Development of a new performance evaluation index and evaluation program for improving the fire control performance of non-residential buildings

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1. Introduction

The fire control performance required by the Building Standards Act for buildings is limited to the minimum level deemed necessary from the perspective of protecting life. Therefore, compliance with the legal standards does not necessarily guarantee the prevention of major fire damage. In recent years, there have been some cases of extensive fire damage in buildings that have complied with the standards, causing the buildings to become unusable for a long period of time or requiring reconstruction. Under such circumstances, it is believed that there is a certain level of demand for securing fire control performance that exceeds the minimum level. However, especially for non-residential buildings, evaluation frameworks, such as performance index systems, remain yet to be developed.

Therefore, this study focuses on non-residential buildings and examines a framework for the quantitative evaluation of their performance to maintain functions after fire damage.

2. Function maintenance performance

This paper defines function continuity performance as the percentage of the total length of time during which the functions provided by a building during its service period are maintained after a fire that reduces the building performance (Figure-1).

$$R = \int_{t_0}^{t_L} \frac{F(t)}{t_L - t_0} dt \quad (1)$$

Here, $F(t)$ is the function ratio of the building, t_0 the point of the start of the analysis, and t_L the end period of the analysis. The functionality $F(t)$ is a variable that represents the condition of the building as a whole. Meanwhile, fires that occur within a building are considered to spread independently in each of the fire compartments that make up the building. Therefore, the functionality is going to be evaluated in units of fire compartment, and the functionality $F(t)$ for the entire building is calculated as follows.

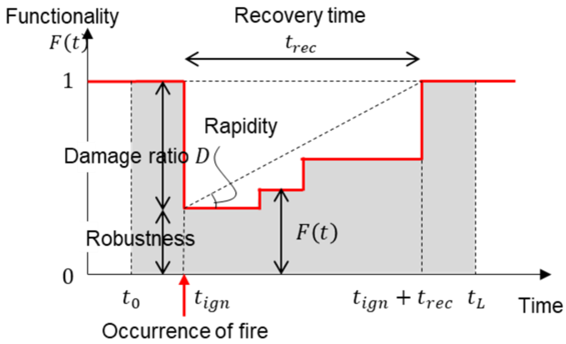

Figure 1: Function maintenance performance of a building with fire damage

$$F(t) = \frac{\sum_{i=1}^{N} w_i \cdot f_i(t)}{N} \quad (2a)$$

$$f_i = \begin{cases} 1 & (t < t_{ign}) \\ 0 & (t_{ign} \le t \le t_{ign} + t_{rec,i}) \\ 1 & (t_{ign} + t_{rec,i} < t) \end{cases} \quad (2b)$$

Here, N represents the number of fire compartments within the building, i the identifier of the fire compartments, w_i weighting factor ($\sum_{i=1}^{N} w_i = N$) according to the functional importance of the fire compartment, $f_i(t)$ the functionality of a fire compartment i, t_{ign} the time of the occurrence of fire, and $t_{rec,i}$ the recovery time.

Incidentally, buildings are made up of various components with different resistance to the heat of fire. Even within the same fire compartment, the degree of damage and the process of restoration work in case of damage vary greatly depending on the component. Thus, the components of a building are classified into structural component S, nonstructural component NS, equipment E, and stored material F. Since the restoration of all these components is a prerequisite for the fire compartment to be usable, the recovery time $t_{rec,i}$ of the fire compartment i is expressed as follows.

$$t_{rec,i} = max\{\sum_x t_{rec,i(x)}, \ t_{rec(R),i}\} \ (x = S, NS, E, F) \quad (3)$$

Here, $t_{rec,i(x)}$ is the recovery time of the component x $(x = S, NS, E, F)$ of the fire compartment i. Yet, to make it simpler, this study assumes that the restoration work at individual sections cannot proceed simultaneously, and that the work on the next section can be started when the work on one section is completed. Also, $t_{rec(R),i}$ is the time required for other fire compartments to be restored, which is a prerequisite for a fire compartment i to be operational.

The evaluation of a recovery time $t_{rec,i}$ of a fire compartment requires the understanding of what type of fire will start in a building and then the evaluation of the area and the extent of the damage. However, since the nature of the fire occurring in the fire compartment cannot be uniquely determined because of the influence of various uncertain factors, the following probabilistic approach is adopted here to obtain $t_{rec,i(x)}$.

$$t_{rec,i(x)} = \int_t t(D_{i(x)}) \cdot p(D_{i(x)} | t^*_{fire,i}) \cdot p(t^*_{fire,i}) \, dt^*_{fire} \quad (4)$$

Here, t^*_{fire} is the equivalent fire duration, D the fire damage rate, and $t(D)$ the recovery time if the degree of damage is D.

3. Case study

To summarize the characteristics of the above method, a case study was conducted on the steel-framed, three-story office building with a total floor area of 3,432 m^2 as shown in Figure 2. Here, we focused on the three items shown in the table (fire resistance period t_R (RS), installation of sprinkler system (SP), and sectioning of room D (C)) and examined the change in functional continuity performance according to the combination of these measures. However, the analysis period $t_L - t_0$ required to determine the functional continuity performance was fixed at one year after the occurrence of the fire. For simplicity, it was assumed that the entire building becomes closed when restoration work is being done in any of the fire compartment after the fire.

Figure 3 shows the outcome of the calculation. The basic condition O means that a fire resistance time t_R is 60 minutes for the main structure with no sprinkler system, and no compartmentalization for room D. In this case, the restoration time t_{rec} was 82.6 days, and the function continuity performance 0.774. In contrast, for conditions RS, C, and SP, where one of the three items was improved, the recovery time t_{rec} ranged from 49.4 to 70.3 days (reduction rate against condition O was 14.9 to 40.2%), and the functional continuity performance ranged from 0.807 to 0.865 (increase rate against condition O was 4.3 to 11.8%). Among the conditions in which multiple items were improved, RS + C + SP was the condition in which the functional continuity performance improved the most, with a recovery time t_{rec} of 29.9 days (reduction rate 63.8%) and functional continuity performance of 0.918 (increase rate 18.6%).

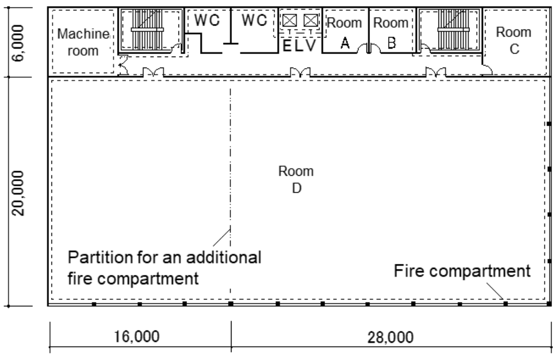

Figure 2: Standard floor plan of the subject building

Table: Conditions of calculation

Condition	Item		Basic proposal (O)	Improved proposal
RS	Fire resistance time t_R	Main structure	60 min	90 min
		Exterior window	20 min	
SP	Sprinkler system		Available	Not available
C	Number of fire compartment in room D		1	2

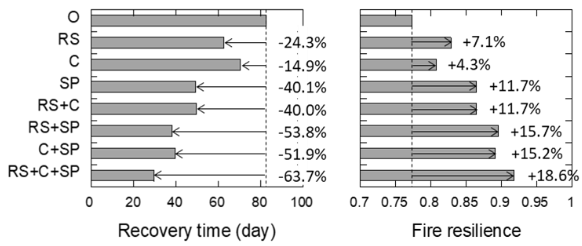

Figure 3: Result of calculating restoration time and function continuity performance

4. Summary

Since the impact of damage to equipment E and stored material F is considered particularly significant for the continuation of functions, future studies will be conducted to enable appropriate assessments.