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Experiment Study on enhancing performance of the air curtain in subsea tunnels

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ABSTRACT

It is difficult to effectively exhaust the smoke from the tunnel because it is typically has semi-closed structural characteristics and moreover, because of rising temperature coupled with toxic smoke, it is difficult to perform evacuation and firefighting activities. In this study, after zoning the area to prevent the smoke from spreading to neighboring area, smoke control performance test by tunnel height was performed using air curtain system which is the local smoke control system that will secure the evacuation passage as well as extend the time for evacuation. Consequently, in case of both the tunnel height 6.3m for ordinary road tunnel and 3.5m for small car, smoke barrier created by air curtain contributed to preventing the hot smoke generated by the vehicle fire in tunnel from spreading to neighboring zone.

1. Introduction

The importance of developing the underground space in a bid to create the new space for the future has been widely recognized at home and abroad and the space newly created is used to accommodate unpleasant facilities, underground new town for urban restoration and existing road into the underground level and high speed double-deck tunnel. Particularly in Europe and the United States, urban deep tunnel road has been built actively in an effort to secure the green

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zone at ground level, deal with the traffic congestion and develop the sustainable new space and green growth. When it comes to the large cities in Asia such as Seoul, they have been implementing underground road scheme, considering that traffic congestion is one of the major factors which hinders the urban competence. In detail, urban tunnel for small cars such as A86 in France and SMART road tunnel in Malaysia are the good examples. Then, in view of the fire occurred in large tunnels, it is mainly caused by defective electrical facilities, engine problem or collision accident (Kim, 2004) and rapid fire spread and smoke exhaust in closed tunnel space remain the critical issues.

As seen from the tunnel fires in the past, the heat and combustion products generated from the car fire mostly moved to the tunnel ends, causing dangerous environment to the cars and people who are evacuating which eventually resulted in loss of lives. Though the tunnel fire occurs not frequently statistically, smoke spreads very fast within the tunnel and evacuation is never easy and furthermore, it is difficult to identify the situation in tunnel and unrecognized cars keep going into the tunnel which may lead to fatal accident. Hence the study to develop the technologies to effectively deal with it is a must.

2. Local smoke control device

A large amount of smoke generated is due to limited oxygen in tunnel which causes incomplete combustion and furthermore, entrapped smoke tends to stay at the tunnel which threatens the life of the drivers and passengers. When fire occurred, the smoke generated at fire source rises to the ceiling due to increased buoyancy by heat and then forms the ceiling jet and extends lengthwise in the tunnel, which begins falling down when smoke layer is developed, which hinders the evacuation activities. Visual disturbance by smoke is caused by carbon particles that block the light, making difficult for the people to find the exit or sign or causing visual impairment. The flame generated from the fire is hot and light and thus, when it reaches to the ceiling, it moves lengthwise in tunnel, sometimes, to the distance up to 5 to 10 times of the tunnel diameter. The frame moving lengthwise on ceiling and the air is mixed at slower pace than lengthwise-moving, which is then stabilized when the lighter smoke is laid on heavier smoke. At this time, turbulent eddies become weak by buoyancy and mixing air is also reduced and importantly, lengthwise flame mixing is made only either side of the flame. As hot smoke combustion product formed under the ceiling may move extended distance without mixing with the air, it is necessary to directly exhaust the smoke from this layer using appropriate equipment or delay the smoke spreading by smoke control device (Yoo, 2010)

When it comes to a long and deep tunnel, mechanical smoke exhaust system is mostly used to deal with fire smoke. However in case of a double-deck tunnel or the tunnel for small car only where smoke spread is fast because of a lower tunnel height or when it takes time to convert to exhaust mode from ventilation mode or when smoke volume is larger than expected, smoke spread area may be extended despite of operating smoke control system. That is, when mechanical supplement to be able to cover the entire length of the tunnel is difficult, the measure to locally prevent smoke spreading is required, and the alternative such as air curtain in Fig 1 which prevents smoke from spreading and securing the evacuation passage could be applied. In foreign countries, EMNantes and CSTB in France conducted the study to secure design data on air curtain system which blocks the heat and air current in tunnel (Elicer-Cortes et al., 2009) In addition, through theoretic review and model test of jet stream discharged from air curtain, the result of the study on effect of the element on air curtain performance and similarity law was presented.

In China, the result of the model test and simulation test of the performance of air curtain which isolates the carbon monoxide (CO), fire smoke and temperature from the fire was made public (Hu, et al., 2008) and in Korea, performance verification of station smoke control system to deal with train fire was conducted by a full-scale test and besides, a full-scale vehicle fire test was conducted in the road tunnel so as to verify the heat resistance performance of air curtain system (Park, et al., 2017) In line with varying structure of the tunnel depending on use, application of local smoke control system which is appropriate to tunnel environment needs to be extended through the study on performance verification for various tunnel heights (Figure 1).

3. Performance evaluation test of air curtain depending on tunnel height

3.1. Ordinary road tunnel (tunnel height: 6.3m)

The test was conducted in unused tunnel (9.8m wide, 6.3m high and 120m long with 2 lanes) As seen in Figure 2, the censors to measure the temperature and CO were set.

Air curtain was set at 20m from the tunnel entrance to evaluate the smoke-capturing capacity to prevent the smoke from spreading and 11 temperature sensors were set at 3m interval from the point 60 inside air curtain and 1 sensor outside air curtain. And 1 CO-measuring loop was set inside and outside air curtain boundary, respectively, to check toxic gas isolation effect. Operation condition of air curtain was discharge velocity 30m/s and discharge angle 15 degree.

Fire source was simulated by burning midsize car and as indicated from precedent study, it is estimated at 3.5MW caloric value (Yoo et al, 2007).

3.2. Test result of ordinary road tunnel

According to the test result, fire smoke began spreading fast along the upper level of the tunnel in 3 minutes after fire occurred and air curtain began operating to block the smoke layer. As seen in Figure 3, smoke barrier was formed by air curtain, which may extend the time necessary for evacuation in a way of constraining the flow of smoke layer when air curtain is installed at certain interval and as seen in Figure 4, the temperature in tunnel began rising quickly at TC 7, the nearest point from the vehicle, in 3 minutes which was followed by TC 2 and TC 3 and in case of TC 12 outside air curtain, it maintained 24°C which was similar to the temperature before the test but different from that inside air curtain by 20 °C

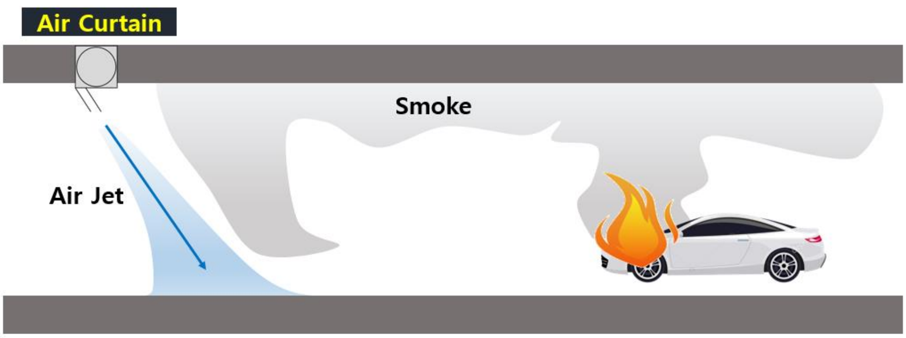


Figure 1. Schematic of air curtain in tunnel fire.

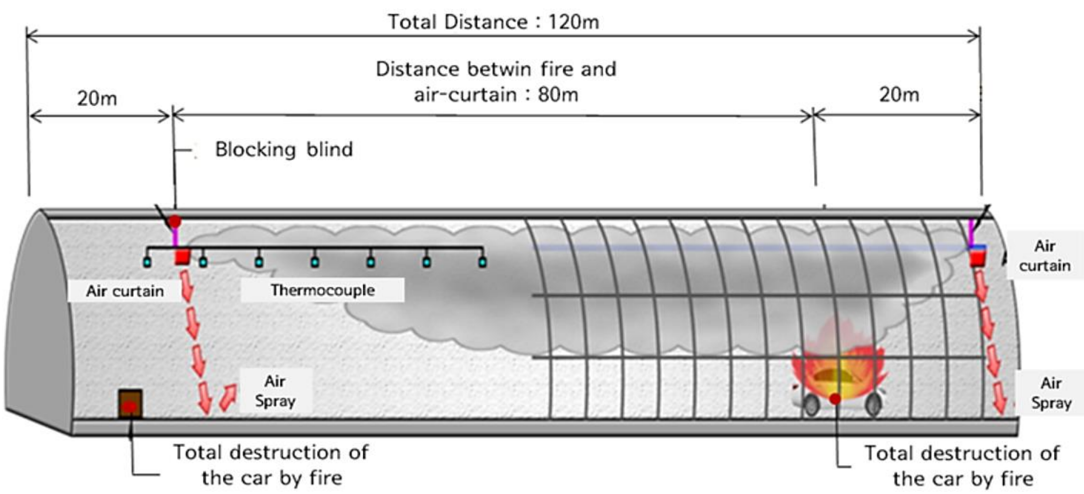


Figure 2. Schematic of fire test for ordinary road tunnel.

thanks to smoke control barrier that blocks hot smoke layer. As a result of measuring CO (Figure 5) which is considered the most harmful factor in fire, it is 0ppm outside the air curtain which is similar level as normal condition but the value measured at 0.5m inside the air curtain was 47ppm which was attributable to incomplete combustion due to low oxygen level controlled by air curtain and in fact, higher temperature smoke and toxic gas are expected near the fire in tunnel.

3.3. Test in tunnel for small car only (tunnel height 3.5m)

Model tunnel was fabricated to provide air curtain performance test in low tunnel (9.5m wide, 3.5m high and 30m long) and as seen in Figure 6, the censors to measure the temperature and CO were set. And tunnel entrance was blocked by tent and air curtain was installed at the exit to evaluate the smoke-capturing effect that prevents smoke from spreading in fire and 10 temperature sensors were set using TC tree at 5m from the boundary inside and outside the air curtain for comparison and analysis. And a CO-measuring loop was set inside and outside the air curtain, respectively, to evaluate the toxic gas isolation performance. Operation condition of air curtain was discharge velocity 30m/s and discharge angle 15 degree and 2,000cc midsize car was burnt completely.

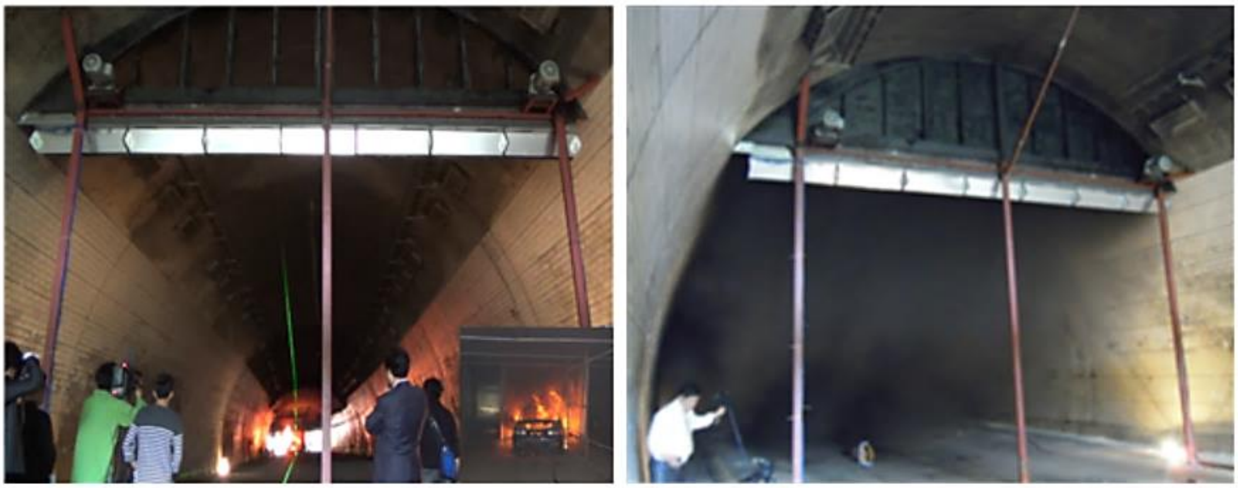


Figure 3. Photo of ordinary road tunneltest (OO Tunnel).

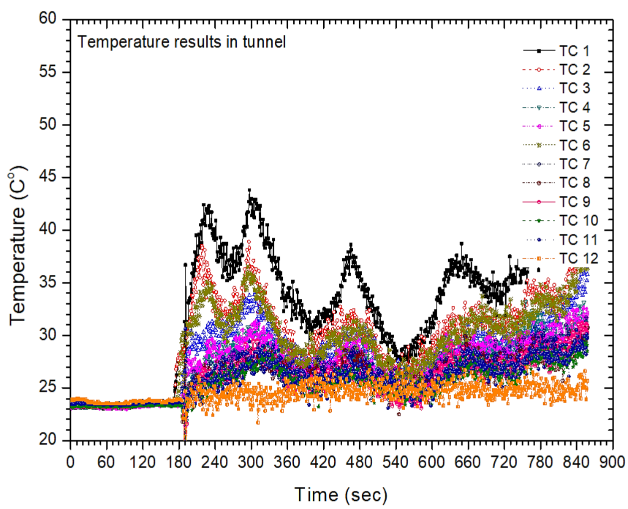


Figure 4. Temperature results of tunnel fire test for ordinary road tunnel.

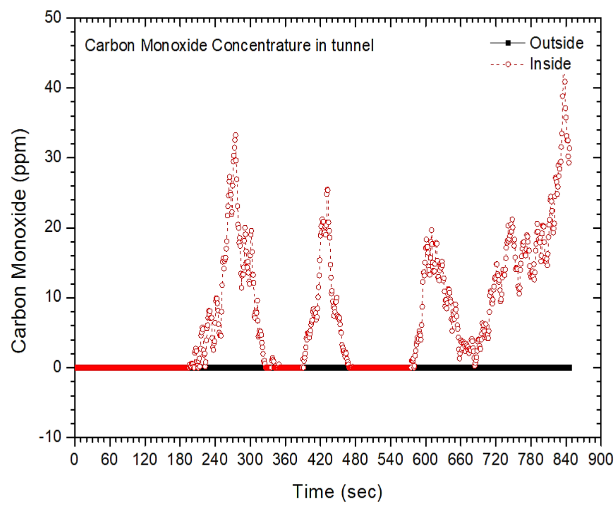
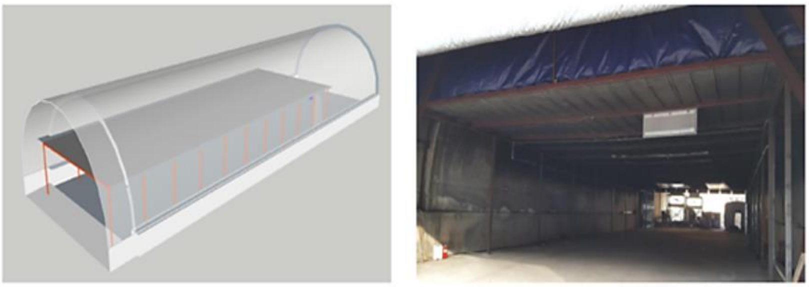


Figure 5. CO concentration of tunnel fire test for ordinary road tunnel.

3.4. Result of the test in the tunnel for small car only

In a minute after fire occurred, smoke layer formed at upper level of the tunnel began spreading rapidly, which was then blocked by air curtain. As seen in Figure 7, smoke barrier by air curtain prevented smoke layer from spreading and as seen in Figure 8, temperature at TC 6 ~ 10 in tunnel rose rapidly in a minute but the temperature at TC 1~5 outside air curtain was maintained at initial level before test thanks to isolation effect of the air curtain. When it comes to carbon monoxide concentration as seen in Figure 9, the value outside air curtain 0ppm was same as outdoor level while the value inside air curtain rose to 60ppm which was similar to temperature variation pattern. Such result was attributable to incomplete combustion due to low oxygen level controlled by air curtain which was further deepened, particularly in tunnel with small section.



(a) Model tunnel for small car only

(b) Set up the sensor measurements (T/C and gas analyzer)

Figure 6. Photo and image for model tunnel and sensor.

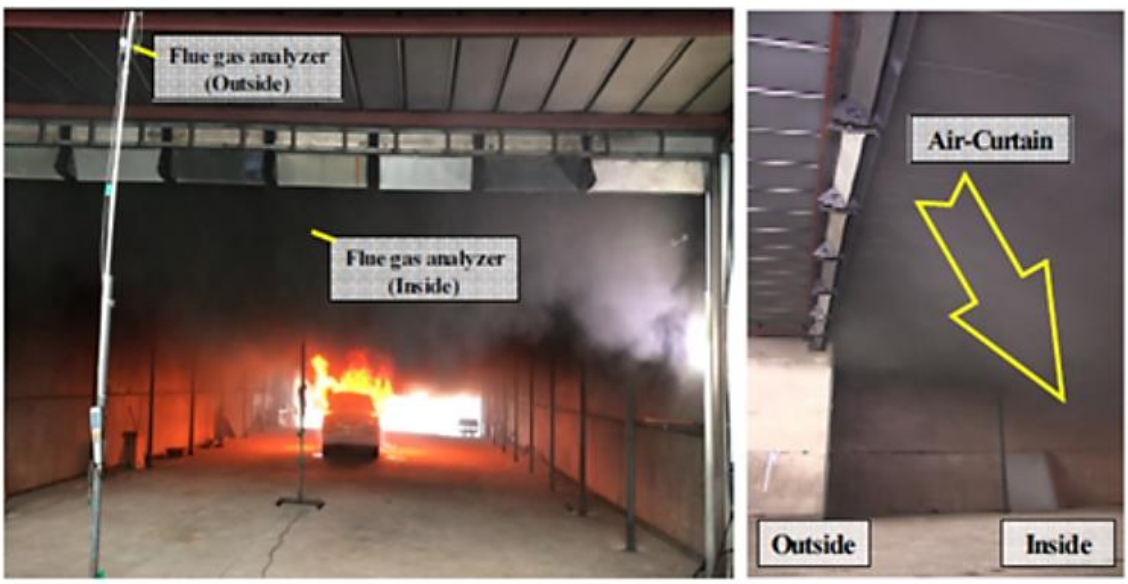


Figure 7. Photo of model tunnel test (small car only).

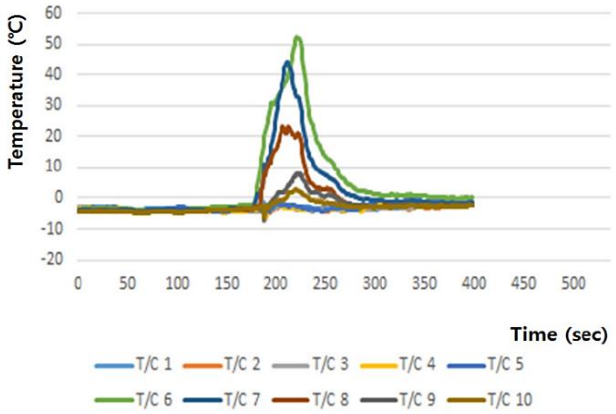


Figure 8. Temperature results of tunnel fire test for small car only.

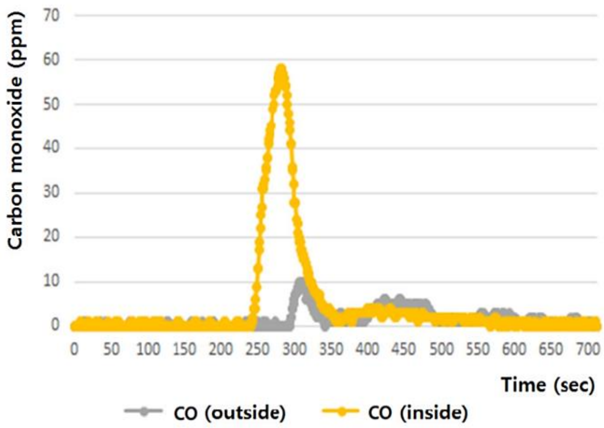


Figure 9. CO concentration of tunnel fire test for small car only.

4. Conclusion

Performance evaluation of air curtain which is under development to apply the local smoke control device for the purpose of enhancing the fire safety in a long and deep tunnel was conducted. Consequently, smoke barrier by air curtain effectively isolated the hot smoke layer generated by the fire in both ordinary high tunnel and low tunnel for small cars, thereby preventing the fire from spreading and the concentration of carbon monoxide inside and outside air curtain was significantly different up to 40 to 60 times.

Air curtain in tunnel proved to be applicable to evacuation of the passengers in tunnel and is particularly useful for the midsize tunnel without smoke control system as supplementary measure to enhance the fire and evacuation safety. To that end, further study on extending the application and improving the efficiency of air curtain system is critical.

5. Acknowledgements

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