Performance Evaluation Method for Drainage Piping Systems with Food Disposers in Actual High-Rise Apartment Houses

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Abstract
Regarding drainage piping systems with food disposers in actual super high-rise apartment houses with a height 100m, results were acquired from the experiments for the initial performance evaluation before habitation as well as the running performance evaluation by drainage load prediction after habitation. The knowledge, which contributed to a performance test, was also acquired. Before habitation, the maximum number of 6 simultaneous units of garbage wastewater, bowl flushing water, etc. was loaded. The maximum and minimum air pressure values in pipes were checked in line with the performance criteria of SHASE-S, and the safety of the initial performance was also verified. After habitation, the maximum number of simultaneous drainages was predicted and it was found that the figure recorded at the time of the initial performance verification was satisfactory. Moreover, the running pressure values in 99% of the occurrence probability were acquired, and the safety of running performance was also verified. Furthermore, the relation between the house drain’s water level as a drainage load index and the pressure was determined, and as a result of comparison of pre-habitation and post-habitation, it was confirmed that there was no significant performance deterioration caused by long-term use.

Keywords: drainage piping system; food disposers; high-rise apartment houses; performance evaluation; actual building

1. Introduction
In Japan, some redevelopment projects are currently underway mainly in urban districts, and as part of this, super high-rise apartment houses are being built, maximizing the use of land. The application of wastewater treatment systems with food disposers, which are garbage processing equipment, is particularly applicable in super high-rise apartment houses not only for the efficiency of conveyance but also for environmental protection which results from reducing the quantity of trash. The purpose of this study is to evaluate and verify the drainage pipe performance of such systems. We implemented the performance evaluation using a super high-rise experimental tower, and investigated the drainage pipe performance when influenced by the system components, such as drainage stack fittings and the like and different food disposers while acquiring the knowledge which contributed to the designing of the system1). Moreover, the design and construction of the system is based on this knowledge. In order to check the practicality of the experiments results, it is necessary that the drainage performance be evaluated using an actual building.

It is considered that the drainage performance in an actual building is classified in two kinds depending on the time. The first one is the initial performance upon construction completion before habitation. The second one is the running performance in a certain period after habitation starts, since slime adheres in pipes with long-term use and the performance deteriorates. In order to quantify the input conditions of this running performance, it is important to assume the drainage load quantity with habitant’s use2). However, there is almost no concrete study indicating the initial and running performance evaluation methods, which are needed with actual buildings. Therefore, in this paper, the experiment for a series of performance evaluations was performed by using actual super high-rise apartment houses. The purpose of this paper is to show the important knowledge gained from the results of a performance test.

2. Experimental method
2.1. Test drainage system
The experiment was performed using high-rise apartment houses (a total of 42 floors above ground, 354 houses with the maximum height of 157m), which are
situated in Minato-ku, Tokyo. A test drainage system is shown in Fig.1. The piping system employs a stack vent system and the height of the drainage stack is 123.7m. The 1st house drain with a length of 7.4m is connected to the drainage stack and the 2nd house drain with a length of 59.1m is connected to the end of the 1st house drain. Food disposers with which median diameter of ground garbage is under 0.6mm, are installed in the drainage system. A total of 35 sinks with the food disposers from all floor are connected to the 1st house drain and only the kitchen drain flows through the pipework.

As for the details of each part, (a) illustrates the horizontal fixture drain branch plans, (b) displays the drainage fitting, the bent fitting at the stack closure is shown by (c), and the 1st house drain plan by (d) in the figure. The drainage fitting is a special drainage fitting of a circular drain type, and is the same as that of reference 1). When comparing results, this reference with a drainage stack height of 93m and a house drain at a length of 107m was quoted.

2.2. Experimental conditions

The experiment was performed in two parts; the experiment before habitation (1) and the experiment after habitation (2).

(1) The experiment before habitation: Conditions of the experiment before habitation are shown in Table 1. The maximum simultaneous drainage number was 6 calculated by the same method as used in the reference1). Garbage wastewater, after 250g garbage was supplied in each food disposer, was drained with supply water simultaneously with the start of grinding. As for the drain of clear water only, 6L water stored in the bowl as one unit was drained as bowl flushing water, and tap running water was drained by constant flow at a flow rate of 0.2L/(s·unit). In these three kinds of drainage, each drainage was loaded with 1~6 simultaneous drainage units from the upper floors, the middle floors and the lower floors.

(2) The experiment after habitation: Conditions of the experiment after habitation are shown in Table 2. After 19 months since the start of habitation, the measurement was carried out for 28 days. The habitation conditions during this period of time were 25 houses out of fully occupied 35 houses. Moreover, average water use was 206L/(d·man) as the result of reading water gauges. This value fell within the limit of 200 to 350 L/(d·man), which is water supply quantity for a design of apartment houses and is specified by the reference5). Thus, as there is a generality in the resident’s use of water, it is suggested that the experiment data is realistic.

2.3. Measurement method

The measurement was narrowed to three items; (1) pipe pressure, (2) water level in a pipe and (3) transport condition. The measurement system is shown in Fig.3. (1) Pipe pressure: Pressure sensors were installed in the drainage stack of the 7th, 19th, 27th and 32nd floors. The maximum positive pressure and the minimum negative pressure of each floor were read in the pressure

![Fig.1. Test drainage system](image-url)
changes of each floor. The maximum system pressure value and the minimum system pressure value were read in these pressures, and it verified that these values were within the performance criteria of ±400Pa in compliance with the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan (SHASE) Standard 218 ⑴.

(2) Water level in the pipe: A water level sensor employing an ultrasound method was installed in the upper part of the 1st house drain (Fig.1. (d)). According to the reference 2), the drainage frequency was read in the water level changes using the method shown in Fig.3. Drainage with a water level over 5mm was counted as 1 time. When drainage overlapped with another steady drainage, like the 5th drainage overlapped with the 4th drainage shown in this figure, they were counted respectively as 1 time. The maximum water level was read in the water level changes, and this value was used to predict drainage load.

(3) Transport condition: The video camera was set at the measurement point of the water level in the clear vinyl pipe. By observation of the video picture, garbage wastewater was distinguished from clear water.

3. Results and discussions

3.1. The experiment before habitation

(1) Initial performance evaluation: The initial pressure distribution by reading the maximum and minimum values in the pressure change of each floor at the time of draining 6 units from the upper floors is shown in Fig.4. This figure shows that the pressure distribution of bowl flushing water is similar to that of tap running water and the positive and absolute negative pressure of garbage wastewater is the greatest of the three kinds of drainage. The reason why the absolute value of the pressure with bowl flushing water is small is suspected to be attributed to the influence of the decrease of the drainage flow rate caused by the increase of the drainage resistance when the food disposer is installed in the sink ⑶.

The maximum and minimum system pressure values are read in this pressure distribution, and the relation between the simultaneous drainage number and each system pressure value is shown in Fig.5. This figure shows that positive and absolute negative pressure increase when the simultaneous drainage number increases. As in the case of the above-mentioned pressure distribution, since the pressure increases caused by the simultaneous drainage number of bowl flushing water is similar to that of tap running water, both can be evaluated as the same clear water drainage. Furthermore, it can be suggested that the garbage wastewater’s pressure is larger than that of this clear water drainage. Moreover, the result of the reference 1) in the experimental tower was also shown in this figure. Compared to the reference, it transpires that garbage wastewater’s positive pressure stated in this paper is smaller by approx. 60Pa, and the negative pressure is graded the same. The cause is speculated to be that the positive pressure resistance stated in this paper is smaller than the figure stated in the reference, as the house drain of 66.5m length mentioned in this paper is shorter than the one with a length of 107m mentioned in the reference. Most importantly, garbage wastewater referred to in this paper falls within the limits of -192Pa to +155Pa. The system pressure value falls within the performance criteria of ±400Pa, and it was verified that the initial performance
before habitation was safe.

(2) Preparation for the experiment after habitation: In order to predict the drainage load after habitation, it is necessary to explain the prediction method in advance of the simultaneous drainage number acquired from the measured water level data. Before habitation, the maximum water level is read in the changes at the time of draining from each floor, and the relationship between the simultaneous drainage number and the maximum water level is shown in Fig.6. This figure shows that the maximum water level increases when the simultaneous drainage number increases and this implies that both have correlation. These equations of relationships differ by garbage drainage and clear water drainage. This leads to the experimental equations for estimating the simultaneous drainage number from the maximum water level and these equations are shown below.

\[
N_G = 1.97 \times 10^{-2} D^{1.77} \quad (1)
\]
\[
N_C = 1.91 \times 10^{-2} D^{2.01} \quad (2)
\]

Note:
- \( N_G \): Simultaneous drainage number of garbage wastewater
- \( N_C \): Simultaneous drainage number of clear water
- \( D \): Maximum water level (mm)

Furthermore, in order to evaluate the drainage performance after habitation, it is necessary to clarify beforehand the relationship between the drainage load and the initial performance. The relationship between the maximum water level and the initial system pressure value, which was obtained here, is shown in Fig.7. According to this figure, when the maximum water level increases in the case of the same drainage load floors, the positive pressure and the absolute negative pressure increase and it transpires that the maximum water level is related to the system pressure value. Even if the type of drainage varies, this correlation can only be determined by the drainage load floors in general. This leads to the experimental equations for predicting the initial system pressure value acquired from the maximum water level. The equations are as follows.

\[
10.7 \leq P_h \leq 1.25 D^{1.41} \quad (3)
\]
\[
-1.19 \leq P_n \leq -0.81 D^{1.53} \quad (4)
\]

Note:
- \( P_h \): Maximum system pressure value (Pa)
- \( P_n \): Minimum system pressure value (Pa)

In addition, since the system pressure value in the same maximum water level changed with drainage load floors, these equations were expressed as inequalities. In the experiment after habitation, drainage load prediction and running performance evaluation are performed using the above experimental equations.

3.2. The experiment after habitation

(1) Drainage load prediction and the validity check of initial performance verification: The instance of water level changes throughout a day after habitation is shown in Fig.8. Many increases of the water level are seen in this figure. According to the method of Fig.3, the drainage frequency was counted from these water level changes. When the drainage frequency is divided into time zones, since the 19th hour zone has the most drainage twelve times in this case, this zone is determined as a peak hour.

The instance of the water level changes during a period of thirty minutes, which is distinct in the figure, is shown in Fig.9. A total of five drainage types are seen in this figure. When different drainage types were distinguished...
by the transport conditions, employing video picture observation, the 1st–2nd drainage were of garbage wastewater, and the 3rd–5th drainage were of clear water. The 1st and 3rd waveforms are similar, regardless of the different drainage type. Thus, because water level changes do not always form a wave pattern as shown in Fig.3, the drainage types were distinguished by means of video picture observation.

All frequency distribution, the drainage of which is distinguished as of either garbage wastewater or clear water, after all drainage during the measurement period were divided by time zones and this is shown in Fig.10. The figure shows that the drainage frequency between the 1st and 6th hour zones is very low, that the drainage frequency between the 18th and 21st hour zones is high, and that the drainage frequency during the 12th hour zone is the highest. As for the garbage wastewater, it is evident that its frequency ratio is 17% of all the drainage frequency, which is a rather small figure when compared with clear water, and that the ratio is comparatively high between the 12th and 19th hour zones.

The all drainage frequency distribution by maximum water level is shown in Fig.11. This figure shows that the clear water ratio is high in the case of the low maximum water level, and garbage wastewater ratio is high in the case of the high maximum water level. The 7mm of the maximum water level, when the frequency is the highest, is converted to about one unit as in the simultaneous drainage number when using the clear water's experimental equation (2). By this, because the drainage of most frequencies is equivalent to about one clear water drainage unit, it can be said that this prediction method is valid. According to the conversion method stated in the reference, the maximum simultaneous drainage number is calculated by excluding 1% from the higher ranks in cumulative frequency ratio. When the cumulative frequency is 99% in this figure, the maximum water level is 19.4mm applying to garbage wastewater only. By use of the garbage wastewater's experimental equation (1), this maximum water level is equal to 3.7 units as in the simultaneous drainage number. By this, the maximum simultaneous drainage number in all drainage was obtained.

The drainage frequency distribution by the maximum water level during the peak hours is shown in Fig.12. When the cumulative frequency is 99%, the maximum water level is 19.8mm, also applying to garbage wastewater only. This maximum water level is converted by the same method to 3.9 units as in the garbage wastewater's simultaneous drainage number and the maximum simultaneous drainage number during peak hours is obtained. The two maximum simultaneous drainage numbers during peak hours and all hours are compared, and the larger one is adopted in view of the safety on the performance verification. Thus, it is checked that the maximum simultaneous drainage number occurs during the peak hours, and it is apparent that this number is equal to 3.9 units of garbage wastewater.
wastewater.

In order to predict the maximum simultaneous drainage number by using the measured value in the hypothetical case of fully inhabited houses, the relationship between the average simultaneous drainage number and the maximum simultaneous drainage number is shown in Fig.13. The curve in this figure is based on Poisson distribution which is used as a drainage load calculation method and which is the following equation 5).

\[
\sum_{k=0}^{M} \frac{m^k}{k!} e^{-m} = 0.99
\]

\[
m = n \frac{T_f}{T_0}
\]

Note:
- \(M\): Maximum simultaneous drainage number
- \(m\): Average simultaneous drainage number
- \(n\): Habitation house number (\(n_1=25, n_2=35\))
- \(T_f\): Duration of occupancy (s)
- \(T_0\): Average interval of a fixture discharge (s)

\[T_f = \frac{w}{q_d}\]

where \(w\): amount of wastewater (L)
\(q_d\): wastewater flow rate (L/s)

The obtained 3.9 units, the maximum simultaneous drainage number \((M_1)\), and the number of actually inhabited houses 25 \((n_1)\) are substituted for this equation and the average simultaneous drainage number in the actual habitation \((m_1)\) is 1.2 units. Here, it is assumed that the duration of fixture occupancy \((T_f)\) show no difference when the number of inhabited houses increases, and the average interval of fixture discharge \((T_0)\) show no difference when this number increases too. Using the \(m_1\) on the actual habitation and the 35 of the hypothetical number of fully inhabited houses \((n_2)\), the average simultaneous drainage number on the hypothetical habitation \((m_2)\) can be calculated by the following equation.

\[m_2 = n_2 \frac{m_1}{n_1}\]

The obtained value and the previous equation (5), the maximum simultaneous drainage number on the hypothetical full habitation \((M_2)\) is calculated to be 4.9 units. It shows that the calculated value is smaller than the maximum simultaneous drainage number of 6 units, which was used before habitation. This number of 6 units was calculated by the method shown in Table 1, which was using provisionally the data of usual drainage system. Since this provisional number is larger than the predicted number of 4.9 units from the actual measurement, this checks that the maximum simultaneous drainage number by the initial performance verification proves to be severe and satisfactory.

(2) Running performance evaluation: The instance of pressure and water level changes during a period of thirty minutes is shown in Fig.14. This figure shows that the pressure changes several minutes before the maximum water level occurs.

During the peak hours, the frequency distributions by running system pressure value as read in this pressure change, is shown in Fig.15. This figure shows that most of the system pressure values fall within ±50Pa, and large positive pressure and large absolute negative pressure hardly occur. The suggested causes are that large drainage load did not occur neither did a great deterioration in the performance. About 99% cumulative frequency ratio after excluding 1% from the higher rank contains the maximum system pressure value +147Pa and the minimum system pressure value -103Pa. By this, the system pressure values fall within the performance criteria of ±400Pa, and it was verified that the running performance after 19 months habitation was also safe.

The relationship between the maximum water level and the running system pressure value is shown in Fig.16. The experimental equations (3) and (4) of initial system pressure value are also shown in the figure. It is apparent that, in general, the positive and negative running system pressure values are within these equations. In other words, there is no significant difference between the
running performance and the initial performance. By this, it was confirmed that no great deterioration was seen in the running performance after 19 months habitation.

4. Conclusions

Regarding the drainage piping system with food disposers in the actual super high-rise apartment houses with a height of 100m, results were acquired from the experiment for the initial performance evaluation before habitation as well as from the experiment after habitation in order to implement drainage load prediction and the running performance evaluation using 25 occupied houses (over four weeks after 19 months from the start of habitation). The following knowledge has also been acquired, which contributes to a performance test.

(1) As a result of simultaneously draining the maximum 6 units drainage of garbage wastewater, bowl flushing water and tap running water from the upper floors, the maximum and minimum pressure in pipes were generated by garbage wastewater. These values varied between -192Pa and +155Pa, falling within the performance criteria, and it was verified that the initial performance was safe. During the implementation of the initial performance verification, it is important to measure the system pressure values of garbage wastewater and clear water drainage and to check that the values fall within the performance criteria.

(2) In order to evaluate any deterioration in the performance after habitation by applying the obtained water level and pressure in pipes before habitation, the arrangement method of experimental equations on the relationship between the maximum water level and the initial system pressure value was introduced.

(3) As a result of observing all drainage after habitation by video picture, the garbage wastewater ratio was 17%, and the clear water drainage ratio was 83%. In drainage type prediction, it is effective to take pictures of transport conditions using a video camera.

(4) The prediction method of the maximum simultaneous drainage number according to the change in the number of inhabited houses was described. As a result, since the maximum simultaneous drainage number for 25 inhabited houses was equal to 3.9 units of garbage wastewater, that for 35 fully inhabited houses was 4.9 units. By this, it was confirmed that the simultaneous drainage number of 6 units at the time of initial performance verification proved to be sufficient.

(5) As a result of clarifying the frequency distribution by running system pressure value, 99% of occurrence probability values were from -103Pa to +147Pa, falling within the performance criteria and it was verified that the running performance was safe. In running performance verification, it is important to check that system pressure values fall within the performance criteria.

(6) As a result of determining the relationship between the maximum water level and the running system pressure value, since this pressure value was within the experimental equations of initial pressure value in general, it was confirmed that there was no significant performance deterioration caused by long-term use. In running performance evaluation, it is effective to use the method relating to the water level as a drainage load index and the pressure as a performance index.

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Notes

1 This drainage flow rate is predicted to be 0.2L/s. This value falls within the value range stated in the reference 7) in the disposer’s lid installation condition.

2 The significant occurrence of detergent bubbles pointed out by the reference 2) was not detected. This is thought to be because dishwashers are installed in the building.

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