Proceedings of the 10th World Congress on Momentum, Heat and Mass Transfer (MHMT 2025)
Barcelona, Spain - April, 2025
Paper No. ENFHT 167
DOI: 10.11159/enfht25.167

Development of a Novel Quantitative Fire Risk Assessment Tool for Deep Underground Subway Stations Based on Evacuation Simulation

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Extended Abstract

Quantitative Fire Risk Assessment (QFRA) is a critical method for evaluating fire hazards and safety measures, especially in complex environments such as deeply underground stations. These environments present significant challenges due to confined spaces, limited ventilation, and restricted evacuation routes, making fire risk assessment particularly important. Traditional QFRA methods generally focus on frequency analysis using event tree modelling, consequence analysis, and risk calculation, while identifying key risk factors such as ignition sources, tunnel geometry, passenger behaviour, and the ventilation system. However, while these methods provide valuable insights, they often fail to capture the dynamic interactions between fire events, infrastructure, and human behaviour in emergency situations. Furthermore, traditional QFRA techniques often rely heavily on frequency analysis to estimate the likelihood of fire incidents, but available data is often insufficient to generate reliable estimates, particularly in unique or complex settings like deeply underground stations.

To address this gap, this study introduces a simulation-based approach that generates new event data to supplement existing datasets. The study aims to enhance the traditional QFRA approach by integrating fire simulations and evacuation simulations, creating a more comprehensive fire risk assessment for deeply underground stations. Using the Fire Dynamics Simulator (FDS), the study examines the effect of escalator operation conditions on life safety by analysing smoke propagation and evacuation dynamics. The escalator speeds considered are 0.5 m/s (working condition) and 0 m/s (non-working condition). The simulations include six carriages in the subway, with 40 passengers on each carriage.

The results indicate that when the escalator is operating, smoke propagates more quickly to the ground floor, whereas in the non-working condition, the smoke tends to move naturally towards the exits. For a fire at the head of the train, visibility (~6 meters) is 84 seconds in the working condition and 87 seconds in the non-working condition. The fatalities are 115 and 157 for the working and non-working conditions, respectively. For a fire in the middle of the train, visibility is 161 seconds in the working condition and 143 seconds in the non-working condition. The fatalities are 7 and 38, respectively. For a fire at the end of the train, visibility is 84 seconds in the working condition and 73 seconds in the non-working condition. The fatalities are 101 and 143, respectively. The total risk is 7.24E-3 for the working condition and 5.77E-4 for the non-working condition.

By incorporating evacuation simulations, this approach provides a more comprehensive understanding of fire risks in deeply underground stations. The dynamic assessment of human behaviour and evacuation under fire conditions ensures that the station's design and safety measures are robust and effective in real-world emergency scenarios. Furthermore, this methodology can be applied to assess the impact of different fire scenarios, helping to identify the most critical vulnerabilities in the station's infrastructure.

Acknowledgement

This research was supported by the Korea Energy Technology Evaluation and Planning (KETEP) with funds from the Ministry of Trade, Industry and Energy, Republic of Korea, grant number 20224B10200110.

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