

PAPER • OPEN ACCESS

## A method to evaluate fire water supply partitions in super high - rise buildings

To cite this article: Jia Gui *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **227** 042018

View the [article online](#) for updates and enhancements.



**IOP | ebooks™**

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

# A method to evaluate fire water supply partitions in super high - rise buildings

Jia Gui<sup>1</sup>, Qi Yang<sup>3,4,5</sup> and Lei Zhu<sup>2</sup>

<sup>1</sup> State Key Laboratory of Fire Science, University of Science and Technology, Anhui 230027, China;

<sup>2</sup> Sichuan public security fire brigade, Sichuan 610036, China;

<sup>3</sup> East China Architectural Design & Research Institute, Shanghai 200002, China;

<sup>4</sup> Shanghai Engineering Research Center of Super High-Rise Building Design, Shanghai 200002, China.

<sup>5</sup> Email:qi\_yang@ecadi.com

**Abstract.** Buildings are getting higher with the development of economic, which brings big challenges to fire water supply systems in super high-rise buildings. Establishing a method to evaluate fire water supply partitions is helpful to solve new problems in the design of fire water supply systems and provides qualitative and quantitative results and suggestions. According to different dividing forms for fire water supply partitions, this paper established a systematic evaluation method in super high-rise buildings to evaluate fire water supply partitions based on reliability analysis. The evaluation includes direct evaluation and comprehensive evaluation. The direct evaluation compares designs with significant unsafe factors to mandatory provisions in current national standards and codes. The comprehensive evaluation can be carried out with different indexes for multi-factor evaluation, and the reliability of components in the system can be calculated as well.

## 1. Introduction

Buildings are getting higher with the development of economic, which brings big changes and challenges to fire water supply systems in super high-rise buildings. According to the current Chinese national standard “Technical code for fire protection water supply and hydrant systems” (GB 50974 - 2014) [1], the fire water supply system should be designed in partitions when the system working pressure is greater than 2.40 MPa, or the hydrant mouth static pressure is greater than 1.0 MPa, or working pressure of the automatic sprinkler system alarm valve is greater than 1.20 MPa. For super high-rise buildings, they may have a lot ways to divide fire water supply partitions. Evaluating reliability and rationality of the design of fire water supply partition and the related fire water supply systems in super high-rise buildings is a common problem in engineering practice.

Establishing an evaluation method for fire water supply partitions in super high-rise buildings is helpful to provide technical guide for the selection of water supply forms. According to the current Chinese national standard “Code for fire protection design of buildings” (GB 50016-2014) [2], stricter fire prevention measures should be taken in buildings which are higher than 250 m. In order to design optimal water supply systems, it is of great significance to choose the best method to divide fire water supply partitions. In China, a lot of studies have been conducted according to the fire water system design [3-11]. Yan Bo et al. [3] respectively valued the fire water requirement of the underground



garage, the commercial building and the residential building according to current related fire protection codes. Zhu Bo [4] explored the problems of indoor and outdoor fire hydrant system, the problem of building fire water supply and drainage network pressure test and the automatic sprinkler system, and the corresponding prevention and control measures were given to improve the water-supply and drainage construction for architectural firefighting. ZHU Xiao-yang [5] analyzed the characteristics of the fire water supply system of the high-rise building, as well as the design and practical application of the fire water supply system in the high-rise building. Wang Hongyu et al. [6] pointed out that the fire water supply system should refer to the design pressure term commonly used in the pressure pipeline, and analyzed the relationship between the design pressure and the vertical division zoning pressure of the fire water supply system. It was suggested that the vertical division zoning pressure and forms of the water supply system should be determined by the nominal pressure, economic rationality and safety and reliability of the system components. Measures to solve the system overpressure were put forward. LIU Shengyun [7] analyzed several fire water supply methods of super high-rise buildings, and discussed the ideas and methods of fire water supply system design on the basis of the characteristics of the design. Cuili Cao [8] outlined the advanced project experiences and technical requirements by FM, including the parts of analysis of water supply capacity, water tank, fire pumps and system inspection and maintenance etc. The key points and the differences from China relevant codes were highlighted as references for the water supply system which was designed according FM Data Sheet.

The issue about the fire water systems design also attracted some researchers in other countries [12-15]. P Grimwood et al. [12] described research by Glasgow Caledonian University into fire-fighting water flow-rates as actually deployed to control and suppress >5000 building fires that occurred in two fire authority jurisdictions in the UK between 2009 and 2012. It was demonstrated that there were critical links between the amounts of water used/required for effective fire-fighting in relation to the occupancy type, the density of the fire load, the estimated heat release from compartment fires and the extent of fire damage that may impact on the building and its contents. PE Santangelo et al. [13] employed the available knowledge on water-mist sprays in an experimental and numerical analysis of the suppression mechanism. A water-mist system was operated within a typical fire case. A good agreement between experimental and numerical results has been obtained, even under some approximations, with specific reference to combustion mechanisms. PE Santangelo et al. [14] presented an experimental approach and parametric analysis to investigate some dynamic aspects of water-mist sprays operating at high supply pressure. Based on an extensive literature review conducted within Edinburgh University's Fire Safety Engineering Group and sponsored by the UK Home Office Fire Research and Development Group, G Grant et al. [15] established the current state-of-the-art regarding the use of water sprays for the suppression and extinguishment of typical (Class 'A') compartment fires and to identify where gaps exist in the current knowledge.

To sum up, most studies were focused on the effectiveness of the fire water systems according to the current codes. This paper aimed to propose a new effective method to evaluate fire water supply partitions in super high - rise buildings within the bound of current codes.

## **2. Fire water supply forms in partitions**

A fire water supply system in a super high-rise building can be divided into several partitions according to comprehensive factors such as pressure of the water supply system, building characteristics, economy and reliability. Generally, partitions are called "stages" if the fire water supply system is divided based on fire pumps, while partitions are called "zones" if the fire water supply system is divided based on pressure relief valves and pressure relief water tanks. In stages, the water can be supplied in the forms of gravity, series fire water tanks and series fire water pumps. In zones, the water can be supplied in the forms of fire relief water tanks and pressure relief valves.

For the fire water supply system in stages and zones, parallel fire water pumps refers to that the fire water network is directly supplied by the fire water pumps on the corresponding level. Series fire pump refers to that fire pumps on the lower levels transfer the water level by level to the fire water

supply network on the target level, and the fire pump on the higher level directly sucks water from fire pumps on the lower level. Usually, in the series fire water tank supply system, fire water transfer tanks are set between different levels. Fire pumps on the higher level sucks water from the fire water transfer tanks which are supplied by the corresponding fire water transfer pumps. Gravity fire water supply systems refers to that the fire water supply network is not directly supplied by fire water pumps but by high fire pools. The systems can satisfy both water pressure and the flow rate in fire water supply systems. When evaluating fire water supply forms in stages and zone, reliability is a key factor to be considered.

### 3. Establishment of evaluation method for fire water supply partitions

For buildings higher than 250 m, we suggest systematical evaluation on fire water supply partitions should be conducted, and a corresponding system assessment report should be formed.

#### 3.1. Evaluation criteria

The evaluation of fire water supply partitions in super high-rise buildings should be carried out in combination with the architectural characteristics of the buildings. The evaluation should be scientific, realistic, objective, and focused on reliability of fire water supply systems. In the evaluation, different designs of the fire water supply system are compared, and one optimal design is chosen. In addition, corresponding optimization measures for the chosen design should be proposed.

The evaluation can be carried out through direct evaluation and comprehensive evaluation simultaneously. Aiming at safety assessment, direct evaluation compares unsafe factors to mandatory provisions in current national standards and codes [1-2, 16]. The unsafe factors can be violation of fire laws and codes, or potential fire hazards that may cause fires. Comprehensive evaluation selects suitable evaluation methods according to different evaluation purposes and objects. The evaluation method includes expert evaluation method, technical and economic evaluation method, model evaluation method and system analysis method. Reliability evaluation of the system should be the final target. Evaluation objects of the comprehensive evaluation can be a single building or building complex. For a single building which shares the fire water supply system, evaluation of the indexes involving system and integrity should be based on the overall situation the building belongs to.

#### 3.2. Reliability analysis

Reliability analysis is adopted for evaluating the fire water supply system in super high - rise buildings. Based on the evaluation for the design of fire water supply partitions, calculation for the reliability of fire water supply components and pipeline network in partitions can be conducted, and the reliability of the fire water supply systems in different partitions can be measured. Reliability of fire water supply components refers to the probability that the components have the ability to complete predetermined function within specified time and under specified conditions. It includes safety, applicability and durability of the components.

In a fire water supply system, a reliability model is established first, then the reliability is calculated. Units and components in the fire water supply system are determined according to different analyzed objects. Fire water supply systems in partitions can be seen as units. Valves, hydrants, sprinklers, pipes and other components of the fire water supply system, as well as the fire pumps, fire water tanks, high fire water tanks, high fire water pools and other equipment can be seen as components.

The reliability model of the fire water supply system is based on system function, failure mode and logical relations. The function relationship between reliability of the system and reliability of units / components should be calculated [17]. Reliability of a series fire water supply system can be calculated according to Eq. (1),

$$R_s(t) = \prod_{i=1}^n R_i(t) \quad (1)$$

where,  $R_s(t)$  is the reliability of the system,  $R_i(t)$  is the reliability of unit  $i$ ,  $i$  is the unit,  $n$  is the number of units in the system.

Reliability of a parallel fire water supply system can be calculated according to Eq. (2),

$$R_s(t) = 1 - \prod_{i=1}^n [1 - R_i(t)] \quad (2)$$

Reliability of a composite fire water supply system can be calculated according to Eq. (3) and Eq. (4),

a) For a series-parallel fire water supply system, the reliability is,

$$R_s(t) = \prod_{j=1}^N R_{js}(t) = \prod_{j=1}^N \{1 - \prod_{i=1}^n [1 - R_{ij}(t)]\} \quad (3)$$

b) For a parallel-series fire water supply system, the reliability is,

$$R_s(t) = 1 - \prod_{j=1}^N [1 - \prod_{i=1}^n R_{ij}(t)] \quad (4)$$

where,  $N$  is the number of subsystems,  $n$  is the number of units in each subsystem.

Reliability of a whole fire water supply system can be calculated according to Eq. (5),

$$R_s(t) = \prod_{j=k}^n \binom{n}{j} R_0^j(t) [1 - R_0(t)]^{n-1} \quad (5)$$

where,  $k$  is the number of effective units ( $1 \leq k < n$ ).

### 3.3. Systematic evaluation

In a super high-rise building, systematic evaluation is conducted for all indexes in different fire water supply designs. The relationship between reliability, safety and economy should be balanced. Combining characteristics of the fire water supply system, the systematic evaluation makes fire extinguishing performance the priority and finally gives recommendation for the best design.

**3.3.1. Evaluation method.** The systematic evaluation of the fire water supply system can be conducted through relational matrix analysis (principle method), analytic hierarchy process (AHP, evaluation factors distributing at multiple levels), fuzzy comprehensive evaluation (FCE, multiple evaluation objects), system reliability analysis and other expert assessment methods and system analysis methods [17-20]. The correlation matrix method is shown in Table 1.

**Table 1.** Principle of the relational matrix analysis.

	X1, X2, ... , Xm	
	W1, W2, ... , Wm	V <sub>i</sub>
A1	V11, V12, ... , V1m	$V_{1i} = \sum_{j=1}^m w_j v_{1j}$
A2	V21, V22, ... , V2m	$V_{2i} = \sum_{j=1}^m w_j v_{2j}$
...	...	...
An	Vn1, Vn2, ... , Vnm	$V_{ni} = \sum_{j=1}^m w_j v_{nj}$

In Table 1, “A1, A2, ... , An” refer to different designs for the fire water supply system; “X1, X2, ... , Xm” refer to evaluation factors, such as different function indexes; W is the weight factor;  $V_{ij}$  is the score. The optimum score is,

$$V_{ij} = \max \left\{ \sum_{j=1}^m w_j V_{ij} \mid i \right\} = \max \{V_i\} \quad (6)$$

**Table 2.** Evaluation indexes and design factors for a fire water supply system.

Evaluation category / Weight	Evaluation index / Score	Design factor
Target and function (Q1) /0.15	Safety/30	The system meets fire safety objectives, such as the range of the fire water supply system and the function of fire extinguishing or fire control.
	Integrity/25	The system is complete and meets mandatory provisions.
	Fire extinguishing performance/25	Flow rate, pressure, and water supply effect.
	Applicability/20	According to fire characteristics in the target buildings or sites, selection of the fire extinguishing system is appropriate, and the location of the system is correct.
System performance (Q2) /0.70	System type/10	Refer to optimal selection of the fire water supply system, includes the temporary high pressure fire water supply system (including the stable high pressure fire water supply system) and the high pressure fire water supply system.
	Reliability/60	Refer to average trouble-free working time and the backup system. It depends on reliability of fire water source, equipment, pipeline systems, and fire power.
	Adaptability/8	Refer to the ability of a system to adapt to changes in operating environment. The fire water supply system is designed according to building characteristics and influence of the environment.
	Maintainability/10	Refer to controllability, testability and operability.
	Flexibility/6	Operation and maintenance are convenient and flexible.
	Rationality/6	Refer to matching problems among water fire extinguishing systems and the selection of design parameters for equipment, such as the matching problems between independent fire water systems in a single building and sharing fire water supply systems in complex, the share issue between fire hydrant water supply systems and fire pool and fire pump in automatic sprinkler systems, the set of fire water supply partitions, valves, and the nominal operating temperature, starting form and selection of nozzles, etc.
Economic effect (Q3) /0.10	Direct effect/60	Refer to initial equipment investment, such as fire pumps, pipes, accessories, maintenance costs, etc.
	Indirect effect/40	Refer to the decrease of fire disaster, the influence of social benefit, as well as the improvement of economic benefit, working conditions, management efficiency and the management level.
Other aspects (Q4) /0.05	Environmentally friendly/50	Refer to effects of water fire extinguishing systems on the environment, such as the environmental problems and water stain problems caused by foam - water spray systems and water systems.
	Health /50	Refer to sanitation problems caused by water supply, such as reflux problems in fire water supply systems and domestic water pipelines, sharing problems between fire pools and life pools, etc.

Analytic hierarchy process (AHP) is a multi-objective evaluation-decision analysis method which combines qualitative analysis with quantitative analysis. When a system has a lot factors which are difficult to obtain, the fuzzy comprehensive evaluation (FCE) is used to evaluate the advantages and disadvantages through the fuzzy set theory.

**3.3.2. Evaluation indexes.** The index evaluation system for the fire water supply system is composed of four categories: target and function, system performance, economic effect and other aspects. Each category should be scored according to the corresponding evaluation indexes [18], as displayed in Table 2.

Scores of the four categories are respectively Q1, Q2, Q3 and Q4. The total score of each category of the index system is 100. The total score of the system is the sum of scores in all the four categories multiplied by corresponding weights.

The evaluation index can be decomposed into a series of sub-item indexes and refinement factors. The total score of the sub-item index can also use the percentage system, which can be converted as required. For example, in the category of system performance, the reliability of the evaluation indexes and scores can be determined based on fire water resource, water supply facilities, systems, stages and zones, equipment and pipes, fire power, fire control and monitor, fire water drainage and other factors, as listed in Table 3.

**Table 3.** Evaluation indexes and refinement factors in the category of system performance.

Sub-item indexes and refinement score	Refinement factor	Score
Fire water resource /8	The system has two reliable municipal water supplies, and is equipped with fire pools which can store all water consumption for indoor fires.	6
	The system has two reliable municipal water supplies, and is equipped with fire pools.	5
	The system has two reliable municipal water supplies.	8
Water supply facilities /8	High fire pools are also used as damping device.	-2
	Pumping head or flow rate of fire pumps is inadequate.	-7
	The system has no check valve on: 1) outlet pipes of high fire tanks and high fire pools; 2) lower water supply pipes of the fire transfer water tanks. Or pipes cannot meet full flow water supply.	-5
	Fire transfer pumps use a sharing back-up for different systems.	-3
Systems /10	Each building uses an independent high pressure fire water supply system.	10
	Each building uses an independent temporary high pressure fire water supply system.	9
	Part of the fire water supply system is sharing, and the system is a temporary high pressure fire water supply system.	5
Partitions /50	The system is not implemented as required according to current national codes.	-30
	The gravity fire water supply system is used. Fire pools and high fire pools store all water consumption for indoor fires.	0

	The gravity fire water supply system is used. The fire pool stores all water consumption for indoor fires. The high fire pool stores part of water consumption for an indoor fire and uses the fire transfer pump to supply water.	-5
	The series fire tank water supply system is used.	-5
	The series fire pump water supply systems is used.	-10
	The parallel fire pump water supply systems is used.	-15
	Fire water supply partitions not on the lowest level use full allowed pressure.	-20
	The quantity is not determined by minimum partitions.	-20
	Besides the gravity fire water supply system, the partitions are divided by pressure relief water tanks.	-10
	The water supply height of the fire water tank on each level is not enough, and the pressure stabilizing pumps and pressure stabilizing tanks should be set.	-3
	No partition is equipped with two main pipes to supply water. There is no standby pressure relief valve set.	-3
	No safety valve is installed after the pressure relief valve group, or no backflow preventer is installed on the outlet pipe of the series fire pump water supply system.	-3
Equipment and pipes /8	Standby alarm valve sets and standby main water distribution pipes are equipped.	8
	Selection of sprinklers, fire hydrants and other equipment is correct.	8
	Fire hydrants are arranged in a vertical ring. The number of main pipes with full flow rate is no less than 2.	8
	The fire hydrant pipe network is arranged in a three-dimensional ring.	5
	The fire hydrant pipe network is arranged in a horizontal ring.	3
	The system has no 100% standby fire transfer pipes.	-3
Fire power /8	Fire pumps on each level is equipped with diesel engine driven water pumps and two municipal power supplies, and powered by diesel generators.	8
	Fire pumps are powered by two municipal power supplies and diesel generators.	6
	Fire pumps are powered by two municipal power supplies.	3
Fire control and monitor /4	The system meet the requirements of codes and Internet monitoring.	4
	The system meet the requirements of codes.	2
Fire water drainage /4	Fire - pump room, fire elevator well, basement, testing system and other drainage measures are designed in the system.	4
	Fire drainage measures are not perfect.	2

In Table 3, the score is the sum of scores for all sub-item indexes including the negative recommendation scores, and the results is not smaller than 0.



#### 4. Results

This paper established an evaluation system for fire water supply partitions in super high-rise buildings. Systematic evaluation is conducted for all indexes in different fire water supply designs in a super high-rise building. Reliability analysis is adopted for evaluating the fire water supply system in super high-rise buildings. In a fire water supply system, a reliability model is established first, then the reliability is calculated. Units and components in the fire water supply system are determined according to different analyzed objects. Fire water supply systems in partitions can be seen as units. Valves, hydrants, sprinklers, pipes and other components of the fire water supply system, as well as the fire pumps, fire water tanks, high fire water tanks, high fire water pools and other equipment can be seen as components.

Through selecting a suitable evaluation method, establishing an evaluation index system, and making qualitative and quantitative analysis for fire water supply forms in partitions, the evaluation system can help effectively solve new problems in the design of the fire water supply system, and provide a new method to improve reliability of the fire water supply system in super high-rise buildings.

#### Acknowledgements

This work was sponsored by the Ministry of Railways of the People's Republic of China and SP Tunnel and Underground Safety Center, which are gratefully acknowledged. The authors would also like to thank Associate Prof. Zhihao Xu and Associate Prof. Zhihui Deng for their help in the experiments, and Dr. Margaret McNamee for her valuable comments.

#### References

- [1] The Ministry of Public Security of the People's Republic of China 2014 Technical code for fire protection water supply and hydrant systems (GB 50974-2014) *China planning press* Beijing China
- [2] The Ministry of Public Security of the People's Republic of China 2014 Code for fire protection design of buildings (GB 50016-2014) *China planning press* Beijing China
- [3] Yan Bo, Su Xiaolin 2018 Discussion on fire water supply design of high-rise commercial and residential building under new fire protection code *Engineering Construction* **4**
- [4] Zhu Bo 2018 Common problems and prevention measures in the construction of fire water supply and drainage in building *Shanxi Architecture* **13**
- [5] ZHU Xiao-yang 2017 Characteristics and Design of Fire Water Supply System for High-rise Buildings *Construction & Design for Engineering* **21**
- [6] Wang Hongyu, He Jizhang, Huang Linlin 2017 Design pressure and zoning pressure of fire water supply system *Water & Wastewater Engineering* **3**
- [7] LIU Shengyun 2017 Fire Water Supply System Design of Super High-rise Buildings *Journal of the Armed Police Academy* **6**
- [8] Cuili Cao 2016 Discussion on Requirements of Fire Water Supply System By FM Global Standard *Water Purification Technology* **S1**
- [9] TONG Hui-jiao, CAO Li-ying, ZHU Lei-ji, XIONG Yong 2017 A state monitoring method of fire water supply system based on sliding filter *Fire Science and Technology*, **5**
- [10] Chih-peng Wang, Ban-jwu Shih 2018 Research on the Integration of Fire Water Supply *Procedia Engineering* **211** 778-787
- [11] Zhu Leiji, Tong Huijiao, Lou Liangliang, Xiong Yong 2017 A state monitoring method of fire water supply system based on hydraulic pressure mean value *13th IEEE International Conference on Electronic Measurement & Instruments*
- [12] P Grimwood, IA Sanderson 2015 The County/Metro research into fire-fighting suppressive capacity and the impact on building fire damage at >5000 UK building fires, 2009-2012 *Fire Safety Journal* **71** 238-247
- [13] PE Santangelo, P Tartarini, B Pulvirenti, P Valdiserri, AW Marshall 2010 Fire suppression by

- water-mist sprays: Experimental and numerical analysis *14th International Heat Transfer Conference* **5** 571-581
- [14] PE Santangelo, P Tartarini, P Valdiserri 2011 Experimental parametric analysis of water-mist sprays: An investigation on coalescence and initial dispersion *International Mechanical Engineering Congress and Exposition* **6(PARTS A AND B)** 1167-1174
- [15] G Grant, J Brenton, D Drysdale 2000 Fire suppression by water sprays *Progress in Energy and Combustion Science* **26(2)** 79-130
- [16] The Ministry of Public Security of the People's Republic of China 2017 Code for design of sprinkler systems (GB 50084-2017) *China planning press* Beijing China
- [17] Yang Qi 2002 A Study on the Reliability of Fire Water Supply System in High-rise Buildings *Fire Technology* **38** 71-79
- [18] Yang Qi 2007 Discussion on Application of System Evaluation in Water Fire Extinguishing System in Buildings *Water & Wastewater Engineering* **33** 94-96
- [19] Yang Qi 2011 Study on selection of water fire extinguishing system in super high-rise buildings *Water & Wastewater Engineering* **37** 91-95
- [20] YANG QI, CONG Bei-hua 2011 Technical and Economic Analysis of Fire Extinguishing System for Super High-rise Buildings *China Water & Wastewater* **27** 25-28