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PAPER F1

PRACTICAL TEST OF EMERGENCY VENTILATION COMBINED WITH BUS FIRING AT THE KAN-ETSU TUNNEL

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SUMMARY

The Kan-etsu tunnel is the longest road tunnel in Japan, equipped with longitudinal ventilation system combined with electrostatic precipitators and vertical shafts. The emergency ventilation system for the tunnel had been studied, through numerical simulation, so that wind velocity in the tunnel would be damped quickly by means of jet fan control in case of fire. The full system proposed in the numerical simulation was installed and detailed tests were performed for the confirmation of the performance of the system before public service. In the test, jet fans or actual trucks were used to simulate the traffic influence. Also jet fans were used to substitute natural wind effect. By controlling the rest of the jet fans a quick reduction of the wind velocity was obtained which was qualitatively similar to the simulation results.

Along with some of the above mentioned tests, trays of gasoline or used busses were set on fire in order to observe the behavior of smoke carried by the controlled wind velocity. In the worst case, dense smoke reached 1000m from the fire point in 20 minutes, which is considered to be a satisfactory result to allow refuge action.

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1. INTRODUCTION

The Kan-etsu tunnel (length:10,926m) is equipped with longitudinal ventilation system with two vertical shaft- and five electrostatic precipitator- stations(1). It will be used for contraflow traffic for several years until the other shaft will be completed in 1991. For this period 48 jet fans are installed in order to induce necessary quantity of ventilation flow in addition to other ventilators. In case of fire jet fans are to be controlled in emergency mode so that the air flow would be reduced as soon as possible.

This tunnel is equipped with an evacuation tunnel parallel to the main shaft with connecting passages every 350m. It is therefore important for the passengers that a favorable evacuation circumstance would be maintained for the first few minutes of a fire. The mass of air is considered as if it were a lump of solid body in acceleration or deceleration. Moreover traffic force after the fire is strongly transient. These two are the main reason that the air in the tunnel should be controlled automatically.

A series of numerical simulations of emergency ventilation had been performed extensively to certify the possibility of various control regimes which the authors had reported in the last symposium(2). In this simulation 48 jet fans were utilized as the actuator of the control system and driven forward or reverse. It gave favorable results in providing a quick reduction of the air flow, which was sufficient reason to install this emergency controller into the actual system besides a more sophisticated control system for ordinary ventilation.

Among various tests and adjustments performed in the meantime between the completion and the opening for service of the tunnel, a series of tests to check the performance of the emergency control system was one of the most unusual because we had had no such experience before then.

Most of the emergency control tests were performed under substitution of traffic force and natural wind with jet fans so that it could reproduce its transient effect. In order to certify the actual traffic force 50 trucks were introduced and were started consecutively before the assumed accident which would correspond to the transient of unbalance in traffic force.

Combined with the performance tests of emergency control, experiments with actual fire was also performed, in which three dimensional behavior of smoke would be observed.

2. TEST OF WIND REDUCTION CONTROL

2.1 Concept of the control system

As soon as a fire is detected, control mode is automatically switched into emergency one. Two vertical shafts and its fans are shut down. The control is executed only through on-off operation of 48 jet fans. The emergency control logic is described as in Fig.1 which is fundamentally a combination of traffic feedforward and airflow feedback. All of the jet fans can be operated reverse, but the number of jet fans to be started in 10 seconds is limited to 14 due to power capacity.

The time history of an event was defined as:

t=-60s an accident happens;

t=0s 60 seconds later fire breaks out,
and all ventilators including jet fans are shut down;

t=90s 90 seconds after the fire breakout, emergency control mode starts;
(This delay was set for the tests only for protection of the motor; in the actual operation the delay is removed for quicker response.)

An accident blocks the traffic flow behind it, on the other hand the vehicles leaving from the point are free. Therefore the effect of traffic force is strongly transient after the accident depending upon where in the tunnel it happens. The traffic force was exerted by either of the following two ways:

1) Jet fans are used to simulate the transient change of the piston effect of the vehicles;
2) Actual trucks are ordered to start, corresponding to 300 vehicles per hour.

The emergency control system installed includes following regimes:

<u>K1</u>: All ventilators are shut down right after the fire breakout. The simplest but not always the best method.

<u>K2</u>: Constant operation of ventilation programmed in advance so that the effect of traffic and natural wind would be minimized.

<u>K3</u>: Feedback control for zero wind velocity with feedforward term of traffic.

<u>K3'</u>: Same as K3 except that partial exhaustion from vertical shafts starts 10 minutes later.

When both traffic force and natural wind are simulated by jet fans, the number of jet fans available for automatic control is 24, half of the total equipment, which will give worse condition in view of quick reduction of air flow velocity in the tunnel.

2.2 Results of emergency control test

Under the conditions of 800 veh./h, 6:4 traffic ratio (South/North bound), 2.5m/s natural wind, various control modes were compared (Fig.2). In the K1 operation the air flow velocity is strongly dependent on the natural wind, reaching a rather high value. Under K3 control the velocity comes down to zero quickly and stays there although there is small fluctuation.

Natural wind was simulated by jet fans as +2.5 m/s, 0 m/s and -2.5 m/s (Fig.3). The effect of natural wind is relevant only in K1 operation. In first two minutes velocity comes down to about 2 m/s equally for each case. After the traffic force diminishes the air velocity gradually approaches to the respective velocity of natural wind.

When an accident occurs in the tunnel the vehicles approaching it bind up at that point, on the other hand the vehicles leaving from the point run away freely. In a long tunnel like the present case the point of the accident, or the fire, has a crucial effect on the phenomena. In Fig.4, when the point is upstream positive drag by vehicles remains for several minutes, and vice versa. The velocity approaches asymptotically to the natural wind velocity after 15 minutes for every case.

Most of the present field experiments were performed under assumed conditions of traffic and natural wind simulated by jet fans. For certifying this method, 50 heavy trucks were employed to exert transient force of 300 veh./h and South/North bound ratio of 0:10. The trucks were started at a constant time interval from downstream of the fire point which would correspond to the actual phenomena. In Fig.5 the results from actual trucks and by jet fan simulation are compared with the same control regime K1. In this case very good agreement is observed. Fig.6 shows comparison under K3' control, in which the wind reduces more quickly in the actual truck test. This is probably because only half(24) of the whole jet fans were available for 'control' in the jet fan simulated test.

The authors performed a series of numerical simulations in order to check the reality of this feedback control system for emergency(2). Although it should be compared with the present test, there were some difficulty because 1) design value of traffic (adopted in simulation) could not be simulated with jet fans, 2) available jet fans were only half, the rest were engaged for traffic and natural wind simulation, 3) detailed control logic were not same between the two. The numerical simulation was therefore performed again with the conditions of the experiment in which the actual operation of fans are transformed to the simulator. In Fig.7 qualitative agreement is seen for both K1 and K3' control regimes. In order to get higher coincidence in future it is recommended to introduce more realistic parameters and coefficients based on experiments.

3. GASOLINE TRAY AND BUS FIRE

3.1 Conditions for fire test

In the study of numerical simulation(2), a one dimensional model was employed so that a simpler and more essential understanding could be obtained. In the actual fire in the tunnel, however, the behavior of smoke may be different mainly because it moves three-dimensionally especially near the fire point due to strong thermal effect. In order to clarify this difference between numerical simulation and actual phenomena, fire tests were performed in which 12 gasoline tray firings and two cases of bus fires were observed under various ventilation regimes. In the gasoline cases, trays totalling 4 square meters were separated into three parts and set on fire with time delay which would enable the smoke generation to be similar to that of an actual bus.

The effect of the water spraying system on the diffusion of smoke was also examined along with the above mentioned bus fire.

Measurements were made on temperature distribution, smoke distribution, intensity of radiation from the fire, CO density, air flow velocity distributions within cross sections, axial movement of smoke and visibility observation by people at several points.

3.2 Distribution of smoke concentration

Typical results for the comparison between the two cases of K1 and K3 operations are presented in Fig.5 and Fig.6 (smoke density distribution in longitudinal-vertical cross section with time). Cs [1/m] is the smoke density defined in

$$\tau = I/Io \exp(- Cs \cdot \ell)$$

where τ:visibility, I:measured intensity, Io: intensity without smoke, ℓ:distance between light source and detector. Cs=0.4 1/m may be considered as a critical value for the passenger to be able to evacuate. Common experimental conditions are

Source of fire: 4 square meter tray of gasoline.
Natural wind: +2.5 m/s (simulated by jet fans).
Traffic condition: 800 veh./h, 34.2% of large vehicle (diesel) ratio,
South/North bound ratio 6:4

In the K1 operation (Fig.5) movement of smoke is considerably greater. After 4 minutes it reaches 600m and 20 minutes later 3000m. Smoke with density 0.4(1/m) comes down to 1.5m above floor level after 10 minutes in the region between 100m and 600m downstream. In K3 mode, on the other hand, air flow velocity comes down to 1 m/s in 3 minutes as a result of jet fan operation to cancel traffic and natural wind effect. The movement of smoke front is dependent on air velocity for the first minutes, and, thereafter, is diffusion driven by thermally induced flow.

The water spray was started 10 minutes after setting fire. During spraying dense smoke was observed near the lower part of the tunnel section within 300m from the fire point. Axial distribution showed little difference.

3.3 Comparisons of the results with numerical simulations

The authors compared the results of the present experiment with the preceding numerical simulation, and established the accuracy and limit of the prediction. In the numerical simulation:

1) distribution of smoke in a cross section is uniform (one dimensional model) which results in quick diffusion to the lower part.
2) Movement of smoke upstream is observed only if the flow is reversed.
3) Quick reduction of air flow is obtained.
4) Overshoot happens more often.

On the other hand the actual tests showed:

1) As a result of thermal effect dense smoke tends to be at high level causing delay of appearance at 1.5m height by several minutes. Attention must be drawn to the fact that the smoke, chilled by traveling several hundred meters, comes down to a level that would interfere with refugees.
2) When the sectional velocity is confined within 1 m/s smoke flows upstream along the ceiling.
3) The velocity of the smoke front has a higher speed and diffuses to a larger extent.
4) Damping is delayed and reverse wind occurs less often.

4. CONCLUSION

Although a series of numerical simulation had shown that the emergency control by feedback was worth adopting into actual system, no one had known if it would work properly until the moment the switch was on. It was fortunate that we had time to conduct the field experiments under various conditions to confirm the performance of the system. The results of the test could be summarized as follows:

1) The actual control system for emergency ventilation has satisfactory performance for the reduction of air flow velocity in the tunnel.

2) The preceding numerical simulation with one dimensional diffusion model proved to give good qualitative estimation, but it generally gives more dangerous result. For a higher accuracy the various coefficients should be refined. One dimensional model is invalid only in the vicinity of the fire where dense smoke creeps along the ceiling.

3) Under K3 or K3' operation the smoke is confined within about 1000m of the tunnel, even 20 minutes after the fire breakout.

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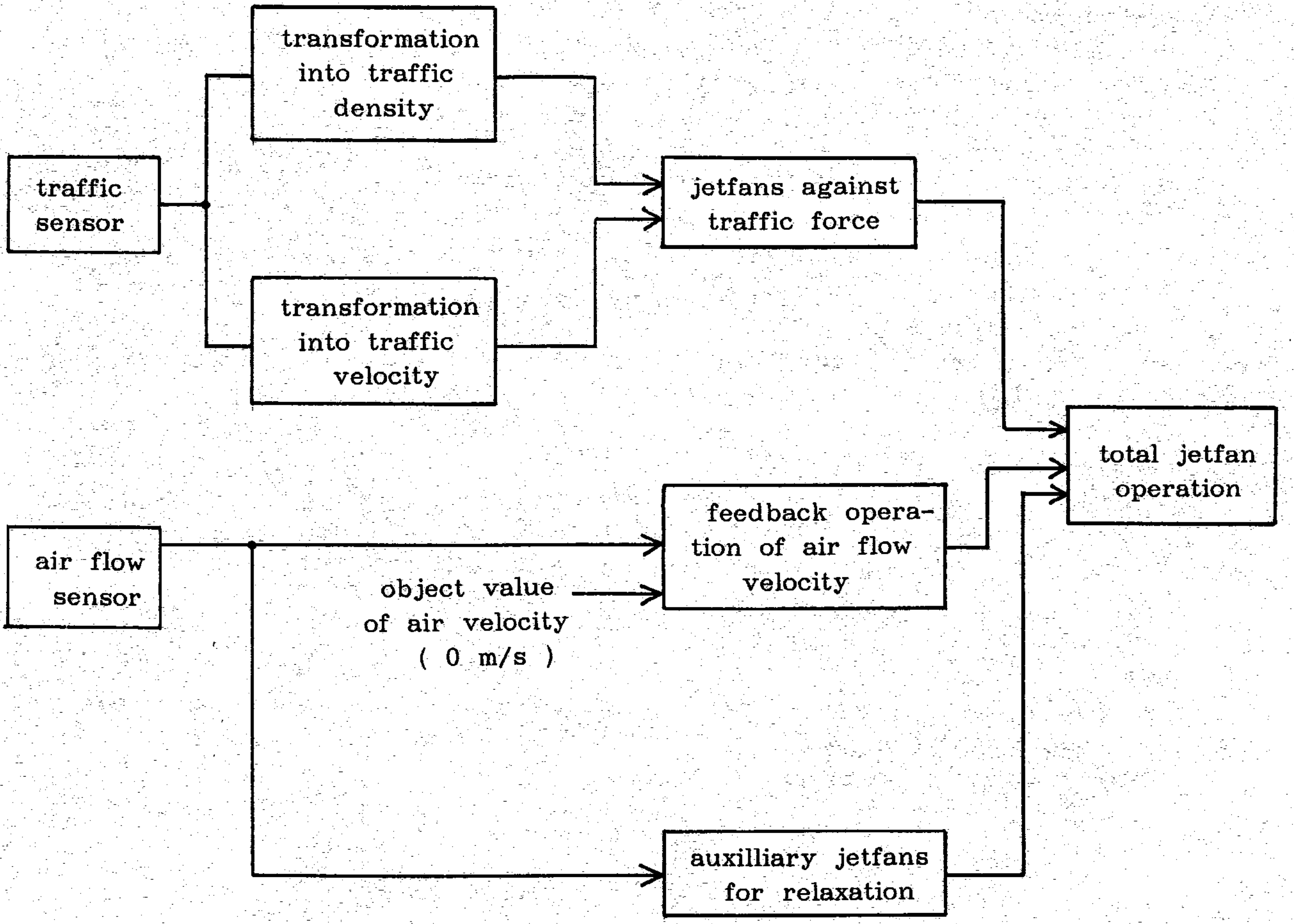
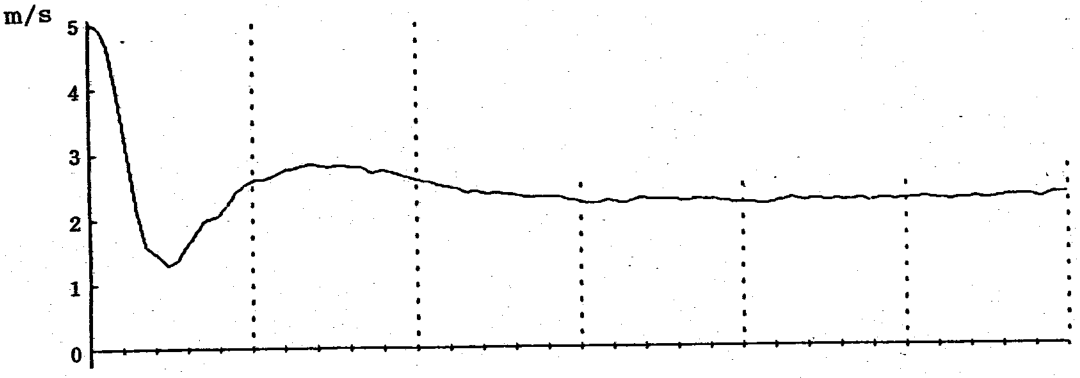


Fig.1 Logical construction of emergency control

K1 operation
Traffic: 800 veh./h
South/North bound ratio: 6:4
Large vehicle(Diesel) ratio: 34.2%
Fire point in 1st. division
Natural wind: +2.5 m/s



K3 operation
Traffic: 800 veh./h
South/North bound ratio: 6:4
Large vehicle(Diesel) ratio: 34.2%
Fire point in 1st. division
Natural wind: +2.5 m/s

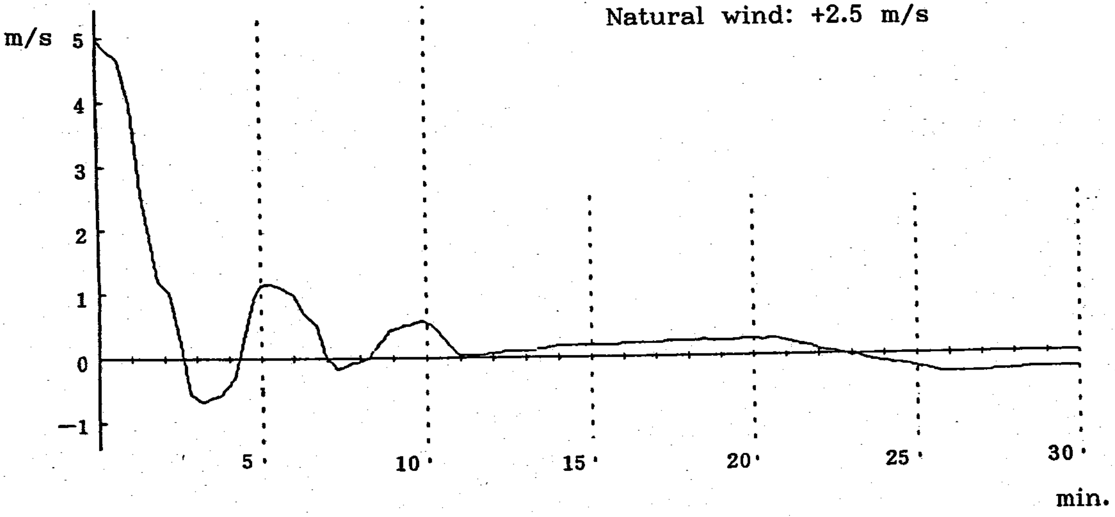


Fig.2 Transient of air flow in the tunnel
(comparison under different control regime)

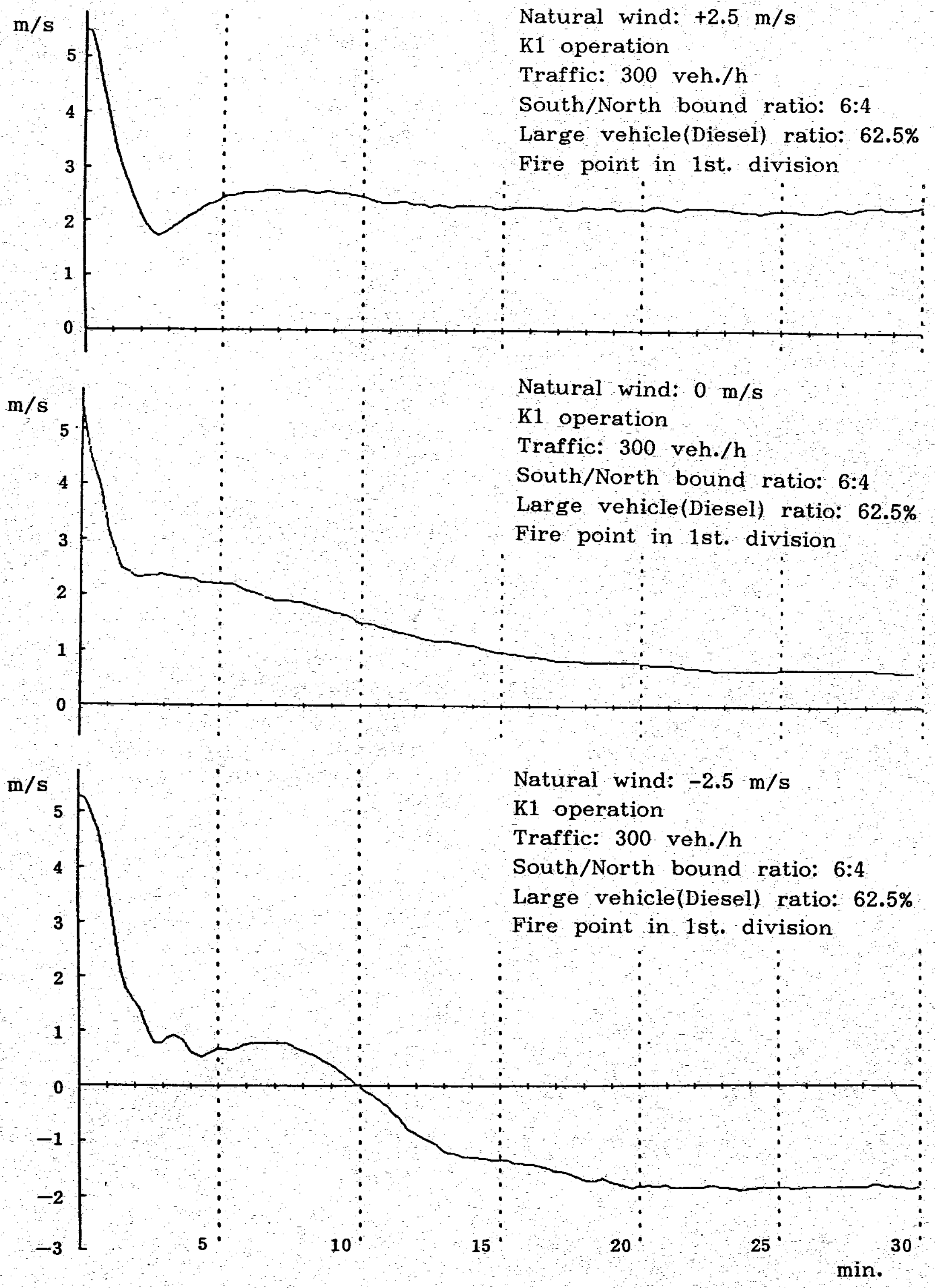


Fig.3 Transient of air flow in the tunnel
(comparison under different natural wind)

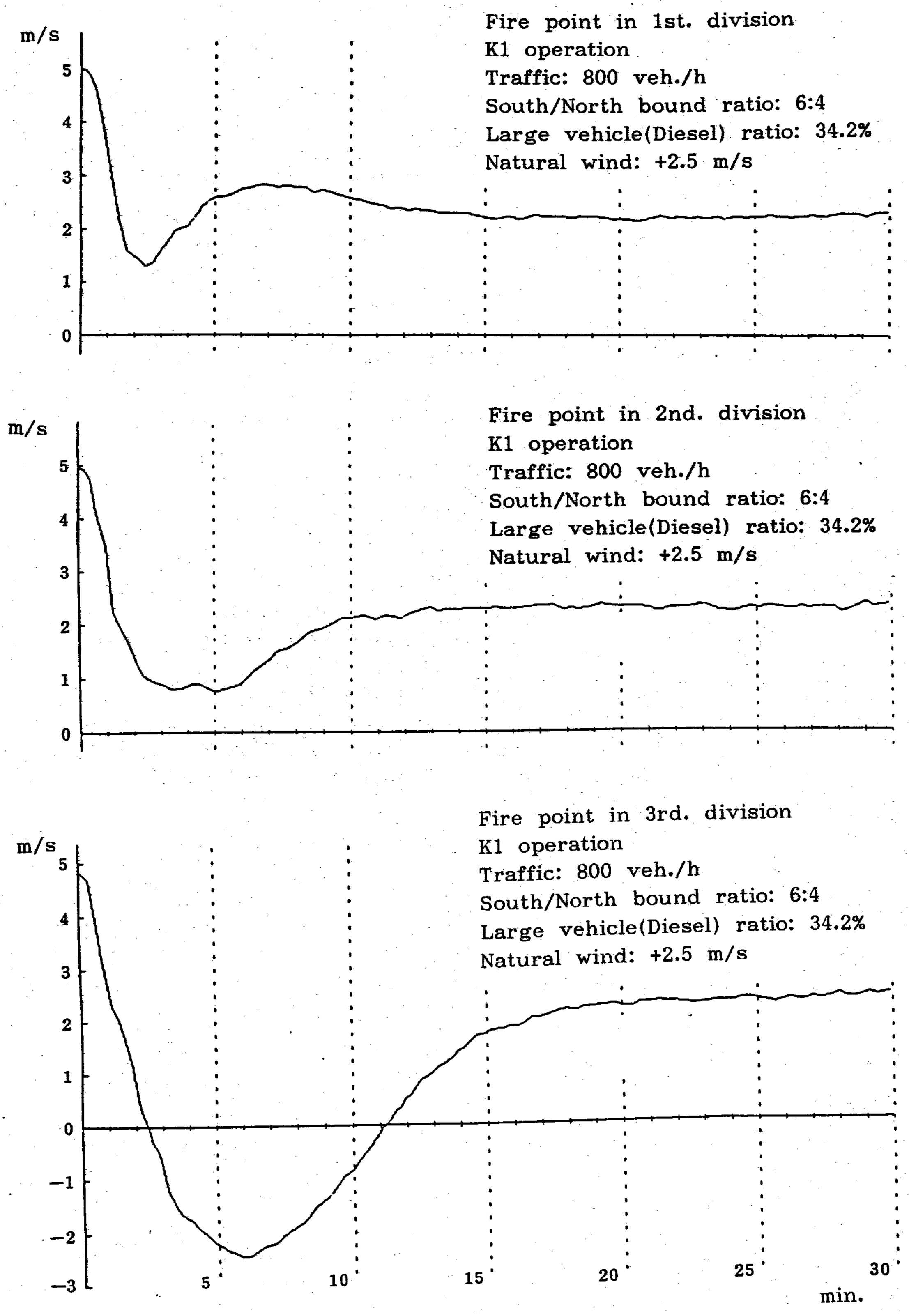


Fig.4 Transient of air flow in the tunnel (comparison under different fire points)

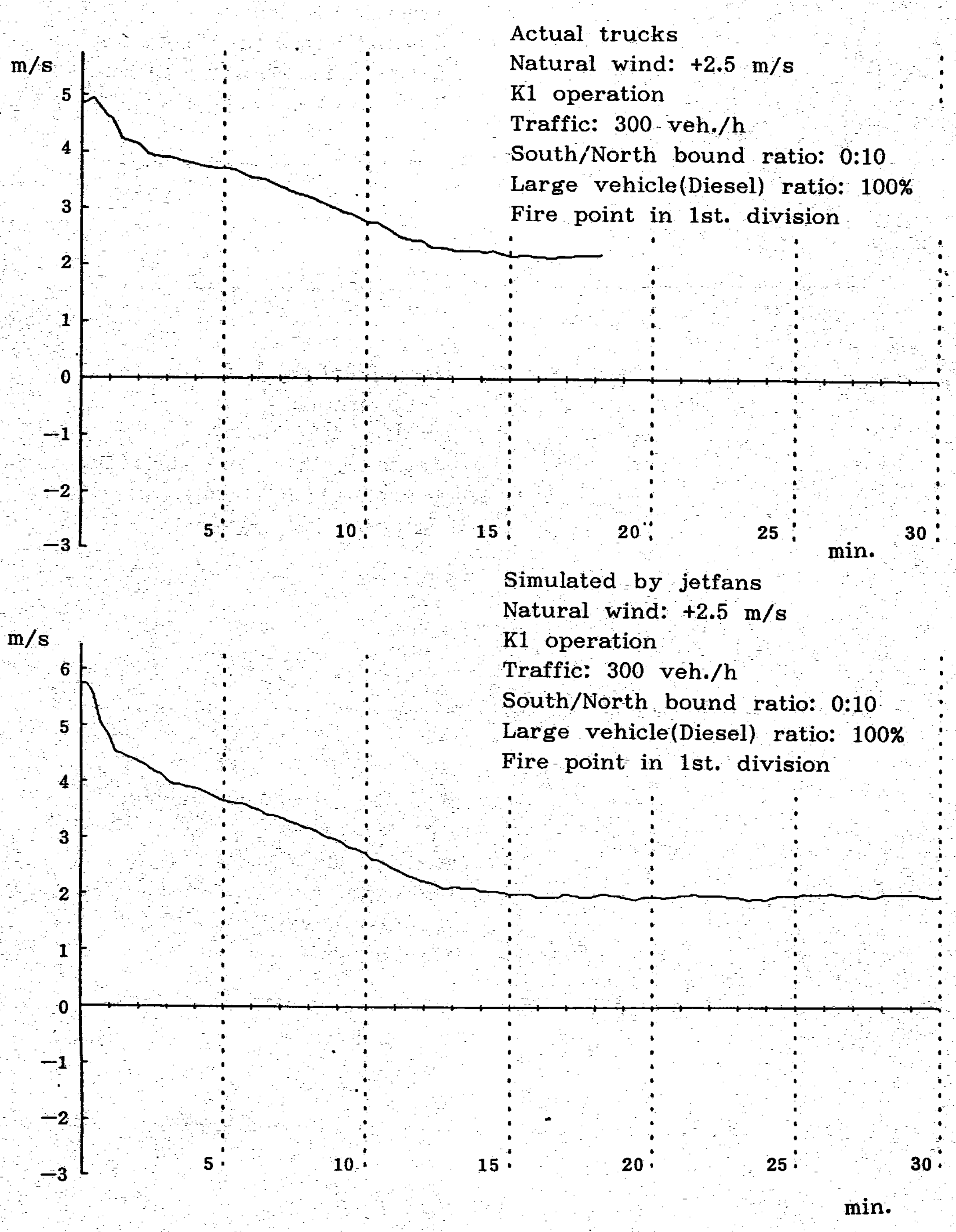


Fig.5 Transient of air flow in the tunnel
(comparison between actual trucks and jetfan simulation)

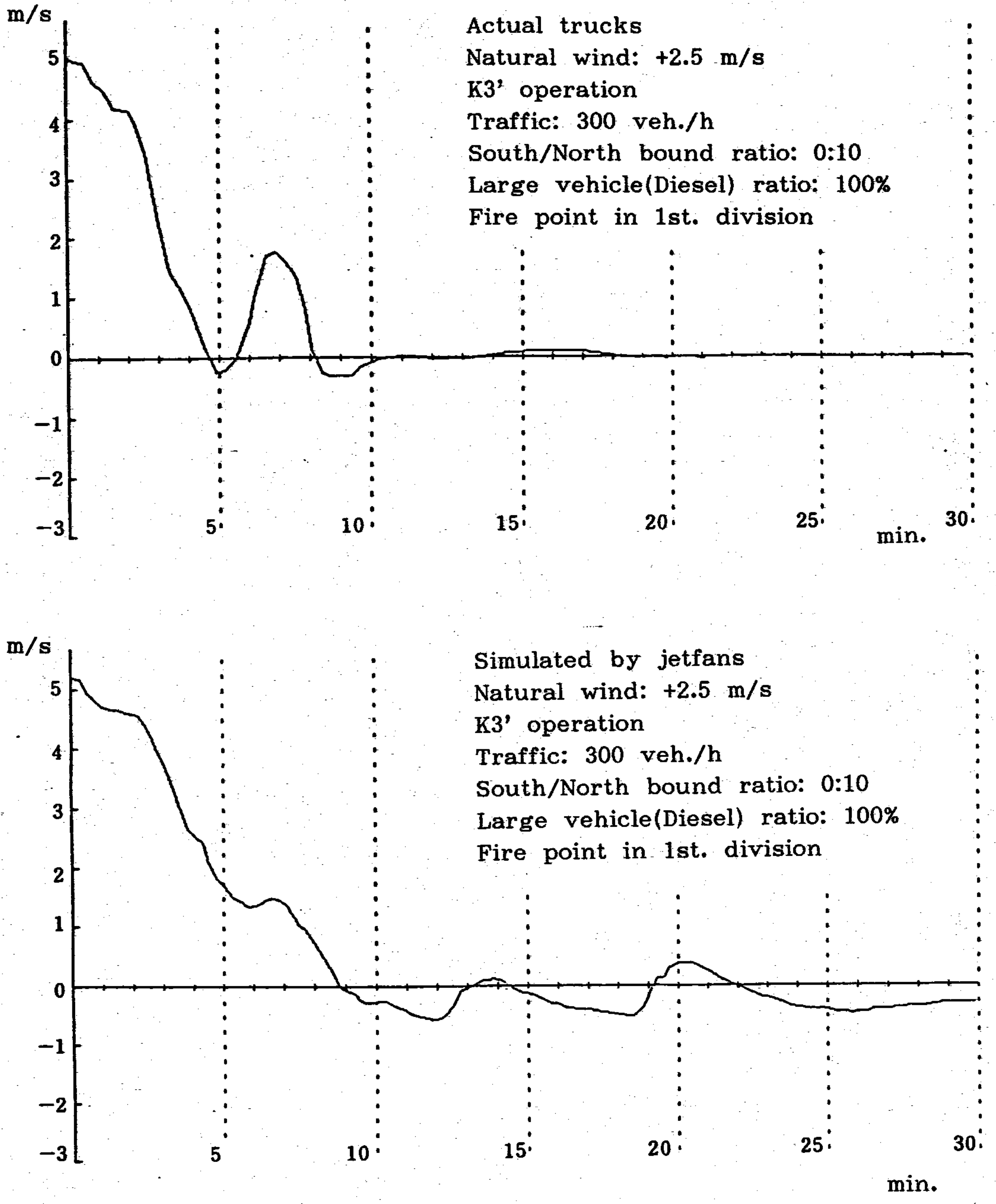


Fig.6 Transient of air flow in the tunnel
(comparison between actual trucks and jetfan simulation)

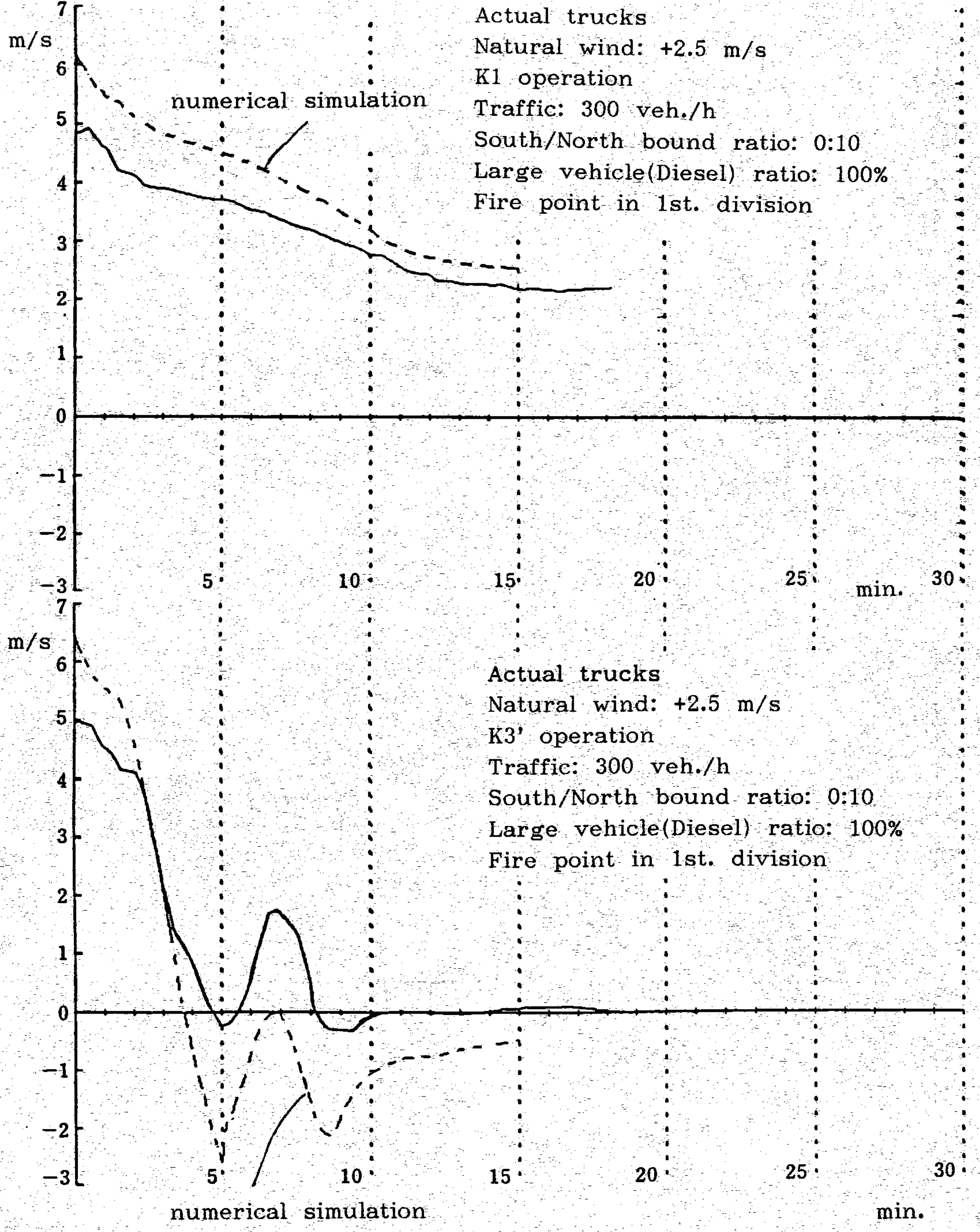


Fig.7 Transient of air flow in the tunnel
(comparison between actual test and numerical simulation)

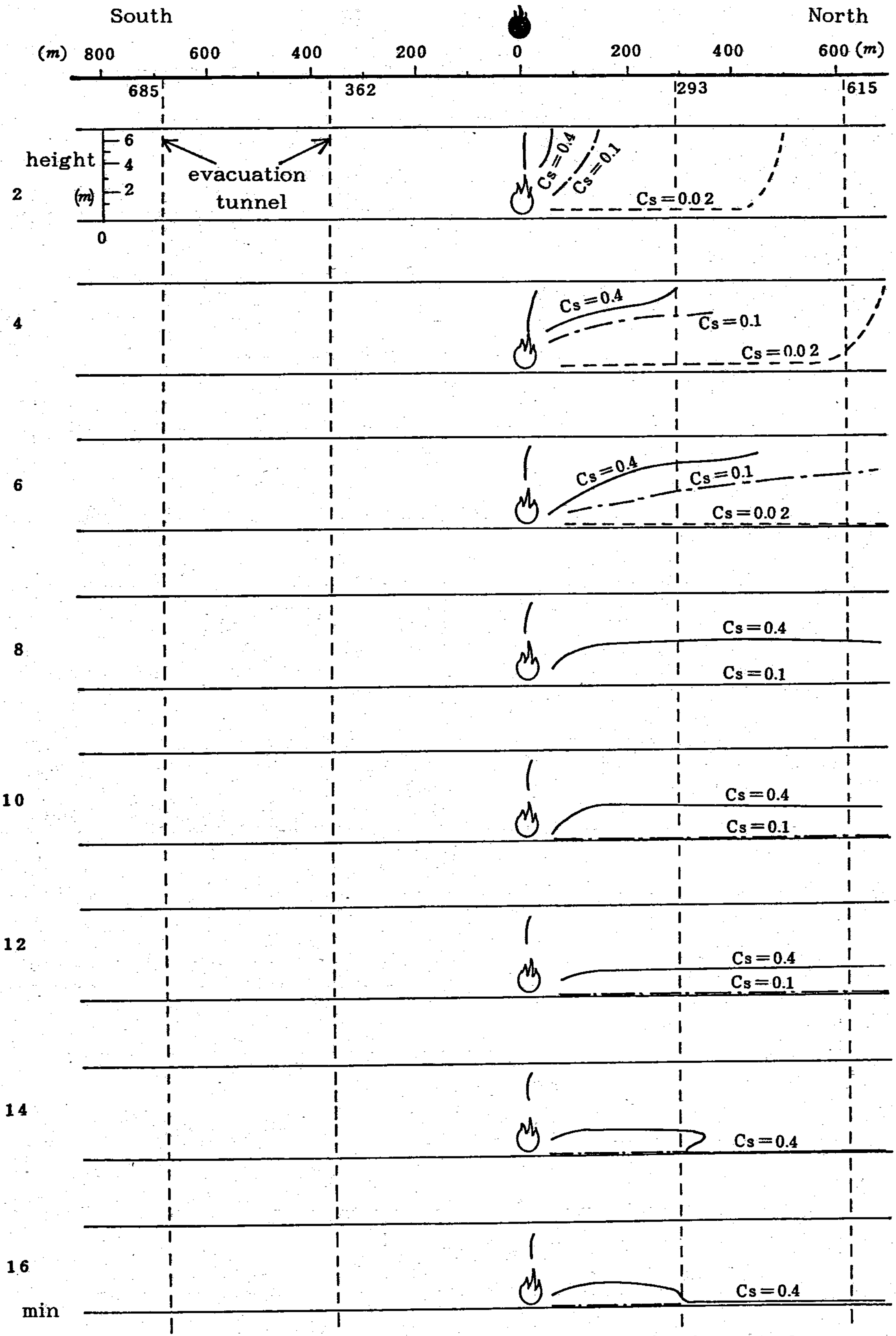


Fig.8 Distribution of smoke density in longitudinal-vertical section (K1 operation)

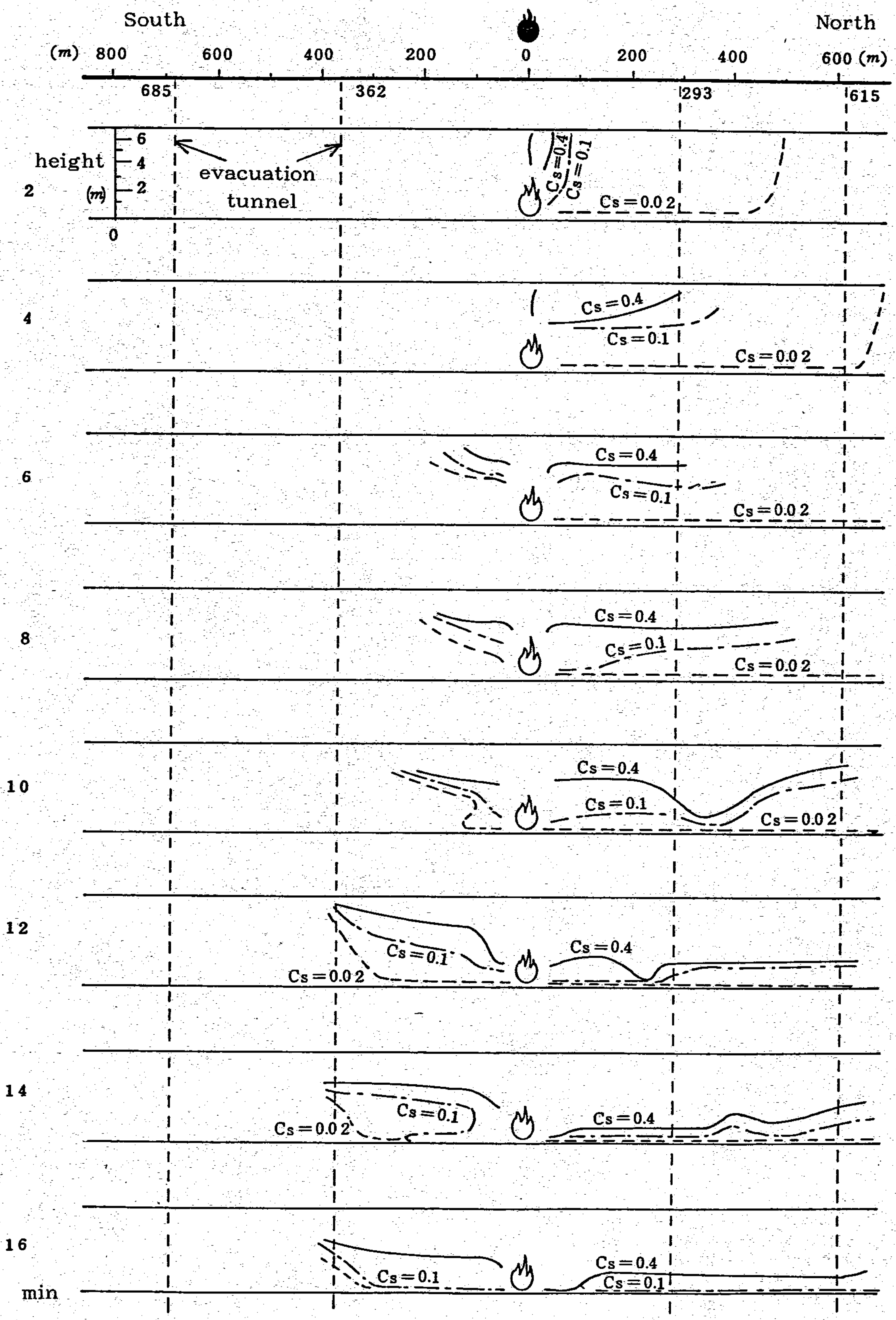


Fig.9 Distribution of smoke density in longitudinal-vertical section (K3 operation)