Design and Exploration of Drainage System based on Pressure Pipeline in Buildings

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Abstract. In order to improve the drainage system of buildings in China, the drainage system based on pressure pipeline is studied. Firstly, the development background of building drainage in China is described, and the flow algorithm of pressure pipeline is introduced. On this basis, the drainage test of single riser and double riser system is designed. Through comparative analysis of the test, the drainage characteristics of the pipeline drainage system are obtained, and the relevant design methods of the drainage system in buildings are obtained based on the pressure pipeline. The drainage performance of double risers is better than that of single risers. Double risers should be used as much as possible in construction, especially in high-rise buildings. Drainage of high-rise buildings is complex, and large changes in water pressure are easily formed in pipeline, which may damage indoor water-using equipment, make odorous gases in pipelines enter indoors, and destroy living environment. The research results can provide data reference for building drainage design, provide parameter basis for testing standards of drainage capacity of residential drainage system, and improve building drainage system in China.

Keywords: Drainage system; Pressure pipeline; Drainage characteristics; Single riser; Double riser.

1. Introduction

With the development of building a well-off society in an all-round way in China, residents' living standards, environmental awareness and the pursuit of a high-quality and high-grade living environment have been improved simultaneously. High-rise buildings have also appeared in large numbers. Residential buildings have gradually changed from three or four households per unit or even more households sharing corridors to one or two households with more comfort and privacy [1].

But in the aspect of indoor drainage, most residential buildings still adopt the traditional indoor drainage method, that is, the drainage riser passes through the lower floor, the drainage horizontal branch pipe hangs below the roof of the lower household, and fixes along the wall to collect the drainage of various sanitary appliances of the upper users (leak pool, water heater, bathtub, flushing tank, toilet, washing machine, floor leakage, etc.). Although the traditional indoor drainage technology has been used for decades in China, some problems still remain unsolved, such as noise, waste water spill-over, drip and leakage, and with the development of the times, some new problems have emerged, such as...
restrictions on the placement of sanitary appliances [2]. These problems will affect the lives of residents, and even cause civil disputes and spread of diseases, resulting in serious consequences. Independence, integrity, freedom, economy and health are the future development direction of building indoor drainage system. Different from low-rise buildings, high-rise buildings have the characteristics of many stories, high height, many vibration sources, high water demand, and large drainage. Therefore, new technical requirements are put forward for the design, construction materials and management of building drainage engineering. New technical measures must be taken to ensure the good working conditions of water supply and drainage system and meet the functional requirements of various high-rise buildings. The improvement and optimization of traditional indoor drainage system is becoming more and more urgent and important. It is necessary to strengthen the research on the improvement and optimization of indoor drainage system [3].

2. State of the art
Since the 1930s, a lot of experimental studies on hydraulic characteristics of building drainage systems have been carried out internationally. Membrane flow theory proposed by the United States laid the theoretical foundation for building drainage. The theory holds that when the water flow fills 1/4-1/3 of the section in DN75 cast iron riser, the water flow in the riser is in the state of water film flow (the water flow in the riser is divided into wall spiral flow, water film flow, and water plug flow in turn with the increase of drainage flow) [4]. When the water flow in the riser or the connection between the riser and the horizontal pipe is in a relatively stable state of water film flow, it is helpful to improve the hydraulic condition of the drainage system. The change of pressure in the riser usually does not destroy the water seal of sanitary utensils on the horizontal branch of the drainage pipe. When the water flow exceeds 1/3 of the riser cross section, the water flow in the riser is in the state of water plug flow. In this state, the pressure in the riser varies dramatically and the water seal is easy to be damaged. Therefore, the flow in the riser should be controlled within the scope of forming water film flow, that is, the flow is filled with 1/4-1/3 of the cross-section of the drainage riser. At this time, the pressure change in the drainage system is controlled within the allowable range, and the drainage function of the riser is fully exerted. Under the condition of water film flow, the ultimate limiting velocity is achieved and multiplied by the cross-sectional area of water flow (1/4-1/3 riser cross-sectional area) and the safety factor is taken into account to calculate the water-carrying capacity of the drainage riser. This method of determining the water-carrying capacity is mainly applicable to multi-storey buildings with ordinary drainage pipe fittings and pipes [5]. Almost all the design conditions of drainage risers in China are in the state of 1/4-1/3 of the cross-section area of the risers filled with water.

With the construction of high-rise buildings in large numbers, people pay great attention to the safety and reliability of building drainage. Correct and reasonable calculation of building drainage pipeline is an important guarantee for safe and reliable building drainage system. Hydraulic calculation of building drainage pipeline involves the maximum drainage capacity of drainage riser, drainage flow of sanitary ware, design second flow of drainage pipeline, diameter and filling degree of drainage pipeline, etc. [6].

3. Methodology
The calculation of indoor domestic drainage system is mainly based on the drainage quota of various sanitary appliances to determine the design flow of the design section, and then the diameter of the pipe is determined according to the design flow. The internal drainage flow is related to the drainage characteristics of sanitary ware and the quantity of sanitary ware drained at the same time. It has the characteristics of short duration, large instantaneous flow, and long-time interval between two drains. The amount of drainage in the building is uneven every day, night and hour [7]. Like water supply, in order to ensure that the maximum drainage at the most disadvantageous time can be discharged quickly and safely, the design drainage flow should be the maximum instantaneous drainage flow in the building, also known as the design second flow. There are three methods for calculating the seconds discharge of drainage design in buildings: empirical method, square root method, and probability method. At present,
the square root method is adopted in China. There are two formulas according to the drainage characteristics of living buildings. For residential buildings, collective dormitories, hotels, hospitals, sanatoriums, elderly homes, office buildings, shopping malls, convention and exhibition centers, primary and secondary school teaching buildings and other buildings, seconds flow rate should be calculated according to the following formula:

$$q_s = 0.12\alpha \sqrt{N_p} + q_{max}$$  \hspace{1cm} (1)

In the formula, $q_s$ indicates the seconds flow rate for calculating the drainage of pipeline section; $N_p$ suggests the total amount of drainage equivalent of sanitary appliances in pipeline section; $q_{max}$ refers to the drainage flow rate of sanitary appliances with the largest drainage amount in pipeline section; and $\alpha$ represents the coefficient determined according to the use of buildings, which should be determined according to Table 1.

| Name of building                  | Residences, hotels, hospitals, kindergartens, etc. | Collective dormitories, hotels and other public buildings |
|----------------------------------|-----------------------------------------------------|----------------------------------------------------------|
| $\alpha$                        | 1.5                                                 | 2.0-2.5                                                  |

If the calculated flow value is greater than the cumulative value of the drainage flow of sanitary appliances on the pipe section, it should be calculated according to the cumulative value of the drainage flow of sanitary appliances.

For industrial enterprise living rooms, public bathrooms, laundries, kitchens, laboratories, theatres, stadiums, waiting rooms and other buildings, the use of sanitary equipment is centralized, the drainage time is centralized, and the drainage percentage is high. The formula for calculating the second flow of drainage design is as follows:

$$q_s = \sum q_p \times n_b \times b$$  \hspace{1cm} (2)

In the formula, $q_s$ is the second flow rate for calculating the drainage of pipe section, $q_p$ is the drainage flow rate of one sanitary appliance of the same type, $n_b$ is the number of sanitary appliances of the same type, and $b$ is the percentage of simultaneous drainage of sanitary appliances. Flushing tank toilet is calculated at 12%.

4. Results and discussion

4.1. Comparison of drainage characteristics between single riser and double riser systems
Firstly, the drainage capacity of the top layer of the system is determined, and the flow rate is taken as a constant to reduce the total height of the system layer by layer. The influence of the height on the pressure change is studied, and the drainage characteristic parameters of different layers are examined. Single variable is the detection method of constant flow and instantaneous flow, so there is a strong contrast between the drainage characteristics of the two drainage modes. After determining the drainage characteristics of the common UPVC (Unplasticized Polyvinyl Chloride) single riser drainage system, a double riser system is constructed to investigate the water capacity and pressure distribution of each layer, and to study the influence of ventilation on the drainage characteristics of the common UPVC drainage system. The specific experimental steps are as follows:
As shown in Figure 1 and Figure 2, the first step is to install an electric regulating valve and an electromagnetic flowmeter in the drainage layer of 1-5 layers, and a pressure sensor in the layers of 14-1 layers, with the pressure change exceeding ±400Pa as the criterion for determining the breakage. In 1-5 layers of drainage, the maximum drainage flow of each layer is 2.6L/s. If the maximum pressure change cannot reach ±400Pa, the drainage layer will be increased downward in turn until the pressure change reaches the criterion of breakage. At this time, the flow rate can be determined as the water capacity of 15 layers. The second step is to install electric regulating valve and electromagnetic flowmeter on 14 layers as drainage layer, remove 15 layers of riser, and ensure that the ventilation conditions of the extension roof remain unchanged, and install pressure sensors on 13 to 1 layer. In 14 layers of drainage, the pressure changes of the lower layers are measured and the water permeability of 14 layers is determined. The third step is to reduce the total height of the drainage system layer by layer.
until the fifth layer of drainage, and test the water capacity of each drainage layer. Finally, determine the drainage capacity of single riser and double riser systems.

4.2. Water capacity of single riser system

In order to examine the correlation between flow rate and pressure change and determine the drainage capacity of a single riser drainage system on the 15th layer, the flow-pressure curve, which has been sorted out by means of many experiments, is shown in Figure 3. The maximum positive pressure and negative pressure of the system increase with the increase of drainage discharge. The negative pressure increases from -52Pa at 0.5L/s to -665Pa at 2.6L/s and from +45Pa at 0.5L/s to +349Pa at 2.6L/s. It can be found that for ordinary UPVC single riser drainage system, when the drainage flow increases gradually, the change range of negative pressure is larger than that of positive pressure. From the positive pressure part, it can be seen that the positive pressure change value has not yet reached +410Pa when the drainage discharge reaches 2.6L/s, so it can be concluded that the positive pressure of the ordinary UPVC single-stand pipe drainage system has relatively small impact on the safety of the system when the drainage discharge is at the high level by using the fixed flow mode; from the negative pressure part, it can be seen that when the drainage discharge is 1.5L/s, the negative pressure change value is -313Pa. When the flow rate reaches 2L/s, the negative pressure change value is -429Pa, which determines the breakage.

Therefore, in order to detect the water capacity of the test system more accurately, the flow accuracy is improved between 1.5L/s and 2.1L/s of drainage flow. Figure 1 detects the pressure variation of each floor at 1.7L/s and 1.82L/s, respectively. When the flow rate is 1.82L/s, the minimum negative pressure change value is -410Pa, which just meets the criterion of breakage and determines breakage. To sum up, when the ordinary UPVC single riser drainage system is tested by constant flow method on the 15th layer, the negative pressure has a stronger influence on the system pressure than the positive pressure, and the change range of the negative pressure is stronger than the positive pressure with the flow, and the water capacity of the system can be determined to be 1.82L/s.

![Flow-pressure curve](image)

**Figure 3.** Flow-pressure curve

The maximum positive pressure and negative pressure of each floor of the ordinary UPVC single riser drainage system is relatively small when the drainage is 0.5L/s in a fixed flow mode on the 15th layer. In the experiment, the most obvious change of positive pressure occurs in layer 1, with the size of +43Pa; the range of negative pressure fluctuation is -27Pa to -53Pa, and the difference of negative pressure variation is only -26Pa. Combined with the pressure change caused by the flow rate, it is shown that the downward flow in the drainage system has a great influence on the air pressure: after the water with solid impurities enters the drainage riser, under the action of friction and gravity on the pipe wall,
the velocity rises rapidly, and the air-water two-phase flow mixed with the original air pressure balance in the pipeline is impacted by the water flow, resulting in the air pressure change. The local pressure in the drainage system decreases due to the dissolution of gas into the water flow in the drainage pipeline, resulting in negative pressure and suction effect on other drainage pipelines. For high-rise buildings, the negative pressure suction effect will be more obvious because the drainage riser is longer and the flow rate of downward flow is faster.

4.3. Water capacity of double riser system

In order to inspect the water capacity of the common UPVC double riser drainage system when using the constant flow detection method, and compare with the single riser system, the parameters of the system design and construction should be consistent as far as possible, including the diameter of the drainage riser, the setting parameters of drainage, the slope of branch pipe and transverse trunk pipe, etc. Firstly, the maximum positive pressure and negative pressure of the system are measured by pressure sensor on the 15-layer drainage system. As shown in Figure 4, the maximum positive pressure and negative pressure of the system increase with the increase of drainage flow. From the positive and negative pressure curves, it can be seen that when the drainage flow reaches 3.45L/s, the positive pressure and negative pressure changes are +346Pa and -345Pa, respectively, which do not reach ±400Pa; when the drainage flow is 4.1L/s, the positive pressure and negative pressure changes are up to +440Pa and -411Pa, respectively, which both exceed the criteria for determining water seal breakage. Therefore, the flow accuracy can be improved between 3.45L/s and 4.1L/s. In Figure 4, the pressure changes of each layer at 3.71L/s and 3.81L/s is detected, respectively. When the flow rate is 3.81L/s, the negative pressure change value is -405Pa, which just meets the criterion of breakage. Therefore, the water capacity of the common UPVC double riser drainage system on the 15th layer can be determined to be 3.81L/s, at which time the maximum positive pressure change value is +421Pa.

According to the experimental data, the positive and negative pressure changes of single riser drainage system at 2.1L/s are +261Pa and -428Pa, respectively, while the positive and negative pressure changes of double riser drainage system at 2.1L/s are +186Pa and -294Pa, respectively. It is seen that the double riser drainage system has obvious effect in alleviating the change of positive pressure and negative pressure, and the ability of balancing the change of negative pressure of the system is more prominent. As mentioned above, when examining the water-carrying capacity of ordinary UPVC single riser drainage system, it is concluded that the water-carrying capacity of the single riser system on the 15th floor is 1.81L/s. Comparing the drainage capacity of single riser drainage system with that of double riser drainage system, it can be found that when the system is high, the drainage capacity of double riser drainage system is twice that of single riser drainage system, so it is more reliable in drainage safety.
4.4. Comparison of water capacity between double riser and single riser

The distribution of water capacity of common UPVC double riser drainage system and single riser drainage system in some floors is shown in Figure 5. The water capacity of each layer of common UPVC double riser drainage system is relatively stable, and its range of variation is between 3.8L/s and 4.1L/s. When the total drainage height is between 7 layers and 5 layers, the water capacity of double riser drainage system increases by 0.14L/s and 0.22L/s, respectively. Comparing the water-carrying capacity of UPVC single riser drainage system with that of double riser drainage system in each layer, it can be seen that the change range of water-carrying capacity is relatively small under both ventilation conditions. The overall trend is that the lower the height of drainage system is, the greater the water-carrying capacity of single riser drainage system increases from 1.81L/s to 2.21L/s, and the water-carrying capacity of double riser drainage system increases from 3.38L/s to 4.11L/s. The water capacity of the double riser system in each layer is nearly twice that of the single riser system.

At the same time, when the total height of the drainage system is greater than 10 layers, the positive and negative pressure changes of the double riser drainage system are relatively large. Taking 3.8L/s as an example, the fluctuation of positive and negative pressure in drainage process is over 400Pa, and its water capacity is determined by both positive and negative pressure. For single riser drainage system, regardless of the layer of the system height, the change value of negative pressure first reaches -400Pa, while the change value of positive pressure is relatively small, and its water capacity is determined by negative pressure.

5. Conclusion

The water-carrying capacity of UPVC single riser drainage system and double riser drainage system is studied, and the correlations among system height, air pressure change, and water-carrying capacity are determined. The following experimental conclusions are drawn: when the single riser drainage system and double riser drainage system adopt the fixed-flow drainage detection method, the relationship between flow size and pressure change presents obvious regularity. The special ventilation pipe can increase the water capacity of the drainage system to twice as much as the original one. When the drainage system is high, the capacity of double riser drainage system is determined by positive pressure and negative pressure; when the total height of drainage system is low, the capacity of double riser drainage system is determined by negative pressure. Compared with single riser system, the negative pressure changes first to -400Pa regardless of the system height, and the positive pressure changes relatively small, so the water capacity is determined by the negative pressure. When the drainage flow is constant, with the height decreasing, the positive pressure change of the double riser system decreases significantly more than that of the single riser system, so the double riser system should be designed as far as possible in the construction.
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