TESTS ON FIRE DETECTION SYSTEMS AND SPRINKLER IN A TUNNEL

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ABSTRACT
During fire tests in a Dutch tunnel thirteen tests were done with linear fire detection systems. One fire detection system was a glass fiber system and the two other systems were line detector systems. The fire size, the place of the fire according to the position of the detectors and the longitudinal ventilation speed were varied. The aim was to determine the time between ignition of the fire and fire detection and to determine the place accuracy.
Another four tests were done with an open deluge sprinkler system on a van and as build trucks. The sprinklers provided large water drops. The aim was to get information if a fire could be extinguished or not. The sprinkler tests were done in combination with or without longitudinal ventilation to know the effect of the longitudinal ventilation on sprinkler.

1 INTRODUCTION

During 2000/2001 the Centre for Tunnel Safety of the Ministry of Transport carried out full-scale fire tests in the Second Benelux tunnel near Rotterdam.

The objectives of the tests were to give answers to questions arising from current projects and to fill in gaps in existing knowledge about fire safety in tunnels build in the Netherlands. Based on a literature study and discussions with designers and rescue personnel involved in ongoing projects seven main goals were defined:

1. A better understanding of heat- and smoke propagation in time, based on developing fires, in relation to chances for escaping.
2. The influence of longitudinal ventilation on fire size and fire development.
3. Knowledge of the consequences of a large drop sprinkler on the fire development; the spread of smoke and steam, the temperature of smoke/air in the tunnel and the temperature of other (not burning) vehicles near the fire.
4. The working of linear fire detection systems for the detection time and accuracy of locating the position where the fire occurs.
5. The qualitative visibility of several types of escape route signing.
6. The accuracy of CFD-methods for predicting fires in tunnels.
7. Providing information to involved parties by showing the extent and characteristics of fires in tunnels, helpful for better understanding and decision making in the choice of safety equipment.

A series of tests were defined in order to achieve goals 1-4. Goal 5 was adressed during these tests. In order for the CFD predictions (goal 6) to really be a prediction, they were performed before performing the tests. In order to achieve goal 7, all tests were recorded with 6 video camera’s and several people were invited to observe the tests.

The series of tests was specified in four categories:

1. Category 1: heat- and smoke propagation: 6 pool fires with n-heptane/toluene
2. Category 2: effect of the ventilation on the fire: 3 car fires and 3 truck fires
3. Category 3: sprinkler tests: 1 van fire, 2 truck fires, 1 large fire in a truck load
4. Category 4: fire detection: 8 tests with small fires and 5 tests in combination with other categories.

The tests were carried out in the 2e Beneluxtunnel near Rotterdam. This brand-new tunnel was well appointed for the tests and refurbished afterwards before opening the tunnel for traffic.

The tunnel is a sink tunnel consisting in 3 tubes for traffic, 1 tube for slow traffic and 2 tubes for the Rotterdam metro. The tests were done in one of the traffic tubes, having a rectangular cross section with a height of 5 m and a width of about 10 m. The tunnel length is about 900 m, the test site was at 265 m from the exit portal. The tunnel is equipped with longitudinal ventilation and escape doors every 100 m. The driving direction is uni-directional as usual in The Netherlands for such tunnels.

This paper deals with the tests of the category 3 : sprinkler and 4 : fire detection.

2 BACKGROUND OF THE TESTS

2.1 Tests on fire detection

The need to use fire detection systems can be described for two situations:

1. Automatic detection of a fire makes it possible to take follow-up actions like warning road users and fire brigade, starting ventilation and pumps automatically without the use of a human operator.
2. Using an automatic sprinkler system with external water valves implies the use of automatic detection to know both the presence of a fire and the location of the fire.

Since over 30 years the current situation in The Netherlands is the use of traffic detection loops in the road surface, closed circuit cameras along each tunnel tube, intercom every 100 m and a 24 hour surveillance of each highway tunnel. Sprinklers are not used.
A weak point in controlling the tunnels could be the human factor. For that reason some fire brigades asked for automatic fire detection systems in new tunnel projects.

Several types of fire detections passed the revue in the discussion, based on the following principles:

- visibility : measuring smoke being much earlier than flames, being a proven system, requires a lot of measuring points to detect quickly;
- toxicity : measuring smoke being much earlier than flames, requires a lot of measuring points to detect quickly, need much maintenance;
- heat-radiation : heat radiation can be expected later than smoke, requires a lot of measuring points to avoid screening by cars and trucks if measured lengthwise;
- heat-temperature: measuring temperature rise by passing smoke, line detector systems seems to be simple and without a lot of maintenance and measure also heat-radiation;
- image-processing: measuring flames or smoke or both, the systems needs for smoke enough contrast against walls which can be a problem with low lighting levels and/or dirty walls.

A decision was made to investigate further on the measuring of temperature by linear detection systems. They are able to detect both the presence of a fire and the location of a fire.
The tests to be done should give answers on questions like:

- how do line detection systems of several types and/or makes react on different types of fires?
- what will be the (delay) time between ignition and detection of a fire?
- how accurate is the location of the fire detected?
- what will be the effect of a longitudinal air flow on the possibility of detection?
- what will be the effect of the horizontal distance in the cross section between the cables and the place of fire?
- will upright exhaust pipes of trucks give false alarms?
- which unexpected problems can happen using such systems?

For the tests several deliverers were invited to take part in the test program. In the end three of them reacted positive and showed their system(s). This paper does not give the names of the firms nor the type-names of the systems. The purpose of the tests was to gain information about the operation and possibilities of such systems, not to compare makes and types and not to approve systems.

2.2 Tests on open deluge sprinkler system

In The Netherlands the density of population is very high. As a result the diversion of dangerous transports to avoid tunnels in highways becomes more and more difficult and undesirable. This leads to the wish to allow all kinds of transportations of goods through the highways tunnels. Because during a large part of the day the traffic intensity on Dutch highways is high the safety equipment should help to avoid too high risks for road users. Within this background a discussion started about the use of sprinkler systems.

Based on a literature study and experiences from Japan and Australia it was concluded that in the Dutch situation sprinklers would only be able to help to avoid BLEVE's of mainly LPG-transports. The purpose of a sprinkler should be then cooling of the fire itself and cooling of tankers near the fire site. For such a purpose large drop sprinklers in combination with the longitudinal ventilation would fit.

In Piarc 1999 (1) some disadvantages of sprinkler are mentioned:

1. Water can cause explosion in petrol and other chemical substances if not combined with appropriate additives
2. There is a risk that the fire is extinguished but flammable gases are still produced and may cause an explosion
3. Vaporised steam can hurt people
4. The efficiency is low for fires inside vehicles
5. The smoke layer is cooled down and de-stratified, so that it will cover the whole tunnel
6. Maintenance can be costly
7. Sprinklers are difficult to handle manually
8. Visibility is reduced

In the Dutch tests we examined the numbers 3, 4, 5 and 8. Supplementary purposes of the tests were:

- Influence on living conditions in the tunnel like temperature, radiation and visibility.
- Influence of delayed switching on the sprinkler

The tests gave the possibility to show the phenomena directly to fire brigades, designers, owners of tunnels and to decision makers.

3 TESTS ON LINEAIR FIRE DETECTION SYSTEMS

3.1 Description of the fire detection tests

One linear detection system consisted in a glass fiber detector cable. The two other types of cables contained electronic sensors on regular distances of several meters.

The position of the cables is given in figure 1. The detection cables were mounted 35 meters lengthwise at each side of the fire location (total length ~70m).

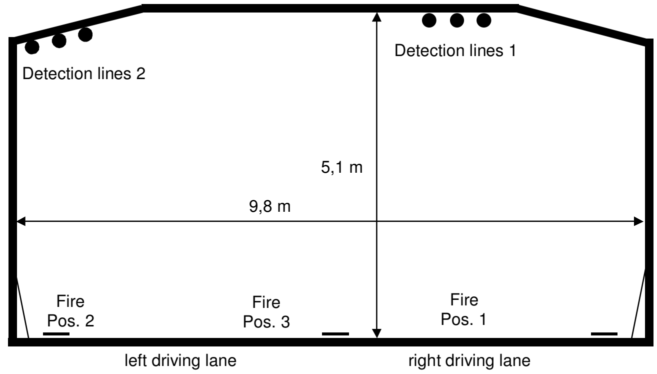


Figure 1 Position of detection cables and fire location in the tunnel

The computers of the three systems registrated at least two types of alarms: passing a maximum temperature and passing a maximum temperature differential. Based on their own experience and knowledge the deliverers adjusted the alarm levels as they thought the best one.

Table 1 gives an overview of all detection tests, the numbers fit in the numbering of the over-all fire tests program.

Test nr.	Type of fire	Fire position	Wind speed	purpose
0C	6 ltr pool 0,5 m^2	Pos. 1	0 m/s	False alarm test
0D	6 ltr pool 0,5 m^2	Pos. 2	0 m/s	False alarm test
0E	12 ltr pool 1,13 m^2	Pos. 1	0 m/s	Alarm required
0F	12 ltr pool 1,13 m^2	Pos. 1	3 m/s	Alarm required
0G	12 ltr pool 1,13 m^2	Pos. 1	5 m/s	Alarm required
0H	12 ltr pool 1,13 m^2	Pos. 3	3 m/s	Alarm required
0I	12 ltr pool 1,13 m^2	Pos. 1	0 m/s	Alarm required
0J	Truck with upright exhaust pipe	Pos. 1	0 m/s	False alarm test
1	4 MW pool fire	Pos. 1	0 m/s	Alarm required
2a/2b	4 MW pool fire	Pos. 1	1 m/s	Alarm required
4	15 MW pool fire	Pos. 1	2 m/s	Alarm required
11	Van (max. 7 MW)	Pos. 1	1 m/s	Alarm required
12	simulated truck load (max. 6 MW)	Pos. 1	3 m/s	Alarm required

Table 1 Overview of conducted detection tests

The 0,5 m^2 and 1,13 m^2 pool fires were conducted with 85% ethyl-alcohol, the other pool fires in the tests 1, 2 and 4 with 60% heptane / 40% toluene.
The choice of the small fire sizes (0,5 m^2 and 1,13 m^2) is based on national codes but also related to the expected size of a starting fire.
The fire positions were varied in order to measure the influence of position related to the detection cables. The wind speed was also varied in order to measure its influence on time and location of detection.

Cables in tunnel.

Small pool fire

Upright exhaust pipe

Figure 2 Pictures of tests

3.2 Results of fire detection tests

The results of the measurements for the 3 detection systems are given in table 2.
To ensure that no comparison between deliverers and types will be made no notification or system descriptions are given.
The time given is the delay time from ignition and the distance given is the distance between the location of detection and the fire site.

Test nr.	System A						System B						System C					
	Line 1			Line 2			Line 1			Line 2			Line 1			Line 2		
	min:s	m		min:s	m		min:s	m		min:s	m		min:s	m		min:s	m	
0C	No detection OK			No detection OK			07:10	4,0	D	02:40	3,2	D	No detection OK			No detection OK		
0D	07:05	0,6	M	No detection OK			02:18	-0,2	D	04:08	-6,8	D	No detection OK			No detection OK		
0E				00:56	0,6	D	04:22	-8,7	D	01:10	-0,8	D				00:36	-0,5	D
0F							06:40	27,3	V	03:40	9,1	V						
0G										06:30	-0,8	V						
0H							05:50	23,1	D	07:40	23,0	D						
0I				04:45	0,6	M	02:50	1,9	D	00:53	1,2	D				00:36	1,5	D
0J										12:40	2,0	D				No detection OK		
1	01:59	0,9	D	00:16	0,8	D	01:17	4,0	D	00:37	-0,6	D	02:07	3,9	M	00:23	3,7	D
2a/2b	01:31	0,9	D				01:17	1,8	D	00:45	1,6	D	02:21	-0,1	M	00:24	0,7	M
4							01:00	0,5	D	00:40	2,2	D	00:46	1,7	D	00:38	0,5	D
11										01:18	2,0	D				01:03	2,7	D
12										03:41	1,3	D				02:53	4,7	D

Table 2 Overview of test results

On the place of the white blank cells an alarm should have been given. The grey blank cells explain which systems were already out of use.

The maximum temperatures measured by the systems were for each test in the same range (about 20-30°C) however their location differed more than 20 meters in the tests 0F, 0G and 0H with wind speeds 3-5 m/s.

From the test series 0C – 0I can be seen system B generates the most alarms leading to the conclusion the alarm level of system B is lower than system A and C. This leads to undesirable false alarms in the tests OC, OD and OJ. At the other hand higher alarm levels did not generate alarms with wind speeds more than 3 m/s which can be seen from the results of system A and C.

From test 0E and 0I can be concluded if a detection cable is right above a fire an alarm can be expected to occur within 1 minute. However if the fire is not just beneath the detection cable delay times up to 4-5 minutes can be expected.
From tests 0F-0H the influence of wind speed can be seen. Normal wind speeds in a tunnel up to 3-5 m/s resulted in alarm delay times of 5-7 minutes for small fires. Even the larger fire in test 12 resulted in a delay of almost 4 minutes.
The larger pool fires of the tests 1-4 are all generated within 1 minute. These fires started at the beginning with 2-3 MW.

The location of the fire is given mostly with an accuracy of less than 5 meters from the fire site. However with wind speeds more than 3 m/s system B gave an alarm more than 20 meters from the fire site, the other systems gave no alarm at all.

3.3 Conclusions on fire detection

From the tests on fire detection can be concluded:

1. In combination with a wind speed less than 1 m/s slow developing fires will be detected within 1-3 minutes if just right beneath the detection cable.
2. If a slow developing fires is not just right beneath a detection cable or if the wind speed is higher than 3 m/s no alarms can be expected; if an alarm is generated the time delay can be expected to be 5 minutes or more.
3. Fast developing fires will nearly always be detected within 3 minutes independent of the wind speed.
4. The location accuracy can be expected less than 5 meters.
5. To avoid false alarms (for instance by upright truck exhaust pipes) a relative insensitive adjustment is needed, however on the contrary this implicates the lack of alarms with high wind speed.

4 TESTS ON OPEN DELUGE SPRINKLER SYSTEMS

4.1 Description of the sprinkler tests

To examine the aspects mentioned in paragraph 2.2 the sprinkler tests 11-14 were defined as described in table 3 (The numbers fit to the tests in the total test program):

Test nr.	Type of fire	Main test purpose
11	Van loaded with wood and 3 tyres, total fire size potential 15 MW (reached 7,5 MW)	To examine the set free of steam by heating up the van as much as possible while the van is staying closed to avoid too much direct contact with sprinkler water and fire, sprinkler to be switched on 10 minutes after ignition (in reality 13 min.)
12	As build aluminium load cabine of a truck with 36 wood cribs and 3 tyres, fire size potential 20 MW	To determine visibility reduction by water/steam/smoke; sprinkler to be switched on 3 minutes after ignition, the 3 minutes period can be seen as the minimum time needed for detecting a fire and starting up the pumps, traffic is likely still driving on and not yet stopped.
13	Same as 12	To determine visibility reduced by water/steam/smoke; sprinkler to be switched on 10 minutes after ignition, the 10 minutes period can be seen as needed for stopping the traffic and giving time to road users to escape from the tunnel tube with fire
14	72 wood cribs and 8 tyres, fire size potential 36 MW (reached 26 MW)	To examine the warming up of a tanker or truck near the fire and the cooling down by sprinkler, a tanker was placed on a distance of 5 m from the fire equipped with temperature measuring points (thermo couples)

Table 3 Description Sprinkler tests 11 – 14

The sprinkler system consisted of a sprinkler section of 17,5 m length above the fire site and a second section with a length of 20 m downstream the fire site joined to the previous one. The sprinkler sections were made of transverse pipes each with 3 sprinkler heads "old style". The lengthwise distance between the pipes was 2,5 m. The spray density on the floor was designed as 12,5 mm/min. Both sections could be switched on by hand independently.
The local fire brigades provided water supply and water drainage because the tunnel systems were not designed for the required amount of water to be handled in the tests.

Figure 3 gives an overview of the test facilities:

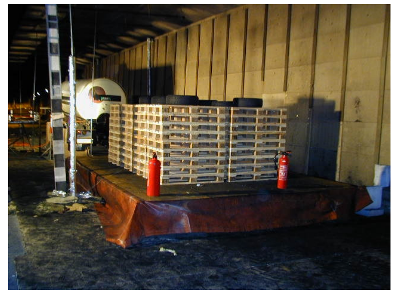
Water supply

Manifold

Sprinkler pipes and heads

van with wood cribs

alum. load cabine with wood cribs



72 wood cribs and tanker on short distance

Figure 3 photo's sprinkler tests

4.2 Results of the sprinkler tests

The photo's in figure 4 give an impression additional to the description of the examined aspects of a sprinkler system.

Test 12 load cabin cooled down by sprinkler

Test 14 wheel and plastic mud guard of tanker

Test 14 situation 50 m downstream minutes after extuingishing

Figure 4 photo's sprinkler tests

The results of the sprinkler tests are discussed per aspect:

The smoke layer is cooled down and de-stratified
This is true. Downstream the fire no real stratification is present. Near the fire stratification will be present in some extend until the fire is cooled down or extinguished.

Visibility is reduced
Immediately after switching on the sprinkler the visibility is brought back to less than 10 meter. A combination of smoke, water drops and steam reduces the visibility.

Delayed switching on the sprinkler
Before switching on the sprinkler it is necessary to stop the traffic to avoid secondary accidents due to reduced visibility and frightening effects by car drivers. A delayed switching on the sprinkler leaded to an outburst of the fire after some time, but when switching on the sprinkler the water could reach the fire resulting in extinguishing. A rather quick switching on cooled down the aluminium covering resulting in a certain fire size. The fire could not be extinguished however be prevented to become larger.

Extinguishing efficiency is low for fires inside vehicles
Fires in closed cars can hardly be extinguished however can be kept within some size. The simulated truckload cabin in test 12 stayed almost complete while the fire was burning causing a lot of smoke. In test 13 (delayed switching on the sprinkler) the cabin was destroyed and the fire was quickly extinguished after switching on the sprinkler.

Steam and living conditions in the tunnel
Unless some sprinkler water evaporated the steam production was not impressive. Most steam arises if water can reach the fire. The measured "air" temperatures downstream the fire were theoretically not above the levels causing damage to humans, however the author could not enter the tunnel downstream 5 minutes after extinguishing the fire of test 14.

Cooling effects
Before switching on the sprinkler the tanker was warmed up to 350°C. The sprinkler above the tanker caused a diminishing of the temperature back to 100°C within 5 minutes (the fire was not sprinklered) and in a further 5 minutes back to 50°C.

Other aspects
An additional test was done using the sprinkler (without a fire) with a longitudinal ventilation speed of 5 m/s and without ventilation. As a result the amount of sprayed water on floor level with ventilation is half of the amount of that without ventilation unless a large water drop system was used. It is assumed that small water drops were blown away. This effect will be larger if sprinkler systems use smaller water drops.

4.3 Conclusions on open deluge sprinkler

From the sprinkler tests the following conclusions can be drawn:

1. Sprinklers do not extinguish a fire in a closed car.
2. A sprinkler system will reduce the visibility immediately after switching on. Escape routes can hardly be seen. Car drivers are not able to drive safe through 'the rain'.
3. Large amounts of steam are not to be expected for fires smaller than 15 MW.
4. After extinguishing a fire of ~25MW downstream the fire the living conditions are not critical however still severe.
5. Other vehicles can be cooled down lowering the chance of fire jumping over.

6. A reasonable longitudinal ventilation speed of 5 m/s will reduce the extinguishing effect of sprinkler.

5 USING THE RESULTS

5.1 Fire detection

In the Dutch situation all tunnels in highways have traffic detection loops in the road surface per lane each 50-60 meters and a 24 hour surveillance. Also all these tunnels are equipped with intercoms giving connection to an operator. Based on experience such provisions provide alarms within less than 1-2 minutes.
Most fires start because of car brake down and will be very small in the early phases. In combination with a regular wind speed (because of the traffic) of 3-5 m/s automatic detection systems will detect such fires with a delay of more than 5 minutes or will not give an alarm at all.
It is concluded that

- fire detection systems will help in detecting a fire, but
- if there is no combination with an open deluge sprinkler system the advantages are small and in many cases not worthwhile the costs because of the presence of other kinds of detection and a 24 hour surveillance, however
- if there is a combination with an open deluge sprinkler system a linear fire detection system is required to establish the place of the fire with sufficient accuracy, and
- if there is no 24 hour surveillance or no other means to detect a fire a kind of automatic fire detection system can be helpful.

5.2 Sprinkler systems

Sprinkler systems can be helpful to reduce the risk of fires. However sprinkler systems are very expensive both in installation and maintenance. It should be kept in mind also other equipment provisions or measurements like organizing the traffic flow or composition can be used. Most of these solutions are also reducing the risk if used in a proper way and are much cheaper than a sprinkler system.
Therefore discussing the use of a sprinkler system is taking in account other solutions and balancing risk and costs.

6 LITERATURE

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