Research on Driving Safety of Urban Interchange Ramp under Crosswind

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Urban interchange ramps serve as important links of the whole road network

During the last decade, urban interchange ramps were widely constructed in China

Crosswind

Traffic safety for ramps has direct and significant impact on the road capacity and the service level of expressway

which also associated with a rapid increasing number of traffic accidents

Wind Speed Measurement → Measurement Result → Numerical Simulation Scheme → Simulation Results

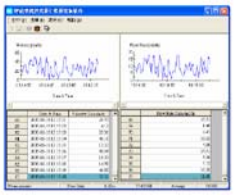
Traffic Accident

- Through the investigation cooperating with Shanghai Traffic Police Department, it was found that several similar traffic accidents have occurred in the same spot of the interchange ramp near the Pudong airport station unexpectedly.
- These accidents usually happened during strong wind period.

Wind Speed Measurement → Measurement Result → Numerical Simulation Scheme → Simulation Results

Experiment Equipment

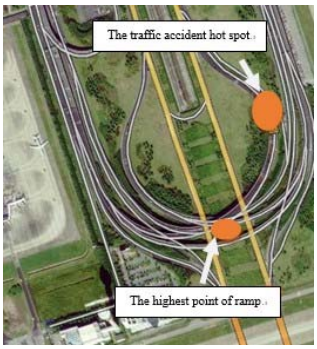
Hot-wire Anemometer



- Easy to Use and Carry
- Fast Measurement
- Wind Velocity Error can be less than 0.01m/s at a sampling frequency of 1 Hz

Experiment Method

Experimental Site



- Traffic Accident Hot Spot
- The Highest Point of The Whole Ramp

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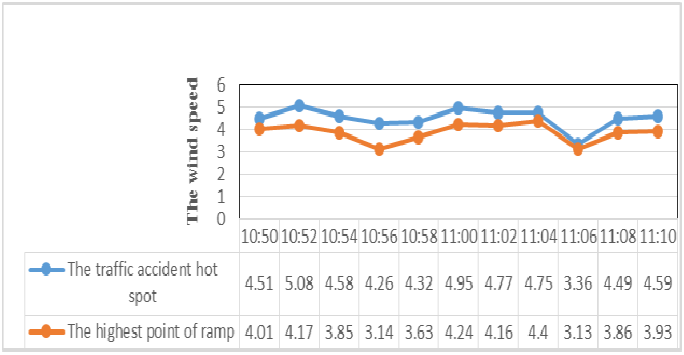

	10:50	10:52	10:54	10:56	10:58	11:00	11:02	11:04	11:06	11:08	11:10
The traffic accident hot spot	4.51	5.08	4.58	4.26	4.32	4.95	4.77	4.75	3.36	4.49	4.59
The highest point of ramp	4.01	4.17	3.85	3.14	3.63	4.24	4.16	4.4	3.13	3.86	3.93

- Both the maximum and average value of crosswind speed at the traffic accident hot spot are bigger than the nearby the highest point of ramp
- One possibility is the influence of the narrow pipe effect.
- Overturn and sideslip accidents are the most common accident types in this area.

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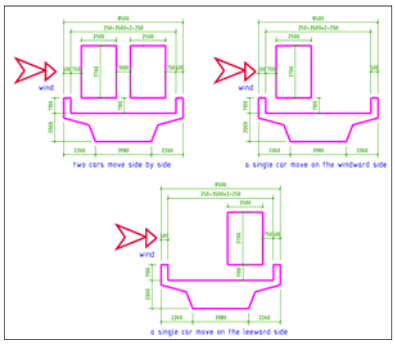
Numerical Simulation Research of Automotive Wind-field



Four situations: Two cars move side by side, A single car moves on the windward side of ramp, A single car moves on the leeward side, A single car moves on the ground.

- The vehicle-ramp system is composed of a typical semi-trailer and the ramp.
- The cross section of the ramp is 8.5m wide, carrying a dual two-lane highway on its upper surface.
- The width of motor lane is 3.5m while the width of marginal strip is 0.25m
- Several parts of model which may have insignificant effects were not taken into account
- The cross section of vehicle and guardrail was simplified
- The cross section of the protection rail at two sides is 0.5m wide and 1.1m high.

Turbulence Model

k-ω SST turbulence model

Turbulent Kinetic Energy Equation

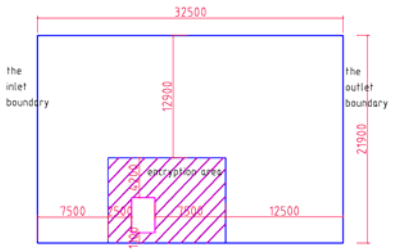
$$\frac{\partial(\rho k)}{\partial t} + \Delta \bullet (\rho U k) = \frac{\partial}{\partial x_j}(\Gamma_k \frac{\partial k}{\partial x_j}) + G_k - Y_k + S_k$$

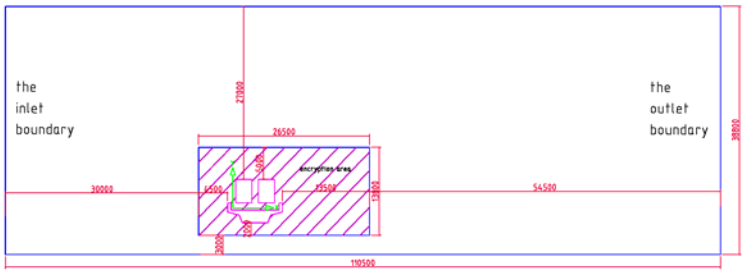
Turbulent Frequency Equation

$$\frac{\partial(\rho \omega)}{\partial t} + \Delta \bullet (\rho U \omega) = \frac{\partial}{\partial x_j}(\Gamma_\omega \frac{\partial \omega}{\partial x_j}) + G_\omega - Y_\omega + D\omega + S_\omega$$

Where G_k = turbulent energy; ω= frequency of turbulent energy; X_j = j^{th} axis in the Cartesian coordinate system; Γ_k = effective divergent terms of k; Γ_ω = effective divergent terms of ω; Y_k = divergent terms of k; Y_ω = divergent terms of ω; t = time; D_ω = orthogonal divergent term.

Computational Domain



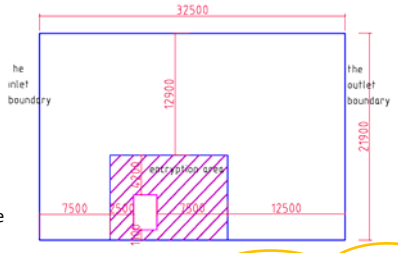


- The size of the computational domain is minimized on the basic premise that the remarkable characteristics of averaged flow velocity distribution around vehicle are obtained.
- A computational domain of rectangle shape is enclosed by six outer boundaries, which have been named b_right, b_left, b_tail, b_head, b_down and b_up

Wind Speed Measurement → Measurement Result → **Numerical Simulation Scheme** → Simulation Results

Boundary Conditions

The left outer boundary is the inflow face from which the wind blows in.



The right outer boundary was specified for this research as a flow outlet with zero pressure.

A uniform crosswind speed of 20 m/s with a 90 degree yaw angle, dissipation ratio of 10, turbulence kinetic energy k of 0.005 and the kinematical viscosity coefficient is $1.7894*10^{-5}m^2/s$ were assigned to it.

All the flow boundaries were enforced with mathematical boundary conditions to approximate the real situation. In addition, in this study, the flows at these boundaries were assumed to be uniform but the flow cannot penetrate the surfaces of a vehicle.

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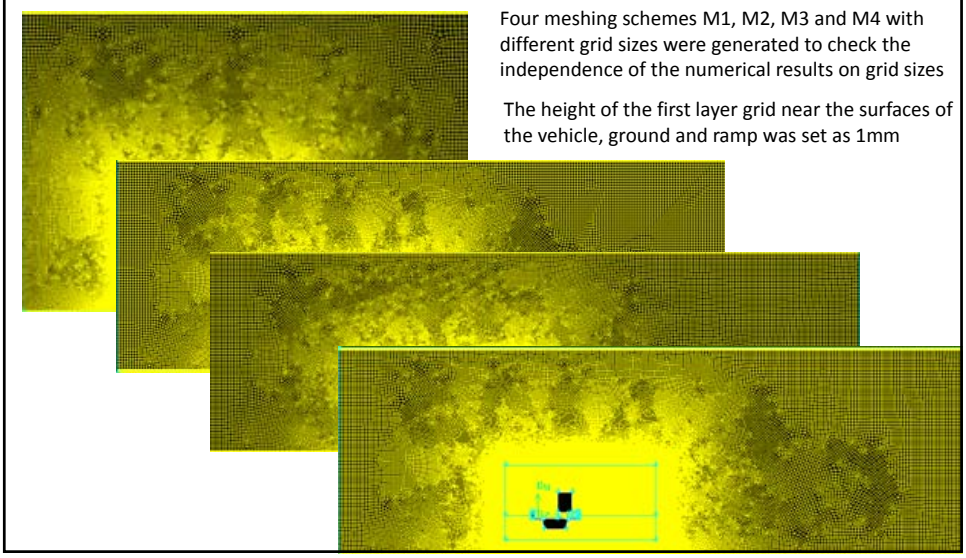
Meshing

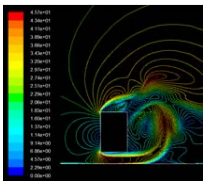


Four meshing schemes M1, M2, M3 and M4 with different grid sizes were generated to check the independence of the numerical results on grid sizes

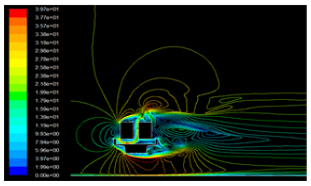
The height of the first layer grid near the surfaces of the vehicle, ground and ramp was set as 1mm

Simulation Results

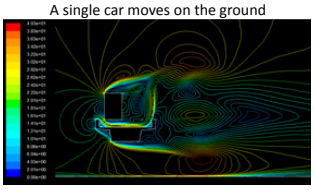
Averaged Flow Velocity Distribution Around Vehicle



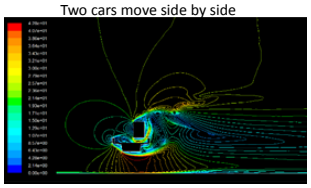
A single car moves on the ground



Two cars move side by side



A single car moves on the leeward side



A single car moves on the windward side

1.The wind speed around the surface of vehicle is low and the corner of vehicle and ramp is of large velocity gradient.

2.The maximum velocity occurs on the bottom and the top of car.

3.Wind field around a vehicle-ramp system is more complex than that around a single car on ground.

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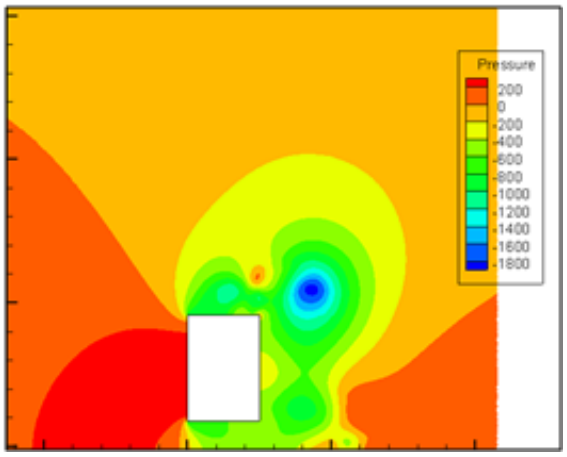
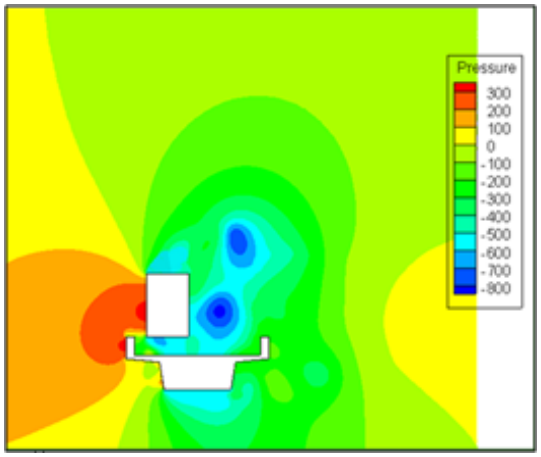
Analysis of Wind Pressure



The wind pressure when the car drives on the ground

When a single car moves on the ground , generally, the positive pressure acts on the windward side while the negative pressure acts on the leeward side of vehicle.

Analysis of Wind Pressure



The pressure when the car moves on the windward side

When a single car moves on the windward side, the side force of the car, which is affected by the guardrail, will increase and the area of negative pressure will be larger.

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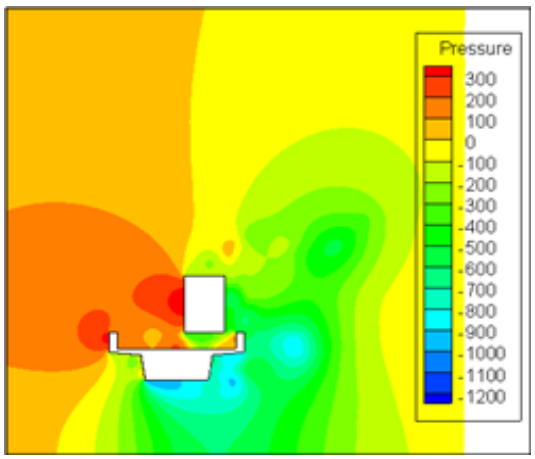
Analysis of Wind Pressure

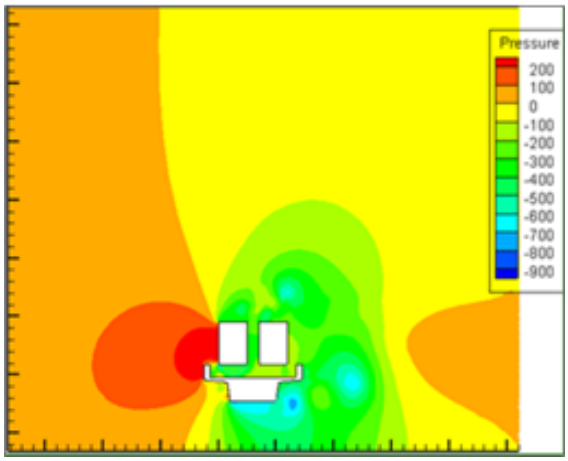


The pressure when the car moves on the leeward side

When a single car moves on the leeward side, this situation is quite similar to the former case.

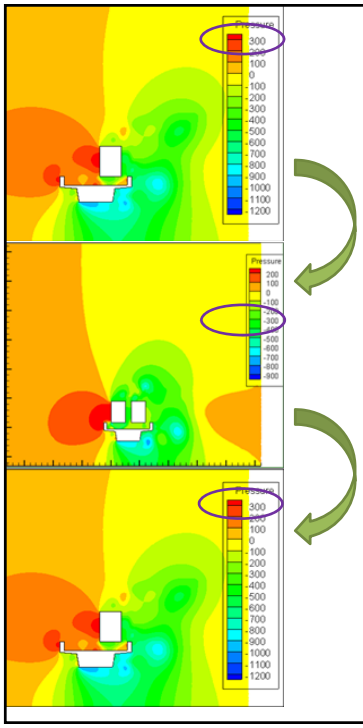
Wind Speed Measurement → Measurement Result → Numerical Simulation Scheme → Simulation Results

Analysis of Wind Pressure



The pressure when two cars move side by side

When two cars move side by side, the wind pressure around the vehicle on the leeward side decreases due to mutual interference. The two cars also present a tendency to approach each other.



During overtaking process, significant changes of the side force of the vehicle on the leeward side will occur, which may cause accidents on the ramp

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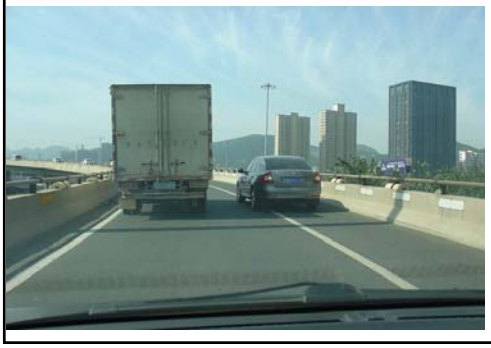
Analysis on The Aerodynamic Coefficient

Situation	C_S	C_L
A single car moves on the ground	5.78	1.01
The car on the windward side (Two cars move side by side)	5.32	1.09
The car on the leeward side (Two cars move side by side)	-1.04	-0.57
A single car moves on the windward side	5.92	1.18
A single car moves on the leeward side	5.67	1.14

- Crosswind will generate different lift and side force
- C_S and C_L are biggest when a single car moves on the windward side of ramp compared to the other scenarios so this situation is most dangerous

Conclusion

- The whole paper discuss and analyse the flow velocity distribution and pressure around vehicle by building simulation model and setting up corresponding parameters
- Wind field around a vehicle-ramp system is more complex than that around a single car on ground



- The movement of a single car on the windward side of ramp is the most dangerous situation
- The aerodynamic force of automobile can change significantly during overtaking process which deserve further study

Thanks !