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Estimation of fire endurance time for RC frame member based on machine learning algorithm

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ABSTRACT

Since the behavior of RC structures exposed to high temperature is complex due to changes in material properties, a sophisticated numerical analysis for fire-damaged RC requires relatively long analysis time. To address this limitation, this study uses a machine learning algorithm to estimate the resisting capacity of fire-damaged RC. While the trial-and-error method must be applied to numerically estimate the fire endurance time of structural members, the suggested prediction model provides direct and rapid estimation within reasonable reliability.

1. INTRODUCTION

To reduce casualties and property damage in fire accidents, it is crucial to predict the behavior of structures at elevated temperatures accurately. However, fire analysis is quite complex because it must consider changes in material properties and structural characteristics resulting from exposure temperatures that vary over time (Hwang et al., 2016). Since transient heat transfer analysis and nonlinear structural analysis must be performed simultaneously, generally, the computational costs are considerable relative to the structural complexity. Machine learning techniques can mitigate these limitations by generating efficient and time-saving prediction models (Kim et al., 2023). This study proposes a prediction model for fire damaged structure using a machine learning algorithm. This model provides effective prediction of fire endurance times not only at the member level but also at the structural level.

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2. NUMERICAL MODEL

Since there are limitations to experimentally acquiring enough data required for a machine learning algorithm, a sophisticated numerical analysis model (Hwang et al., 2016) that has been verified with experiment was used to obtain data-set.

2.1 Material models

The total uni-axial strain ($\Delta\varepsilon_{\mathrm{tot}}$) of concrete and steel at time *t* after fire can be divided into mechanical strain ($\Delta\varepsilon_{\mathrm{m}}$) and non-mechanical strain ($\Delta\varepsilon_{\mathrm{nm}}$) as shown in Eq. (1):

$$\Delta\varepsilon_{\mathrm{tot}}(t) = \Delta\varepsilon_{\mathrm{m}}(f, T) + \Delta\varepsilon_{\mathrm{nm}}(f, T, t) \quad (1)$$

where *f* denotes the stress at temperature *T*. The non-mechanical strain of concrete is composed of thermal, creep, and transient strain. For the steel reinforcement, thermal and creep strains are considered. More detailed information about material models applied to numerical analysis can be found elsewhere (Hwang et al., 2016).

2.2 Data-set

A numerical parametric study was conducted using numerical analysis that sequentially coupled with transient heat transfer analysis and nonlinear structural analysis. The temperature-time curve was assumed to be exposed to the ASTM E119 standard fire curve. The number of 1770 P-M diagrams was obtained as a result of numerical analysis, which varied the width (*B*) and height (*H*) of the rectangular cross-section, the amount of reinforcement placed in each direction (*BN* & *HN*), and the fire exposure time (*R*). For each case, the data-set was constructed to include all possible combinations of P and M within the corresponding P-M diagram (see Fig. 1).

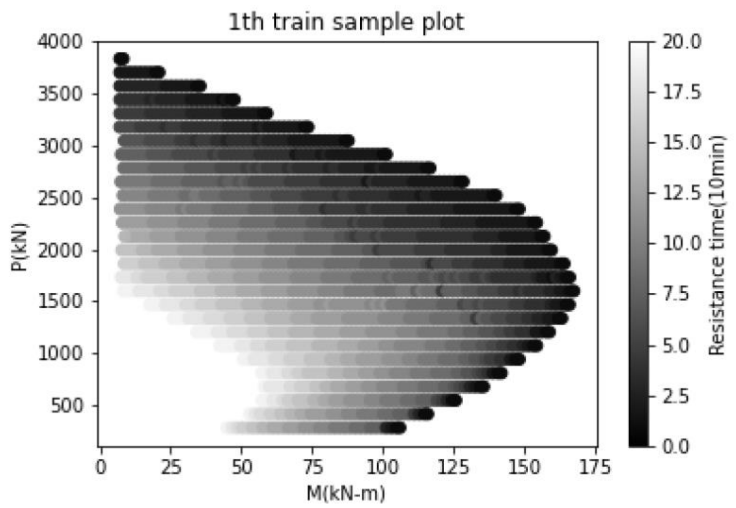

Fig. 1 Example of data-set

3. MACHINE LEANING BASED PREDICTION MODEL

Among various machine learning algorithms, a decision tree model, which can easily take into account mechanical constraints (Pei & Hu, 2018), was used to make a prediction model through learning. It was trained to distinguish between withstand and collapse in a binary form for given cross-sectional and loading conditions by fire exposure time. The proposed model can effectively predict the fire endurance time of each member of an RC frame subjected to loads. Compared to the results by sophisticated numerical analysis, there is a difference of up to 5 time steps as shown in Fig. 2; however, the overall tendency, based on the change in load conditions, is similar. The fire endurance time is predicted conservatively compared to the numerical results, resulting in a prediction that is on the safe side. As shown in Fig. 2, there is a discrepancy of up to five time steps when compared to the results by numerical analysis. Nevertheless, the overall trend in response to variations in load conditions is similar to numerical results. Additionally, the predicted fire endurance time is conservative relative to the numerical results, thereby providing a safe-side prediction.

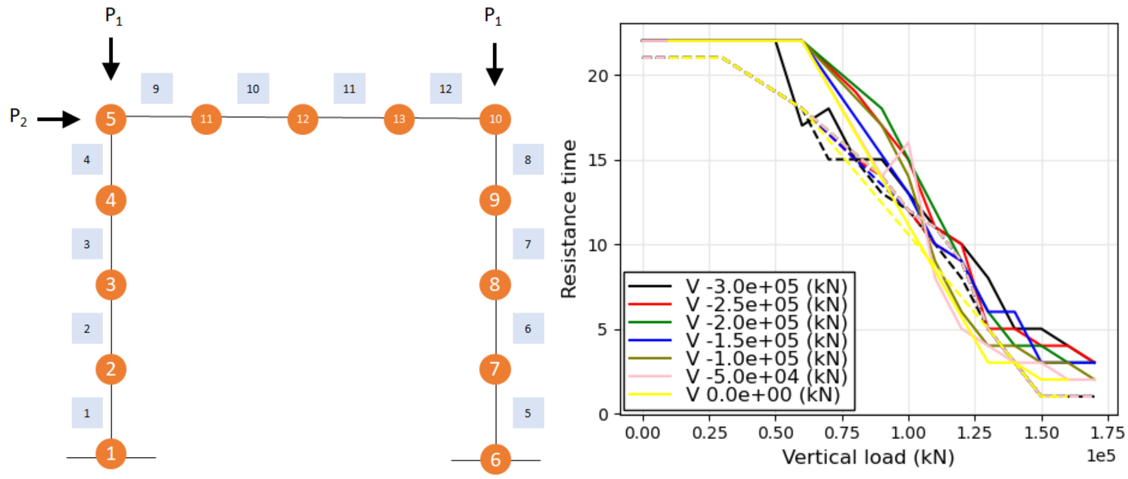

Fig. 2 Prediction of fire endurance time of RC frame

4. CONCLUSIONS

This study proposes a machine learning-based prediction model that predicts the endurance time of RC frames exposed to elevated temperatures. The proposed prediction model is expected to be of great help in quickly and effectively identifying vulnerable areas within the entire structure in the event of a fire.

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