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A design method of drainage and fire protection based on multi-layer fuzzy comprehensive evaluation method

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Abstract. To improve rationality of water supply and drainage and fire protection design of super high-rise buildings in rainy cities at low altitude, a kind of method for water supply and drainage and fire protection design based on multi-layer fuzzy comprehensive evaluation method is proposed. Firstly, fuzzy comprehensive evaluation model selected for optimization of domestic water supply system of water supply and drainage experiment platform is built, which consists of factor set, evaluation set and evaluation matrix; secondly, for the issues of multiple factors or indicators in the design process, fuzzy integrated decision-making that multiple factors affect matters is designed to achieve effective design of water supply and drainage and fire protection design of super high-rise building; finally, the effectiveness of proposed algorithm is verified through simulation experiment.

Key words. Low altitude, Super high-rise, Water supply and drainage, Fire protection de-sign.

1. Introduction

With the continuous deepening of the reform and opening-up policy, industrialization, urbanization and modernization move forwards at unprecedented speed. Accordingly, urbanization process in various regions of China is constantly deepened. Urban population is gradually intensive, and multi-layer residential quarters and various high-rise, super high-rise buildings in the cities at all levels spring up like mushrooms. As the leading building function–for human habitation, it cannot be separated from water supply and drainage. Therefore, building water supply and drainage technology obtains the considerable development. Many new systems, technologies and methods are derived out, and more research results will be obtained from building water supply and drainage. However, higher system and function re-

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quirements are proposed for supporting technologies of building water supply and drainage engineering of various high-rise and super sigh-rise buildings. Building water supply and drainage engineering development will face increasingly difficult challenge of new subjects.

For the effective volume of fire pool of super high-rise buildings in rainy cities at low altitude, the Article 4.3 and 11 of *Technical Specification for Fire Water Supply and Hydrant System* stipulates that the minimum effective water level of high-order fire pool shall meet the working pressure and flow required by water extinguishing installation it serves, and the effective volume shall meet fire demand within duration of fire. When high-pressure fire water supply system supplied from high-order fire pool is used for high-rise civil buildings, fire demand in storage room of high-rise fire pool is difficult, but water replenishment is reliable in case of fire. The total effective volume shall not be less than 50% of indoor fire demand. It can be seen that the volume of high-rise fire pool can be set as per 100% and more than 50% of indoor fire water consumption. To ensure security and reliability of fire water supply system, the water storage volume of high-rise fire pool is different and the control of fire water supply system should be correspondingly adjusted, but it is not directly mentioned in the *Technical Specification for Fire Water Supply and Hydrant System.*

The leading thought of the Thesis is to research and discuss system selection scheme of all systems for water supply and sewerage works by fuzzy comprehensive evaluation theory of fuzzy mathematics based on the system selection principle and hydraulic calculation method of system pipeline of water supply system, water drainage system, hydrant extinguishing system, sprinkler system and water spray system in water supply and drainage engineering of super high-rise buildings in rainy cities at low altitude, and introduce characterization coefficient method suited to the experiment platform but inconvenient for use in design calculation method of sprinkler system into branch-pipe characterization factor to simplify calculation, and the optimization design idea is applied in experiment platform to test and verify rationality of these methods through water supply and drainage experiment platform after completion of installation and debugging.

2. Fuzzy comprehensive evaluation method selected for optimization of domestic water supply system of water supply and drainage experiment platform

The type of domestic water supply system is determined through one-step method (one-time comprehensive evaluation) in multi-layer fuzzy comprehensive evaluation of fuzzy comprehensive evaluation theory. The mathematic model of fuzzy comprehensive evaluation consists of factor set, evaluation set and evaluation matrix. Fuzzy comprehensive evaluation method and theory can be applied in domestic water supply system of experiment platform as per the following steps:

(1) Establish factor set $U = \{u_1, u_2, \cdots, u_n\}$. Each element in the set refers to indicator for evaluation of certain water supply method, such as reliability of water supply, water quality, pressure stability, etc.

(2) Establish evaluation set $V = \{v_1, v_2, \cdots, v_n\}$. It is actually the set of evaluated objects. Each element refers to water supply method;

(3) Establish evaluation matrix for various water supply system schemes to be selected according to the evaluation set in Step 2;

(4) Comprehensively analyze the evaluation results to obtain the evaluation results.

8 kinds of water supply methods in the most representative water tank with and without high level to be selected in experiment platform are determined as evaluation objects through summary of engineering cases of domestic and overseas building water supply method, design specifications and technical measures related to domestic water supply and drainage trade. Except weight of the above-mentioned factors, the fuzzy concept quantization is mostly reflected through element in evaluation matrix. The evaluation objects (water supply method) are scored through comparison of indicators of each factor according to the engineering practices and relevant data and then normalized to obtain element in evaluation matrix R of the Thesis. The results are shown in Table 1.

Table 1. Evaluation matrix R of each influence factor in domestic water supply system of experimental platform

Factor	1	2	3	4	5	6	7	8
Reliability of water supply	0.187	0.128	0.144	0.124	0.103	0.087	0.131	0.096
Water quality assurance	0.077	0.072	0.075	0.102	0.157	0.157	0.180	0.180
System operation management	0.148	0.095	0.116	0.114	0.118	0.112	0.159	0.138
System adjustment capacity	0.170	0.139	0.141	0.133	0.080	0.080	0.135	0.122
Stability water pressure	0.171	0.163	0.161	0.127	0.071	0.071	0.121	0.115
Influence on external network	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Construction cost	0.138	0.148	0.158	0.178	0.101	0.108	0.078	0.091
Power consumption	0.168	0.174	0.090	0.098	0.087	0.073	0.176	0.139
Cost of water supply	0.166	0.166	0.121	0.127	0.087	0.082	0.139	0.111
Utilization of municipal surplus pressure	0.136	0.132	0.112	0.112	0.122	0.122	0.132	0.132
Energy consumption	0.144	0.174	0.104	0.102	0.089	0.067	0.184	0.136
Environment influence	0.122	0.086	0.103	0.141	0.122	0.124	0.151	0.151
Floor area	0.067	0.053	0.075	0.136	0.114	0.141	0.194	0.220
Construction method	0.103	0.086	0.117	0.125	0.121	0.119	0.169	0.160

3. Multi-layer fuzzy comprehensive evaluation method

3.1. Basic concept

Fuzzy comprehensive evaluation is the most commonly used and effective method in fuzzy decision. In practice, it usually needs to evaluate (or assess) a matter, and generally refers to multiple factors or indicators. At the moment, we are required to make comprehensive evaluation on matters as per the factors. This is the so-called comprehensive evaluation, namely comprehensive evaluation is made on matters (objects) affected by multiple factors. Therefore, fuzzy comprehensive evaluation is also known as fuzzy comprehensive decision or fuzzy multi-factorial decision.

Basic concept of F set [?]: requirements of well-known common set (known as common set to distinguish from fuzzy set): with regard to subset $A \subseteq U$, it must be $u \in A$ or $u \overline{\in} A$ for each element u in domain U; ambiguity is not allowed. Therefore, subset A can be depicted by 0 and 1.

Definition 2.1 [?]: a map is provided on domain U

$$A : U \to [0,1] \,,$$

$$u| \to A(u) \,,$$

A is called fuzzy set on U; $A(u)$ is called membership function of A(or membership of u on A).

Definition 2.2 [?]: map is

$$T : f(U) \to f(V)$$

F transfer from U to V.

Theorem 2.1[?]: given $R \in f(U \times V)$, only determined F transfer from U to V is written as:

$$T_R : f(U) \to f(V) \,,$$

For any $A \in f(U)$,

$$T_R(A) = A \circ R \in f(V) \,,$$

Where:

$$(A \circ R)(v) = \bigvee_{u \in U} (A(u) \wedge R(u,v)) \quad v \in V \,.$$

3.2. Model of fuzzy comprehensive evaluation

Many things are of unobvious boundary, so it is hard to fall into a category on evaluation. Therefore, we firstly evaluate single factor and then conduct fuzzy comprehensive evaluation on these factors to prevent omission of any statistical information and loss of information in the middle way, which contributes to solve the issues which are deviated from objective reality arisen from certainty evaluation of “yes” or “no”.

Definition 2.3[?]: evaluation object is set as P: (1) for factor set $U = \{u_1, u_2, \cdots, u_m\}$, it is assumed that there are m factors related to the evaluation object; (2) for evaluation level set $V = \{v_1, v_2, \cdots, v_n\}$, it is assumed that there are n comments which may appear; (3) Evaluation of single factor, namely evaluation of single factor $u_i (i = 1, 2, \cdots, m)$ to obtain F set $(r_{i1}, r_{i2}, \cdots, r_{im})$ on V. therefore, it is a F map from U to V.

$$f : U \to f(V)$$

$$u_i| \to (r_{i1}, r_{i2}, \cdots, r_{in})$$

As per theorem 1, a F relation can be determined through F map f; $R \in \mu_{m\times n}$ is called evaluation matrix.

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}$$

It consists of F sets on evaluation of single factor.

As the position of factors is not equal, the factors should be weighted. F set $A = (a_1, a_2, \cdots, a_m)$ on U refers to weight coefficient distribution of factors; the comprehensive evaluation set $B = (b_1, b_2, \cdots, b_n)$ is obtained through composition of F set and evaluation matrix R,

$$A \circ R = B = (b_1, b_2, \cdots, b_n)\,.$$

Where,

$$A = (a_1, a_2, \cdots, a_m)\,.$$

$$R = (r_{ij})_{m\times n}, r_{ij} \in [0,1]\ .$$

$$b_j = \bigvee_{i=1}^{m} (a_i \wedge r_{ij}), j = 1, 2, \cdots, n\,.$$

It is comprehensive evaluation on factors. The Grade v_j corresponding to the maximum b_j in comprehensive evaluation set B is selected as comprehensive evaluation result. Therefore, the comprehensive evaluation mode I (recorded as $M(\wedge, \vee)$) is obtained.

In case of comprehensive evaluation, additive multiplication of real number can be used to replace "$\wedge, \vee$" operation to obtain F set. Only if certain conditions are satisfied, $a_i (i = 1, 2, \cdots, m)$ refers to weight. Therefore,

$$A \circ R = B = (b_1, b_2, \cdots, b_n)\,.$$

Where,

$$A = (a_1, a_2, \cdots, a_m), \sum_{i=1}^{m} a_i = 1, a_i \geq 0\,.$$

$$R = (r_{ij})_{m\times n}, r_{ij} \in [0,1]\ .$$

$$b_j = \sum_{i=1}^{n} a_i r_{ij}, j = 1, 2, \cdots, n\,.$$

It is called Model II (recorded as $M(\bullet, +)$). In case the obtained comprehensive evaluation result is not normalized result, $B = \{b_1, b_2, \cdots, b_m\}$ is obtained after normalization. Accordingly, the evaluation grade of object P can be determined.

Definition of Class 1 fuzzy comprehensive evaluation model is as follows:

Definition 2.4 [**?**]: the function $f : [0,1]^n \to [0,1]$ of n variables is set to meet:

(1) $f(0, 0, \cdots, 0) = 0$, $f(1, 1, \cdots, 1) = 1$;

(2) If $x_i \le x'_i$, $f(x_1, x_2, \cdots, x_n^{)} \le f(x'_1, x'_2, \cdots, x'_n)$;
(3) $\lim\limits_{x_i \to x_{i_0}} f(x_1, x_2, \cdots, x_n) = f(x_{1_0}, x_{2_0}, \cdots, x_{n_0})$;
(4) $f(x_1 + x'_1, \cdots, x_n + x'_n) = f(x_1, x_2, \cdots, x_n) + g(x'_1, x'_2, \cdots, x'_n)$;
f is evaluation function; where $g : [0,1]^n \to [0,1]$.

3.3. Multi-layer comprehensive evaluation

If there are many factors related to evaluation objects, it is hard to reasonably determine weight coefficient distribution, namely it is difficult to truly reflect the overall position of factors. At the moment, multi-layer evaluation is required.

For example, a certain design scheme should be evaluated from multiple factors of researched design of water supply and drainage in professional evaluation. As there are many factors affecting design of water supply and drainage, each category is subject to comprehensive evaluation firstly, and then the result is regarded as a single factor evaluation. The four categories of design of water supply and drainage are regarded as four factors and provided with weight A to conduct the Layer 2 comprehensive evaluation. The model is as follows:

Model III

$$C = A \circ B = A \circ \begin{bmatrix} A_1 \circ R_1 \\ A_2 \circ R_2 \\ A_3 \circ R_3 \\ A_4 \circ R_4 \end{bmatrix} = A \circ \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \end{bmatrix} = A \circ (b_{ij})_{4 \times m}\,.$$

Where B_i refers to the result of ith category of design of water supply and drainage; C refers to the comprehensive evaluation result among categories. If there are still many factors in each category on Layer 2 evaluation, each category can be divided as per a certain property to conduct Layer 3 or above comprehensive evaluation.

4. Experiment analysis

The method of performance test of hydrant extinguishing system and domestic water supply system is the same: fire hydrant of 10L/s in the most adverse points of system serves as flow for test of water supply pump; pressure (212. 81KPa) required by hydrant water supply system is for test of water supply pump. A pipeline which little contributes to calculation from exit point of hydrant system water pump to the most adverse points of fire hydrant of system is selected to calculate frictional head loss (eight) and local head loss h_j from water supply point to set point (with equivalent length method) (step size is set as 1m). The theory pressure P_1 for test at the set point can be obtained through the pressure for test at the exit point of water pump minus frictional head loss h_i and local head loss h_j from water supply point to set point, and then the energy attenuation curve of hydrant extinguishing system on experiment platform from exit point of water pump to the most adverse points of fire hydrant is made as shown in Fig. 1 according to the calculated data in

Table 2, namely the relation diagram of decrease in pressure P (KPa) along pipeline L (m) in the pipe.

Table 2. Calculation table of energy attenuation of hydrant system from exit point of water pump to the most adverse points of fire hydrant

No.	(L/s) Flow (L/s)	(mm) Pipe diameter (mm)	(m) Flow velocity (m)	(m) Actual length of pipe section (m)	Equivalent length of pipe section (m)	Total length of pipe section (m)	Hydraulic slope (degree)	h_r (KPa)	$\sum h_r$ (KPa)	Pressure at set point
1	10	70	0.039	1	3.7	4.7	0.945	4.439	4.439	208.371
2	10	70	0.039	1	0	1	0.945	0.945	5.384	207.426
3	10	70	0.039	1	2.1	3.1	0.945	2.928	8.312	204.498
4	10	70	0.039	1	1.8	2.8	0.945	2.645	10.957	201.853
5	10	70	0.039	1	4.3	5.3	0.945	5.006	15.963	196.847
6	10	70	0.039	1	0	1	0.945	0.945	16.907	195.903
7	10	70	0.039	1	3.9	4.9	0.945	4.628	21.536	191.274
8	10	70	0.039	1	0	1	0.945	0.945	22.480	190.330
9	10	70	0.039	1	0.2	1.2	0.945	1.133	23.614	189.196
10	10	70	0.039	1	1.8	2.8	0.945	2.645	26.258	186.552
11	10	70	0.039	1	0.3	1.3	0.945	1.228	27.486	185.324
12	10	70	0.039	1	0	1	0.945	0.945	28.431	184.379
13	10	70	0.039	1	3.7	4.7	0.945	4.439	32.870	179.940
14	10	70	0.039	1	2.1	3.1	0.945	2.928	35.798	177.012

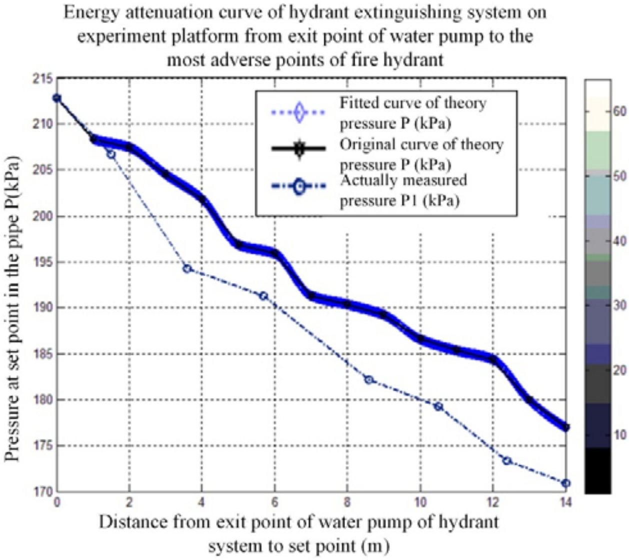

Fig. 1. Attenuation curve of hydrant extinguishing system on experiment platform from exit point of water pump to the most adverse points of fire hydrant

The method for determining pressure at set point of pipe section of hydrant system is the same as that of water supply system. The pressure is measured at 1.7m, 2.85m, 4.9m, 8.2m, 10.lm, 12.2m and 14m from water supply point of fire hydrant pump at the most adverse pipe section selected by resistance-type pressure sensor or compound pressure gauge according to the diameter of the pipe section, and it should be marked on (Fig. 1).

It can be seen from the Fig. 1 that the actually measured pipe pressure is smaller than theoretically calculated data under the circumstance of regarding the pressure in the pipe as control parameter for test on the experiment platform of hydrant system, and the reason is that the flow distribution in the calculation method of hydrant system is too conservative, namely it is assumed that all flow of system only pass through a pipe (namely flowing from the most adverse pipe to fire hydrant), but the actual condition of hydrant system is that all flow of system can flow from pipe network to the most adverse hydrant. Therefore, the actual flow in hydrant system pipeline is less than calculated flow, which causes that the actually measured pressure is relatively smaller than the theoretically calculated value. However, it can improve security of the hydrant extinguishing system in line with actual operation condition of hydrant system. Therefore, it can be identified that the hydrant system on experiment platform reaches design requirements and is qualified in the test.

The method for determining actual pressure at set point of the pipe section which is mostly unfavorable for calculation selected for sprinkler system on experiment platform is the same as that of domestic water supply system and hydrant extinguishing system. The pressure is measured at 1.7m, 3.1m, 5.6m, 7.0m, 9.0m, 11.2m and 13.7m from exit point of water supply pump by resistance-type pressure sensor and compound pressure gauge, and its data curve should be marked on Fig. 2.

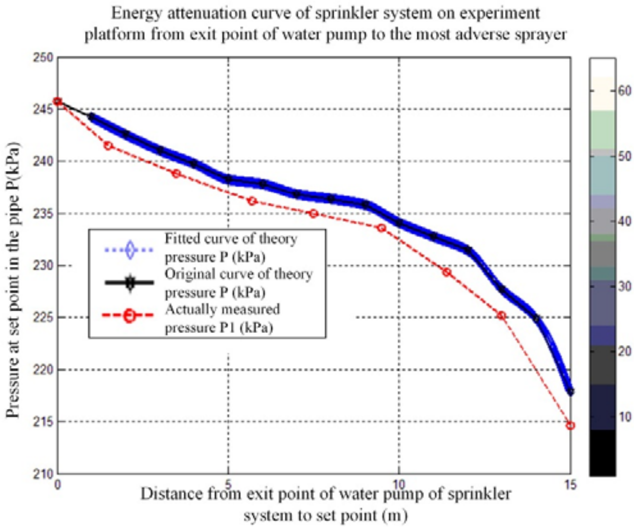

Fig. 2. Energy attenuation curve of sprinkler system from exit point of water pump to the most adverse sprayer

It can be seen from Fig. 2 that the flow at sprayer of sprinkler system on experiment platform of water supply and drainage is of better balance. The curve in scatter diagram of actually measured pipe pressure of sprinkler system after curve fitting is basically in line with that of theoretically calculated pressure under the circumstance of regarding the pressure in the pipe as control parameter for test on the experiment platform of hydrant system, which indicates that the sprinkler system on experiment platform reaches design requirements and it is qualified in the test.

5. Conclusion

A kind of method for water supply and drainage and fire protection design based on multi-layer fuzzy comprehensive evaluation method is proposed in the Thesis, and fuzzy comprehensive evaluation model selected for optimization of domestic water supply system of water supply and drainage experiment platform is built. Meanwhile, the fuzzy integrated decision-making that multiple factors affect matters is designed to achieve effective design of water supply and drainage and fire protection design of super high-rise building. Accordingly, the water supply system, hydrant extinguishing system and sprinkler system of experiment platform are tested respectively. The pipe pressure actually measured in water supply system and sprinkler system is around fitted curve of scatter diagram of theoretically calculated pressure; the pipe pressure actually measured in hydrant system is smaller than that theoretically calculated. The reason lies in that the calculation method is too conservative, namely it is assumed that all flow of system only flow from the most adverse pipe to fire hydrant, but the actual condition is that all flow of system can flow from pipe network to the most adverse hydrant. Therefore, the actual flow in hydrant system pipeline is less than calculated flow, which causes that the actually measured pressure is relatively smaller than the theoretically calculated value. However, it can improve security of the hydrant extinguishing system in line with actual operation condition of hydrant system. Therefore, it can be identified that the domestic water supply system, hydrant system and sprinkler system on experiment platform reaches design requirements and is qualified in the test.

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