step must be established based on the free vibration wave patterns of seal water.

Table 1 shows the results of analysis at time-steps, logarithmic decrement σ and damping ratio ζ obtained from the equation (6).

As ζ when ts＝0.025 was the closest to the experimental results, this value was used in subsequent calculation.

parameter	Simulation					Experiment
time step T_s [s]	0.01	0.025	0.05	0.075	0.1	-
logarithmic decrement σ [-]	0.0476	0.139	0.182	0.230	0.375	0.139
damping ratio ζ [-]	0.00758	0.0218	0.0290	0.0368	0.0568	0.222

Seal loss rate

Seal loss occurs when water level in the outlet leg flows over the dip. The loss rate depends on how large the water level fluctuations are.

As it is difficult to simulate the actual water level conditions, we estimated as follows.

$\gamma = 0.001$ when $y_{max} < 8mm$, $\gamma = 0.1$ when $8mm \leqq y_{max} < 15$, $\gamma = 0.8$ when $y_{max} \leqq 1$

4. Discharge experiment o induced siphonage

We constructed a stack vent drainage system with special drainage fittings in a 16-story experimental tower and conducted a discharge experiment to obtain data on fluctuations of pressures in drain and seal water in actual drainage situation.

The experimental drainage system is shown in Figure 3. Stacks with 100 A diameters and horizontal branches with 50 A diameters were used in the experiment. PVC traps were placed on the 9th floor.

Constant discharges (1.5, 4.5 L/s) and fixture discharge (1 WC and 3WC) were made. Constant discharges were made from the floors 14 and 15, fixture discharges form the floors 13 ~ 15. Average flow rate of fixture discharge from WC q_d was 2.2L/s.

Table 2 Shape parameters of P trap

diameter	Cross-sectional area	Seal depth	volume
0.03m	$7.1 \times 10^{-4} m^3$	0.05m	150mL

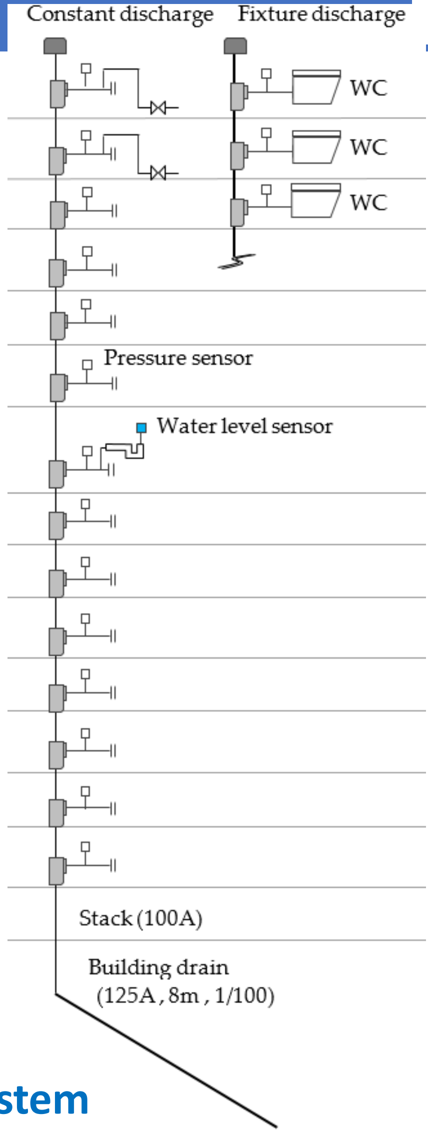


Fig. 3 Experimental drainage system

Pressure fluctuation in drain and seal water fluctuation

Experimental results of air pressure fluctuations (Pa) in drain, and experimental and simulated results of seal water fluctuation (mm) with constant discharge of 1.5 L/s and 4.5L/s, and fixture discharge with 1 WC and 3WC are shown in Figure 4.

Experimental and simulated results of seal water fluctuation indicated the similar trend in response to fluctuation of air pressure in drain.

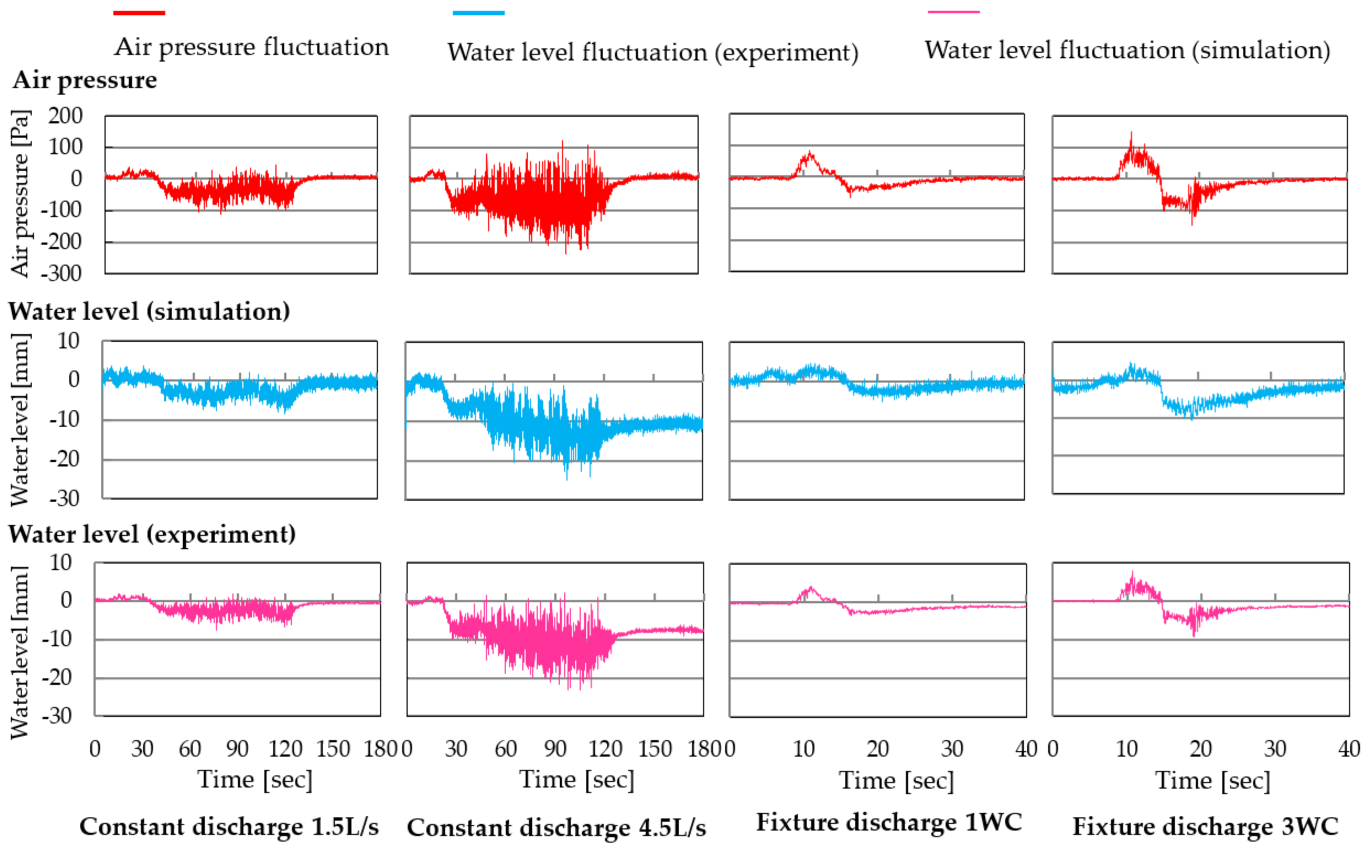


Fig. 4 Experimentl results of air pressure fluctuation and experimental and simulated results of seal water fluctuation

5. Validation of simulated results

Maximum and minimum air pressure and water level in simulation were a 10% smaller than those in experiment.

However, maximum seal water level with constant discharge of 4.5 L/s only showed larger values than maximum negative pressure in drain. This seems to indicate that some type of resonance phenomenon had occurred.

Table 3 Maximum and minimum values of seal water level and seal loss

Discharge load		Air pressure [mm Aq]		Water level [mm]				Seal loss [mm]	
				Experiment		Simulation		Experiment	Simulation
		Max	Min	Max	Min	Max	Min		
Constant discharge	1.5L/s	4.5	-11.0	3.8	-8.5	1.9	-7.5	0.08	0.7
	4.5L/s	12.2	-23.8	2.5	-24.9	2.1	-23.2	11.6	6.2
Fixture discharge	1WC	8.4	-6.6	4.7	-5.1	4.0	-3.8	0.9	0.7
	3WC	14.9	-14.8	4.6	-10.7	6.9	-9.2	1.9	1.6

<u>*Power spectrum iof pressure in drain and seal water fluctuation*</u>4.

Power spectrum distributions of air pressure and seal water fluctuation with constant discharge of 1.5 L/s and 4.5L/s, and fixture discharge with 1 WC are shown in Fig. 5.

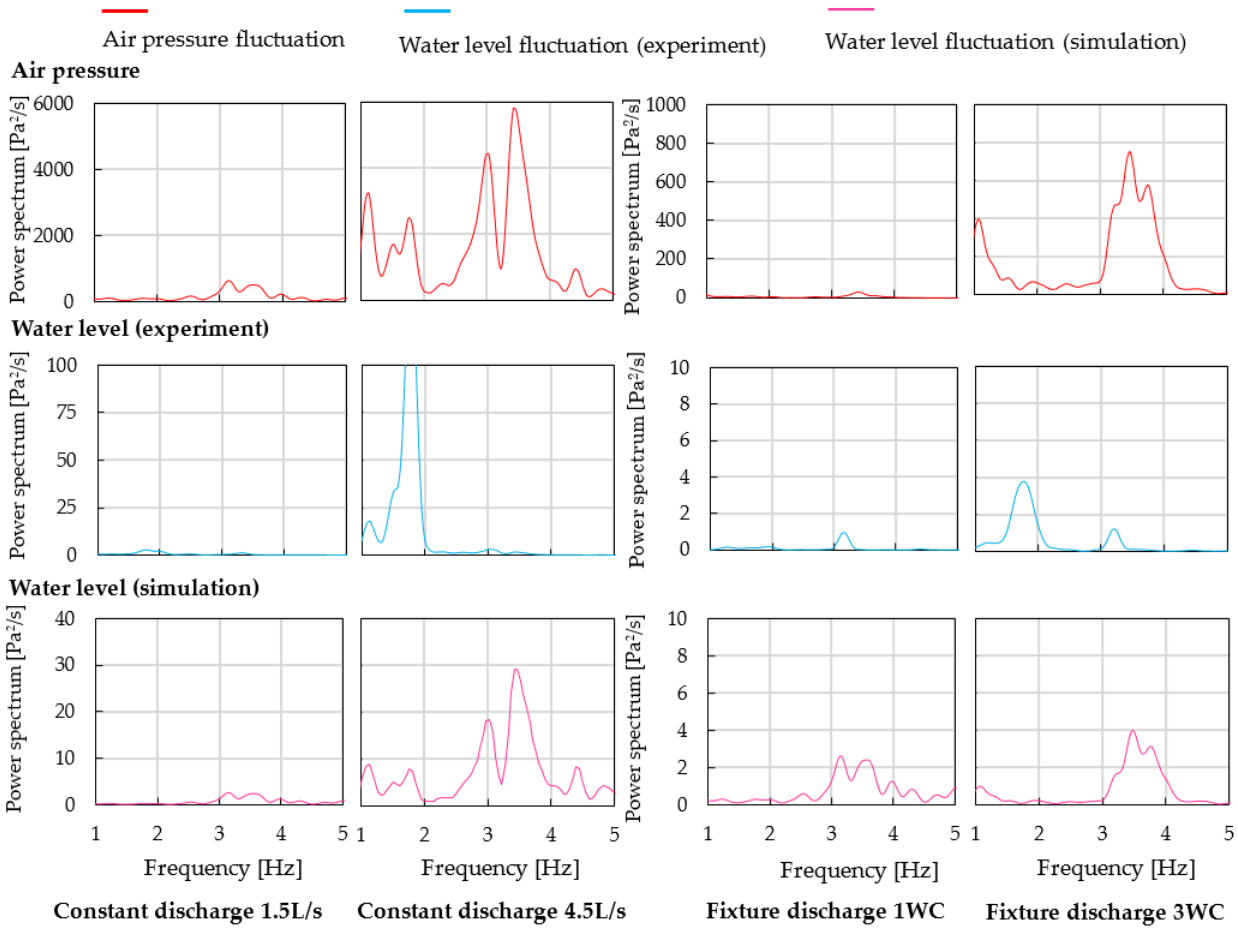


Fig. 5 Power spectrum distribution of air pressure and seal water fluctuation

5. Validation of simulated results

Dominant frequency of air pressure fluctuation with constant discharge of 1.5 L/s and 4.5L/s, and fixture discharge with 1 WC in Experiment shown in Table 4.

Table 4 Dominant frequency of air pressure fluctuation

Dominant frequency [Hz]	Constant discharge		Fixture discharge	
	1.5L/s	4.5L/s	1WC	3WC
The first	3.17	3.42	1.22	3.47
The second	3.56	3.03	6.59	3.22
The third	3.96	1.12	3.47	3.76
The fourth	2.54	1.78	2.25	1.07
The fifth	4.3	1.51	2.0	1.51

5. Validation of simulated results

The power spectrum distribution of simulated seal fluctuation corresponds to that of pressure in drain. Experimental dominant frequencies in the seal water power spectrum distribution 3.2 ~ 3.5 Hz is roughly identical to those of pressure in drain.

The first dominant frequency of seal water fluctuation at the constant discharge flow rate of 4.5 L/s was 1.76 Hz, which roughly corresponds to the natural frequency of trap. This also confirms that partial resonance phenomena had occurred.

Table 5 Dominant frequency of seal water fluctuation

Dominant frequency [Hz]	Constant discharge				Fixture discharge			
	1.5L/s		4.5L/s		1WC		3WC	
	Exp.	Sim.	Expt.	Sim.	Expt.	Sim.	Expt.	sim.
The first	1.81	3.17	1.76	3.42	3.17	3.47	1.75	3.47
The second	3.32	3.56	1.12	3.03	-	1.22	3.22	3.76
The third	1.22	4.0	3.02	1.12	-	2.25	1.12	1.07
The Fourth	-	4.3	2.29	4.39	-	4.05	-	1.95
The fiffth	-	2.54	3.42	1.76		4.88	-	1.51

6. Conclusion

The results of analysis can be summarized as follows.

(1) The trend of simulated seal water fluctuation roughly corresponded to experimental data.
(2) Simulated maximum and minimum seal water level, and seal depth were 10 to 20% smaller than experimental data.
(3) The first and second dominant frequencies of pressure in drain fluctuation fell in the range of 3.0～3.6Hz except for fixture discharge with 1 WC.
(4) The simulated power spectrum distribution of seal water fluctuation resembled to that of pressure in drain.
(5) Partial resonance phenomena seem to have occurred in constant discharge load of 4.5 L/s as the maximum water level exceeded the maximum negative pressure (water head) in experiment. This has been confirmed by the analysis of the power spectrum, but the simulation analysis failed to give any supportive evidence to this finding.

Based on these we can safely conclude that our simulation was validated in its application. As for (2) and (5), small damping coefficient may have contributed to the results. Along with seal loss rate, it prompts future studies.