IH-635 Managed Lanes Project
Depressed Managed Lanes

Preliminary Tunnel Fire Simulation

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1 Executive Summary

1.1 Introduction

This study report documents the modeling and analysis of the IH-635 Depressed Managed Lanes, in the event of a truck fire accident.

The objective of this study is to determine the behavior of smoke inside the Depressed Managed Lanes and its effect on motorists traveling in the opposite direction of the event. Detailed CFD models have been built to simulate scenarios of a truck on fire inside the Depressed Managed Lane Section. A mix of vehicles consisting of cars, buses and trucks are assumed backed up behind the fire. The incoming traffic in the opposite direction is also assumed stopped.

This fire study consisted of the following two simulations:

- A 30 MW fire, simulating a truck or a bus fire, with a no-wind condition.
- A 30MW fire simulated with a 10 miles per hour wind condition. The wind is assumed to blow in the most critical direction; across the surface roadways, from the side where the fire is located.

The Depressed Managed Lanes configuration consists of three lanes in each direction, 10’ outside shoulders and 5’ inside shoulders. The fire source truck is assumed to be traveling in the outside (slow) lane. This location allows the study of smoke behavior where the over-hang may guide the smoke towards the incoming traffic side. If the truck was in the inside (fast) lane, the smoke and hot air are more likely to rise quickly through the opening and out of the depressed section. This study is intended to model the anticipated worst situation. This report summarizes the results of the analysis and characterizes the predicted smoke behavior under steady state.

1.2 Predicted Smoke Behavior

The no-wind model predicts the smoke and hot air will spread in both directions from the origin along the travel lanes to more than 150 ft in each direction. Except in the vicinity of the truck on fire, smoke and hot air will rise to the overhang level and be above the level of vehicles occupants; approximately 5 feet above the ground. The smoke is not anticipated to horizontally cross the top opening and hence the smoke will not be in the lanes of incoming traffic. The upper level general purpose lanes (surface roadways) are not affected.

The 10 miles per hour wind blowing across the Depressed Managed Lanes model predicts the smoke and hot air will also spread along the travel lanes, but be limited to less than 150 ft. The bottom of the smoke layer is also anticipated to be a minimum of 5 feet off the ground within the Depressed Managed Lanes. The smoke does not go to the other (incoming traffic) side, but covers the General Purpose Lane surface roadway over the incoming depressed lane traffic side for a total length of 150 feet.

1.3 Conclusions

Based on the results from the computer modeling, it appears that the smoke and heat generated by a 30 MW fire will not get to the other side of the Depressed Managed Lanes. However, the smoke may cloud the general purpose lane (surface) level of incoming traffic if there is a transverse wind blowing from the on-fire side.
The analysis is a simulation of steady state condition. This means the results model the final picture of the fire, and does not tell how the smoke develops with the fire at start-up. In the early stages of a tunnel fire, there usually is much smoke but the air is not hot yet. Therefore there is no buoyancy effect to lift the smoke, and smoke tends to spread more in the horizontal direction than it would in the steady state when the air is hot. A detailed transient analysis is needed to determine whether the smoke will get into the other side of the Depressed Managed Lanes before the steady state condition is reached. This steady state is usually reached within 30 to 45 minutes after start of the fire. After that time frame, the other side of the Depressed Managed Lanes will be free of smoke as shown in this study.

1.4 Recommendations

Although this study does not show serious smoke situation of a 30 MW truck fire inside the Depressed Managed Lanes, it shows the smoke could cloud the upper level roadway under wind condition. An emergency response plan for the Depressed Managed Lanes and traffic redirection plan for both the Depressed Managed Lanes and general purpose upper level roadway is recommended.
2 Introduction

2.1 Tunnel Information

The typical cross section of the Depressed Managed Lanes is shown in Figure 1 below. A cross strut or bent every 100 feet is assumed for support of the over-hang portion of the upper level roadway.

![Figure 1. Typical cross section](image)

2.2 Purpose of the Study

The purpose of this study is to evaluate the smoke propagation during a fire incident inside the Depressed Managed Lanes. Detailed CFD models have been built to simulate fire scenarios involving a fire in a truck which has stopped in the Depressed Managed Lanes causing traffic to queue back to the entry point of the Depressed Managed Lanes. It is assumed that traffic downstream of the incident has cleared the Depressed Managed Lanes. The queued traffic mixture is assumed to consist of about 71% cars and 29% buses and trucks.

The traffic flow in the Depressed Managed Lanes is bi-directional with three lanes in each direction. No tunnel ventilation equipment is installed.

Fire and smoke dynamics is truly a three dimensional phenomenon. The advent of modern Computational Fluid Dynamics (CFD) has shown that original one- or two-dimensional airflow calculations may be not accurate for tunnels or partially covered depressed lanes, especially for fire situations when many cars, buses and trucks are backed up in the depressed lanes.

For this study, a large CFD model is built to simulate the Depressed Managed Lanes and the upper level roadway. In the model, the typical cross section is modeled to the actual size, its profile and elevation are assumed to be straight and level.
2.3 Study Methodology

2.3.1 Study Approach

The tunnel fire simulations consist of computer modeling of smoke and temperature distribution in the Depressed Managed Lanes during a fire incident.

The detailed analyses will use FLUENT, which is a Computational Fluid Dynamic (CFD) computer program. CFD software has the capability of analyzing 3-dimensional models of the tunnel and predicting the airflows, temperatures and smoke concentration fields.

Computational Fluid Dynamics (CFD) is a field-modeling technique that solves, in three dimensions, the partial differential equations of fluid flow using numerical methods. The technique can account for turbulence phenomena and the various modes of mass transfer in most fluid flow situations. The CFD program used for these analyses is Fluent, Version 6.0 made by Fluent Incorporated, 10 Cavendish Court, Lebanon, NH.

2.3.2 CFD Model Representations and Assumptions

Geometric and Computer Models

A full three-dimensional model has been built to represent the depressed managed lanes geometry. The cross section shape is modeled based on preliminary design drawings. A 400-foot long section of the Depressed Managed Lanes is modeled with about 200 feet in front of and behind the fire.

Vehicle Traffic Representation

Traffic in the Depressed Managed Lanes is accounted for by inserting representative shapes of vehicles in the model. The assumed traffic mix is 71% cars and 29% buses and trucks. The traffic mix is not a critical factor for this analysis.

Heat and Smoke Representation

A 30MW heat release rate, as would result from a truck or bus fire, was used in the model. A smoke generation rate of 71 m³/sec was incorporated into the model. The effects of heat transfer due to radiation are also incorporated in the model.

The smoke generation rate information for a 30 MW fire is interpolated from the fire size table in the US National Fire Protection Association (NFPA) 502 – Standard of Road Tunnels, Bridges, and Other Limited Access Highways.

Boundary Conditions

- Depressed Managed Lanes walls were modeled as having the characteristics of typical tunnel wall such as surface roughness and reflectivity.
- The ends of the Depressed Managed Lanes are modeled as pressure boundaries; hence air is free to travel across the boundaries.
- As previously mentioned, a traffic ratio of 71% cars and 29% buses and trucks is used to model the traffic.
- In case of wind, the top level far field is set to velocity inlet with prescribed wind velocity.
3 Results

3.1 No Wind Condition

The result of no-wind condition is a by-product of this study. In the CFD simulation, the calculation is done first without wind, and then the wind boundary condition is imposed. With very little extra effort, the difference caused by wind can be demonstrated.

Figure 2 shows the smoke concentration contours on the cross-section plane at the location of the truck on fire. The dark blue shade represents minimal smoke concentration and good visibility. It can be seen that smoke does not cross the gap into the other side of the Depressed Managed Lanes. The smoke accumulates in the upper corner of the Depressed Managed Lanes, then flows under the upper roadway plate and turns straight upward.

Figure 3 shows the smoke mass concentration contours on a longitude plane that is near the edge of the over-hang roadway plate. The smoke spreads in both forward and backward directions to more than 150 feet. The phenomena of smoke flowing backward is called “back layering”, which is typical in tunnels without mechanical ventilation. Examination of the result reveals the back-layering does not impose much danger to the motorists trapped behind because the smoke is higher than 5 feet from the ground.
Figure 4 and 5 show the temperature contours on the cross section and longitude plan. The maximum temperature on the wall is 610°F.
3.2 Wind Condition

It is assumed in this study a prevailing wind of 10 miles per hour, across the surface road, is blowing from the side on fire toward the other side.

Figure 6 shows the smoke concentration contours on the cross-section plane at the location of the truck on fire. Under the wind condition, the smoke reaches over to the overhang edge of the other side, but does not get to the other side of the Depressed Managed Lanes. Instead, the smoke covers a good part of the upper level roadway for a distance about 150 feet long.

Figure 7 shows the smoke mass concentration contours on a longitude plane that is near the edge of the over-hang roadway plate. The smoke spreads in both forward and backward directions to less than 150 feet. Examination of the results reveals the back-layering does not impose much danger to the motorists trapped behind because the smoke is higher than 5 feet above ground.

Figure 8 is the smoke streamlines plot, it shows how the wind blows the smoke to the other side the roadway.

Figures 9 and 10 show the temperature contours on the cross section and longitudinal planes. The maximum temperature on the wall is 760°F.
Figure 6. Smoke Mass Concentration Contours

Figure 7. Smoke Mass Concentration Contours
Figure 8. Smoke Particle Trace

Figure 9. Temperature Contours
4 Conclusions

From steady state results, the smoke and heat generated by a 30 MW fire will not get into the other side of the Depressed Managed Lanes. But it may cause visibility problem and other smoke related hazards on the upper level roadway if there is a wind blowing across the tunnel from the on-fire side.

This study is only a simulation of the steady state, which is reached in typically 30 minutes after fire start. The current results do not apply to the transient period.

5 References