Fire Risk Assessment for Commercial Buildings Based on FRAME Method

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Abstract. Fire risk assessment is an important part of fire science and system safety engineering. "FRAME" means Fire Risk Assessment Method for Engineering. It is a widely used and comprehensive building fire risk assessment method based on a fixed index system, and compared with other methods, FRAME method can avoid artificial subjective influence, and it is more convincing. The paper discusses the advantages and calculation methods of FRAME, and takes a commercial building in Shijiazhuang as an example. By using the method, the fire risk of the building is evaluated and the strengthened fire protection measures are proposed based on the method.

1. FRAME method introduction
FRAME (Fire Risk Analysis Method for Engineering) is a semi-quantitative fire risk assessment method for building fires. It is developed from SIA81, which is developed by the Swiss engineer M. Gretener [1]. With the help of the FRAME, one can obtain the fire risk for the content, the occupants and the activities [2]. Compared with other semi-quantitative fire risk assessment methods, FRAME method has some unique advantages, the most important one is objectivity.

Most semi-quantitative fire risk assessment methods are rely on experts’ opinion to assign the weights of indicators, and the results are inevitably affected by subjective factors, such as Fuzzy Comprehensive Evaluation method (FCE) and Analytic Hierarchy Process (AHP) [3]. The FRAME method, on the contrary, is based on a fixed three-level index system [4] (as is shown in figure1), which covers building functions, fire loads, fire combustion reactions, fire separation, evacuation facilities, ventilation, fire detection, fire extinguishing systems, water supply and so on. And the calculation method of each indicator is fixed. The risk is determined by three first-level indicators: potential risk P, acceptable level A and protection level D[5], and calculated by Equation (1):

\[ R = \frac{P}{A \cdot D} \]
2. Calculation of fire risk based on FRAME method

2.1 Potential risk

Because the fire risk is made separately for the property, occupants and activities in it, the calculation of P is also different. For the property potential risk P, the calculation can be seen in Equation (2):

$$P = q \times i \times g \times e \times v \times z$$

(2)

where q is the fire load factor, i is the spread factor, g is the area factor; e is the level factor, v is the ventilation factor; z is the access factor.

The potential risk for occupants $P_1$ and for activities $P_2$ can be calculated by Equation (3) and (4):

$$P_1 = q \times i \times e \times v \times z$$

(3)

$$P_2 = i \times g \times e \times v \times z$$

(4)

It can be seen that the calculation of P involves of six secondary indicators, and each factor can be calculated as shown in table 1:

Table 1. The calculation of P

| Factor                        | Calculation |
|-------------------------------|-------------|
| The fire load factor q        | $q = \frac{2}{3} \lg(Q + Q_m) - 0.55$ |
| The spread factor i           | $i = 1 - \frac{T}{1000} - 0.11g m + \frac{M}{10}$ |
The venting factor $v$
$$v = 0.84 + 0.1\log m - 0.1\sqrt{k}$$

The area factor $g$
$$g = \frac{b + 5\sqrt{l} - b^2}{200}$$

The level factor $e$
$$e = \left[ \frac{|E| + 3}{|E| + 2} \right]^{|0.4|}$$

The access factor $z$
$$z = 1 + 0.05 \times \text{INT} \left[ \frac{b + H^+ - H^-}{20Z} \right]$$

2.2 Acceptable level $A$
For a certain fire risk, when the probability of fire is small and the fire result is not very serious, people can also accept such fire risk. In FRAME, it is represented by acceptable level $A$, which contains five sub-factors: active factor $a$, evacuation factor $t$, environmental factor $r$, property factor $c$ and dependent factor $d$.

Similar to potential risk $P$, the calculation of $P$ is also different for property, occupants and activities. For the property, the calculation can be seen in Equation (5):
$$A = 1.6 - a - t - c$$

For occupants $A_1$ and for activities $A_2$:
$$A_1 = 1.6 - a - t - r$$
$$A_2 = 1.6 - a - t - d$$

The calculations of each factor are as shown in table 2:

| Factor           | Calculation                                                                 |
|------------------|-----------------------------------------------------------------------------|
| The active factor $a$ | $a = \sum a_i$                                                             |
| The evacuation time factor $t$ | $t = \frac{px \left[ (b + l) + (X / x) + 1.25H^+ + 2H^- (b + l) \right]}{800K \left[ 1.4x(b + l) - 0.44x \right]}$ |
| The environment factor $r$ | $r = \log (Q_1 + 1) + \frac{M}{10}$                                       |
| The Content factor $c$ | $c = c_1 + c_2$, $c_2 = \frac{1}{4} \log (V / 7 \times 10^6)$              |
| The dependency factor $d$ | The values are given in FRAME manual                                       |

2.3 The protection level $D$
Protection level is an important part of fire risk assessment, the higher the protection level is, the lower the loss of fire will be. Protection level $D$ contains six sub-factors: water supply factor $W$, the normal protection factor $N$, the special protection factor $S$, the fire resistance factor $f$, the escape factor $U$ and the salvage factor $Y$. For the property:
$$D = W \times N \times S \times F$$

For occupants $D_1$ and for activities $D_2$:
$$D_1 = N \times U$$
$$D_2 = W \times N \times S \times Y$$

The calculations of each factor are as shown in table 3:
Table 3. The calculation of D

| Factor                      | Calculation                                      |
|-----------------------------|--------------------------------------------------|
| The water supply factor W   | \( W = 0.95^w \sum w_i \)                      |
| The normal protection factor N | \( N = 0.95^n \sum n_i \)                      |
| The special protection factor S | \( S = 1.05^s \sum s_i \)                      |
| The fire resistance factor F | \( F = \left[ 1 + \frac{f_s}{100} \right] \times \left[ 1 - \left( \frac{1}{40} \right)^{2.5} \right] \) |
| The escape factor U         | \( U = 1.05^u \sum u_i \)                      |
| The salvage factor Y        | \( Y = 1.05^y \sum y_i \)                      |

3. Fire risk assessment and analysis of commercial building

3.1 Project profile
The paper takes a large-scale commercial complex as an example. The project has 10 floors above ground and 4 floors underground, providing commerce, office, catering and entertainment services. The height of building is 65.25 m, it is a Class I high-rise building with a fire-resistance grade of I. The paper selects a men's store on the fourth floor of a commercial building as an example.

The main fire load of the compartment is cotton clothing and wooden counters. The compartment is 4.7m high and the total area is 3446.4m². There are two smoke proof staircases, with a total evacuation width of 12.8m. The fire compartment is covered with automatic sprinkler facilities, smoke detectors, evacuation signs, emergency lighting devices and mechanical ventilation systems.

3.2 The results of assessment
By calculating various factors of the fire compartment through FRAME method, the results can be obtained. The results of potential risk P, acceptable level A and protection level D are shown in table 4, table 5 and table 6 respectively.

Table 4. The results of potential risk P.

| Factor                      | Explanation                                      | Result |
|-----------------------------|--------------------------------------------------|--------|
| The calculated value of q is 1.65 |                                  |        |
| Immobile fire load density  | Totally Incombustible                           | 0      |
| Mobile fire load density    | Ordinary fire hazard with high fire load         | 2000   |
| The calculated value of i is 1.15 |                                |        |
| Average dimension m         | Defined by the combustibles                      | 0.3    |
| Flame propagation class M   | Class D                                          | 3      |
| The calculated value of g is 2.21 |                              |        |
| Theoretical length l        | The longest distance between the centres of two sides | 96.15  |
| Equivalent width b          | Divide this area by the length to obtain the equivalent width | 35.84  |
| Frontage                    | Building only accessible at its narrow side       | narrow |
| The calculated value of v is 1.08 |                                |        |
| Height h                    | The height between floor and ceiling in the compartment. | 4.7    |
| Smoke venting ratio k       | Nominal flow of mechanical (smoke) ventilation systems | 12     |
|                             | Total area of compartment                        | 3446.4 |
The smoke venting ratio $k = 0.35\%$.

The calculated value of $e = 1.54$

Level E

The number of the floor $= 4$

The calculated value of $z = 1.05$

Access directions

The number of accessible directions is $Z (1$ to $4)$. $= 3$

$H$

The height of the compartment $= 22.8$

Equivalent width $b$

See as above $= 35.84$

Table 5. The results of Acceptable level A

| Factor | Explanation | Result |
|--------|-------------|--------|
| Total value of the activation factor $a$ | 0.2 |
| Main activities | Most industries, large stores, retail shops | 0.2 |
| Electrical Installations. | In compliance with the rules and regularly checked | 0 |
| Evacuation time factor $t$ | 0.61 |
| Number of occupants | Sales area on floors above access floor | 689 |
| Mobility factor | 70% adults, 15% children, 15% old man | 2.2 |
| Content factor $c$ | 0 |
| Relative value | The contents can be replaced easily | 0 |
| Absolute value of property | Value of property in million of EUR | 3 |
| Reference value | Value in EURO (corrected for inflation) | 1.72 |
| Environment factor $r$ | 0.3 |
| Reaction to fire class of surfaces $M$ | Same as above | 3 |
| Dependency factor $d$ | 0.3 |
| Added value /turnover ratio $d$ | Average for most businesses | 0.3 |

Table 6. The results of Protection Level D

| Factor | Explanation | Result |
|--------|-------------|--------|
| Water supply factor $W$ | 1.65 |
| Water storage type $w_1$ | Water storage for general use, automatically filled | 0 |
| Water storage capacity $w_2$ | Result | 0 |
| Distribution network $w_3$ | Nominal diameter of main water piping | 0 |
| Hydrant hose connections $w_4$ | Average distance between connection on the building perimeter | 24 |
| Static pressure $w_5$ | Result | 0 |
| Normal protection Factor $N$ | 0.81 |
| Fire brigade arrival | Arrival after 10 to 15 min | 2 |
| Occupants' training | Only a limited number of persons trained | 2 |
| Special protection factor $S$ | 2.18 |
| Automatic fire detection | Smoke alarm units | 2 |
| Use of water | Reserved for fire fighting only | 2 |
| Pressure / Flow energy source | Single flow/pressure source | 2 |
| Fire resistance factor $F$ | 1.93 |
| Structural / compartments | Average fire resistance of the structural elements: | 180 |
| Outside walls | Average fire resistance of the outside walls | 60 |
| Ceiling or roof | Average fire resistance of the ceiling or the roof (RE) | 15 |
| Interior walls | Average fire resistance of interior walls (EI) | 45 |
| Escape protection factor $U$ | 8.99 |
| Sub compartments | EI60 | 4 |
| Exit path protection | More than one enclosed and smoke protected inside stair | 4 |
| Sprinklers | All of compartment is protected by sprinklers | 10 |
| Salvage factor $Y$ | 1.8 |
| Compartmentation | EI60 | 4 |
By solving various indicators above, the final risk value of the building can be obtained, which is shown in table 7.

Table 7. The final results

| Item            | Value |
|-----------------|-------|
| Potential risk P|       |
| P               | 7.36  |
| P₁              | 3.33  |
| P₂              | 4.46  |
| A               | 0.79  |
| Acceptable level A|      |
| A₁              | 0.49  |
| A₂              | 1.10  |
| D               | 3.43  |
| Protection level D|     |
| D₁              | 7.32  |
| D₂              | 3.19  |
| Fire risk value R|      |
| (Initial Risk R₀=3.94) | |
| R               | 2.71  |
| R₁              | 0.93  |
| R₂              | 1.27  |

3.3 Analysis of assessment results

The fire risk value of the building can be obtained by using FRAME method. Now, the results are analyzed and Suggestions are given to improve the fire safety of the building.

(1) For initial Risk R₀

In FRAME manual, when the value of R₀ is between 1.6 and 4.5, the building need to improve the reliability of sprinkler system, and if R₀ is greater than 2.7, water supplies need to be strengthened [6], such as increasing the number or capacity of fire pools, the number of water pumps or fire hydrants.

(2) For potential risk P

In the module of potential risk P, if the value for the venting factor v is greater than 1.1, it indicates that the mechanical exhaust smoke volume should be increased to avoid the threat of smoke [7]. Besides, when the access factor z is greater than 1, a fire lane around the building is required to give a better access to the building for firefighters [8].

(3) For acceptable level A

Generally speaking, the fire prevention separation, evacuation facilities, activities and other aspects of the compartment is relatively comprehensive, but there are some aspects can be strengthened. In terms of evacuation factor t, we can increase the width of the walkway and improve emergency lighting or evacuation broadcast system to avoid panic of evacuees; In terms of environmental factors r, the owner can store clothes separately to reduce risks. Conditions permitting, fireproofing treatment can be carried out on the counter, which can mainly reduce flame propagation class M.

(4) For protection level D

In this part, special inspection is required to find out and deal with fire hazards. Besides, the manager should organize all the staff to receive basic fire training and be able to use fire extinguishing facilities. In addition, in order to improve the level of fire safety of the building, some key areas need special protections, such as gas extinguishing system, powder extinguishing system and foam extinguishing system, which will improve the fire control and fire extinguishing capacity of high-risk areas.

4. Conclusion

FRAME method is a widely used method for fire risk assessment, which considers various aspects of fire, such as building structure, fire load, fire separation and fire-fighting facilities system. By using FRAME method, the risk of building can be calculated objectively, but there are still shortcomings in the method. Firstly, the basic data of FRAME can’t keep pace with economic development in recent
years, the data needs to be updated. Besides, some of factors are not reasonable, such as the evacuation time factor $t$, it doesn’t consider the warning time and preparation time. Therefore, further research of the innovation and improvement is needed.

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