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Instantaneous liquid release from a rail tanker: The influence of noise shields on pool shape and pool size

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ABSTRACT

In the Netherlands, the Betuweline is a dedicated freight railway. It will, among other things, be used for transportation of all kinds of hazardous materials from the Port of Rotterdam to the German Hinterland and vice versa. The line is approximately 150 km long. Alongside the line, more than 100 km noise shields have been constructed. The question is how, and to what extent, this noise shield will affect the pool shape and size of an instantaneous release of a flammable liquid, such as liquefied petroleum gas (LPG).

In case of an instantaneous release of liquid from a rail tanker (50 m^3), both risk analysts and emergency responders use a circular pool shape of about 600 m^2 would result. To assess the influence of a noise shield, a full scale test was conducted on an already constructed part of the Betuweline. A rail tanker was filled with 50 m^3 red-colored environmentally safe liquid. The liquid was instantaneously released.

A very peculiar pool shape actually results due to the presence of a noise shield. A zone between the rails and the noise shield (2 m wide and 90 m long) is within 2–3 min filled with 15 cm of liquid. The total pool size area was about 750 m^2. Both shape and size deviate substantially from the traditional figures. These insights are both relevant to emergency responders for disaster abatement purposes and to risk analysts for effective modeling purposes. The Dutch Ministry of Transport is examining possible strategies to deal with these results.

The results of this study are based upon one single instantaneous release test. In addition, it is valuable to find out what the pool shape and size would be in case of a continuous release from the rail tanker near a noise shield.

1. Introduction

In the Netherlands, the Betuweline is a dedicated freight railway that will, among other things, be used for transportation of all kind of hazardous materials from the Port of Rotterdam to the German Hinterland and vice versa. The line is approximately 150 km long. The railway is aligned close to, and in some cases, through multiple cities and villages. Because of that, noise shields were designed to protect the inhabitants for high noise levels of passing trains. Alongside the line, for more than 100 km, noise shields have been constructed. The effect of noise shields on hazardous material releases is not a part of the deliberations thus far. One of the possible accident scenarios on the Betuweline is the instantaneous release of material from a rail tanker, for example one filled with a flammable liquid [1]. The question is how and to what extent a noise shield will affect the pool shape and size of an instantaneous release of a flammable liquid, such as liquefied petroleum gas (LPG).

2. Analysis of some previous studies

The pool shape and size of released fluid can be determined in various ways: by modeling or (full scale) testing. In fact, models should be validated as well by empirical data. Brambilla and Manca [2] present several critical issues on the use of pool shape models. One concern is the shortage of empirical test data to validate models and justify the use of them in actual events. In case of an instantaneous release of a rail tanker (50 m^3) both risk analysts and emergency responders use a circle-like pool shape of about 600 m^2 [3]. This shape and size is based upon a full scale test without a noise shield or any other barrier near to the rail tanker. Models provided in the literature usually consider a punctiform release in which the pool spreads in all directions at the same velocity. Consequently, the pool has a circular shape under the conditions of the axisymmetric hypothesis [4]. The fluid could flow in all directions without being hindered by any barrier at all. The liquid flows through the permeable ballast of the railway and forms a circular

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Table 1
Design characteristics of the rail tanker

Aspect	Specification
Type	Tanoos 896
Maximum volume	75 m^3
Release jaws (2)	80 cm × 20 cm
Height release jaw—rail	40 cm

pool. The depth of this pool is relatively small, about 5 cm. Large amounts of the liquid descend into the earth. In case of a fire, the pool size in combination with its depth determines the heat release rate and the time the pool is on fire. Both size and depth have repercussions on fire fighting considerations, such as how much foam should be used for repression or how to access the emergency. In 1994 and for the Betuweline, fire brigades guaranteed that they would be able to repress a 600 m^2 pool fire. They did not account for the possible presence of a noise shield alongside the track. That is why it is important to determine if designed noise shields influence the pool shape and size, and to what extent. This paper only deals with the results of a full scale test concerning pool shape and size. Brambilla and Manca [4] present four cases: one under the axisymmetric hypothesis and three cases refraining from the axisymmetric hypothesis. Their third case accounts for a bund in front of a parallel piped tank and coincides most directly with the full scale test as it mimics the case of a noise shield parallel to the railway. However, there are several differences: they modeled where we tested, they supposed a continuous release where we tested an instantaneous release, they supposed a solid base in which the fluid was released where else we released the fluid above the ballast from the railway track.

3. The full scale instantaneous release test

To assess the influence of the noise shield, a full scale test was conducted on an already constructed part of the Betuweline [5]. A rail tanker was filled with 50 m^3 red-colored, environmentally safe liquid, using water from the nearby ditch and a coloring agent. We used water instead of a flammable liquid for safety reasons, environmental aspects and costs. At 20 °C, water has almost the same viscosity as flammable liquids.[2] This viscosity is important because it determines the flow pattern of the liquid.

Table 1 shows some design aspects of the rail tanker that was used in the full scale test.

These design aspects show the liquid is released from about 40 cm height through a hole of the release jaws about 3200 cm^2 (2× 80 cm × 20 cm). Combined with the instantaneous character of the release, these design aspects indicate the enormous force with which the liquid lands on the track.

The test was conducted near the villages of Leerdam and Vuren, about 25 m away to highway 15, at hectometer 34.7. The test location was relatively horizontal (hardly any elevation). This flat location prevents the liquid from flowing in one dominant direction (the lowest point). On one side of the rail tanker, a noise shield including a door in the shield is apparent. The shield is dug in a small sand dike that is 60 cm high. The door is important because its frame and doorstep are not dug in a small sand dike. During the test, the door is closed. At the test location, markers were positioned and connected with red–white striped ribbon. This ribbon is used as an iso-distance line and assists observers in making their observations of the pool size. The distance between the ribbons is 5 m, and starts from the centre of the rail tanker.

Fig. 1. Test site photograph.

Fig. 1 shows the test location, including the rail tanker, the noise shield, the door in the shield and the ribbons.

The liquid (50 m^3) was instantaneous released. The results were observed in two ways:

- Three police camera's (one helicopter and two police cars).
- Three observers (one at each side of the rail tanker, and one behind the noise shield).

An observation protocol was developed. The three police cameras were coordinated by the police control room near the test site. One liaison of the test team was present in the police control room. The test leader was in contact with the liaison and the observers. The observers were in contact using the new Dutch emergency response communications system C2000. The test leader coordinated the observations by indicating the start of the release. Using C2000, the test leader requested the observers to indicate the pool shape at the times specified below.

Each of the observers had his own observation map. The observers were asked to indicate the pool size on the papers by marking the size on a pre-specified raster. Four observations were made by each observer after release of the fluid: 2 min 30 s, 5 min, 7 min 30 s and 20 min.

Both observers and policemen were instructed before the test. This instruction clarified the goal of the test and the observations that should be made. Fig. 2 shows the test arrangement.

Table 2 shows the relevant test data.

4. Results

The pool shape and size did not develop significant differences between 2 min 30 s, 5 min, and 7 min 30 s from the release moment. After 20 min, the liquid flowed underneath the ballast and grit (pebble-sand). The latter could only be seen by observers at the test location. Cameras did not record this liquid flow. The mechanism causing this delayed liquid flow is that the liquid initially is stored in the ballast and grit. Later, when the ballast and grit under and surrounding the rail tanker are saturated, the liquid flows from the ballast and grit to the lower points. Figs. 3 and 4 show the pool shape after 7 min 30 s and 20 min respectively from the release moment. As can be seen from Figs. 3 and 4, the total pool consists of several sub-parts, such as a long extension, a small nearly round part past the noise shield, a roughly triangular part and a trench.

[2] The nominal viscosity of water is 1.0 mm^2/s and is in the range of viscosity numbers of flammable liquids like gasoline [6]. For organic liquids, other fluids might be more appropriate for such full scale tests.

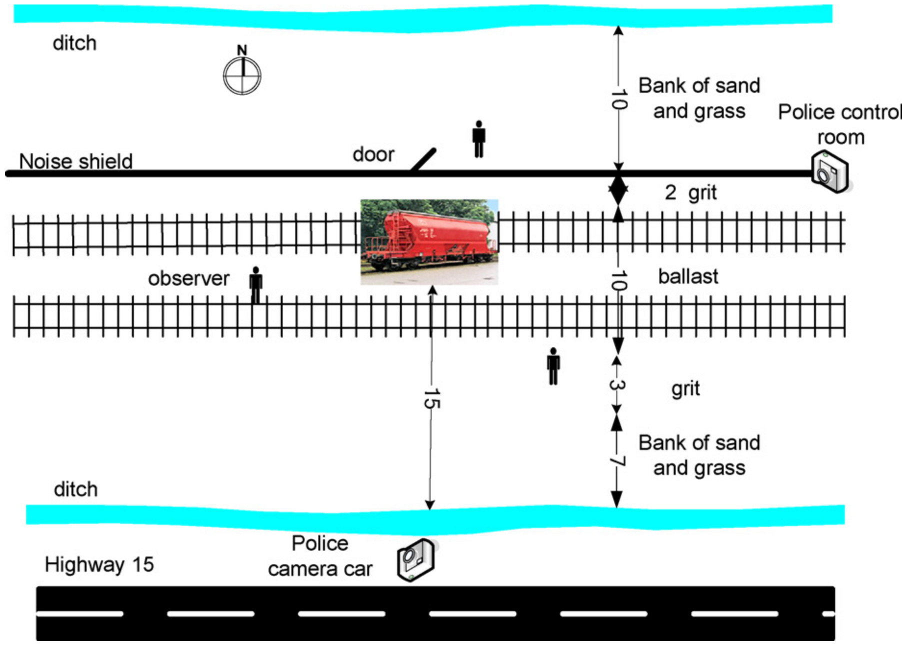

Fig. 2. Test site schematic overview.

Table 3 summarizes the observations made by observers and cameras. The upper 2 rows indicate the moment at which the pool shape is observed. For the pool size, the cells contain square meters. For the dispersion of the liquid in the trench, the cells indicate the length in meters over which liquid spots appeared.

The difference between the observations after 7 min 30 s and 20 min is about 200 m^2 (about 550 m^2 and 750 m^2, respectively). The liquid buffer in the ballast and grit caused this delayed increase after 20 min. At that moment liquid flows underneath the ballast and grit. This delayed flow also influences the pool shape in the ballast and grit zone: after 7 min 30 s the pool was like a triangle where it is a rectangle after 20 min.

A very peculiar pool shape results due to the noise shield. A trench is created between the rail track and the noise shield (2 m wide and 90 m long) and is filled with 15 cm of liquid within 2–3 min. The total pool size was about 750 m^2. Due to the noise shield, both pool shape and size deviate substantially from a circular pool.

These findings are significant from the point of view of spread of fire, given the liquid is flammable and ignites. Instead of the circular pool (diameter of 37 m), a maximum length of spread along the track is 90 m. This may increase the fire threat to other rail cars considerably. Also, in case of a very volatile flammable as LPG, it may enhance the possibility of a vapor explosion. This would depend on wind direction and strength, given the fluid confinement by the noise shield at one side and the rail cars at the other.

In addition, the following aspects were observed during the test:

- The developed trench (15 cm deep) between rail track and noise shield stretches in a western direction (about 55 m) more than an eastern direction (35 m) due to a small elevation.
- The remaining parts of the pool are at most several centimeters deep.
- During filling activities, small leakages caused liquid to flow under the rail tanker and under the door frame.
- The pool stretches about 10 m on the rail track in the transport direction, meaning that the liquid only flows under the two directly adjacent rail cars.
- The earth below the door frame is completely washed out.
- The dispersion in the ditch behind the noise shield is hampered by vegetation in the ditch and therefore spots occur instead of a continuous size.
- Five railway sleepers were washed out involving a hole 75 cm deep.
- The ballast stones were dispersed over a distance of 5 m from the rail tanker.

Table 2
Test site data

Aspect	Specification
Date and time	24 June 2005, 11.00 a.m.
Temperature	30 °C
Weather conditions during test	Dry and sunny, hardly any wind
Weather conditions 1 week before test	Heat wave: 5 days, 30 °C
Location ditch (north) behind noise shield	10 m from noise shield
Ground conditions noise shield-ditch	Sandy and covered by grass, dry
Ditch (north) behind noise shield	Cleaned 1 week before test, one-side dammed, hardly any current
Width ditch (north) behind noise shield	3 m
Location noise shield	4.75 m from the centre of the rail track
Location noise shield	2 m from ballast
Noise shield	60 cm earth dike outside the noise shield, except for the doors
Width door in noise shield	1 m
Width ballast rail track 1	5 m
Width ballast two tracks	10 m
Width grit along side tracks	3 m
Width grit-ditch (south)	7 m
Ground conditions grit-noise shield (south)	Sandy and covered by grass, dry
Location ditch (south)	15 m from rail tanker
Ditch (south)	Not cleaned, connected to open water, hardly any current
Width ditch (south)	3 m

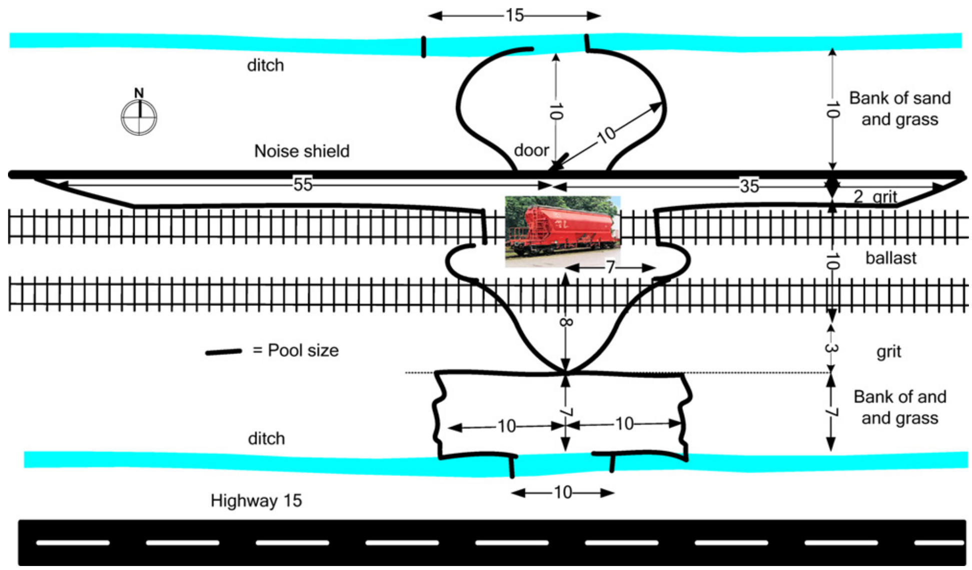

Fig. 3. Pool size after 7 min and 30 s (is the same for 2 min 30 s and 5 min).

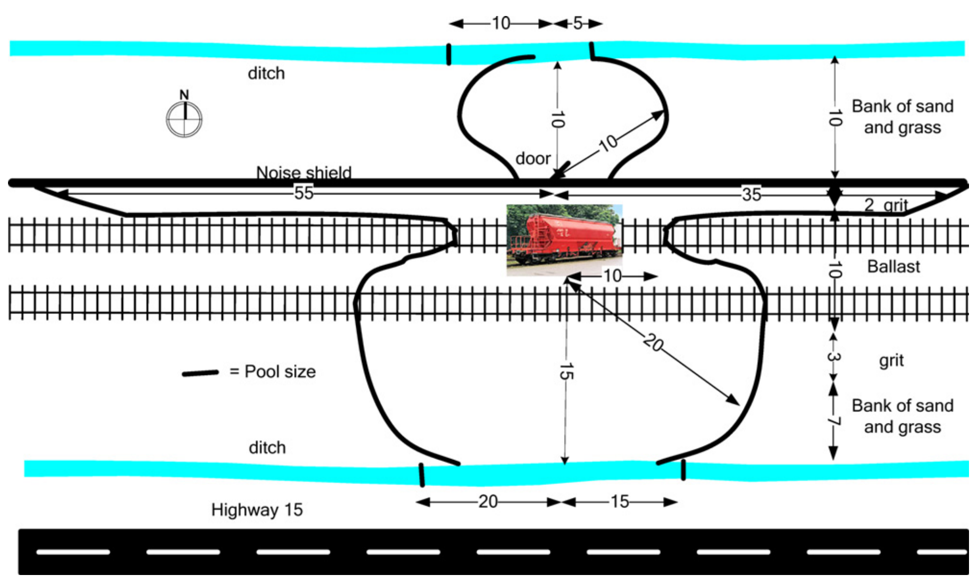

Fig. 4. Pool size after 20 min.

Table 3
Results instantaneous release

Characteristic part of the pool	Observation after . . . minutes					
	Pool shape (7.5)	2.5	5	7.5	Pool shape (20)	20
Behind noise shield	Half circle	160 m^2	160 m^2	160 m^2	Half circle	160 m^2
Grit along noise shield (west)	Trench	110 m^2	110 m^2	110 m^2	Ditch	110 m^2
Grit along noise shield (east)	Trench	70 m^2	70 m^2	70 m^2	Ditch	70 m^2
Ballast rail track	Rectangle	15 m^2	15 m^2	15 m^2	Rectangle	20 m^2
Ballast between two tracks	Trench	20 m^2	20 m^2	20 m^2	Ditch	40 m^2
Ballast and grit	Triangle	55 m^2	55 m^2	55 m^2	Rectangle	150 m^2
Pool south (A15)	Rectangle	140 m^2	140 m^2	140 m^2	Rectangle	210 m^2
Total surface	–	570 m^2	570 m^2	570 m^2	–	760 m^2
Ditch behind noise shield (north)	Spots	15 m	15 m	15 m	Spots	15 m
Ditch (south)	Spots	10 m	10 m	10 m	Spots	35 m

Such knowledge regarding pool size and pool shape is relevant both to emergency responders for disaster abatement purposes and to risk analysts for effect modeling purposes. It is important for emergency responders because it determines:

- The amount of foam to repress the emergency.
- The accessibility of the emergency scene.
- Heat radiation to other rail cars and hence possible domino effects.

For risk analysts it is important because it determines:

- Heat release rate.
- Evaporation rate.
- Heat radiation to other rail cars and hence possible domino effects.

5. Conclusions and recommendations

The following conclusions are drawn:

1. The pool size is about 550 m^2 after 7 min 30 s and about 750 m^2 after 20 min.
2. Along the noise shield, a 2 m wide trench that is over 90 m in length originates, and is about 15 cm deep.
3. The noise shield blocks the liquid flows in lateral direction, except for the door in the noise shield.
4. The doors proved to be the weakest link in preventing the released liquid from entering the nearby irrigation ditch.
5. The released liquid reaches the parallel ditch relatively fast (within 2–3 min) causing that this ditch cannot be used for repression purposes.
6. Underneath the ballast and grit, liquid flows without being clearly visible from above, causing unexpected threats to firemen.

The following recommendations are made:

1. Develop a pool fire repression strategy, thereby reckoning for the pool shape and size as a result of the noise shield. In addition, take care of the length of the trench parallel to the noise shield and the liquid flowing underneath the ballast and grit.
2. Reconsider the door frame construction so that substantial amounts of liquid will not flow underneath the door frame into the ditch.
3. Reconsider the primary direction for repression activities with respect to the noise shield presence.
4. Use the information found here to calculate the burning time of the resulting pool and the effect of the noise shield on the heat release rate.
5. Assess the influence of noise shields on both sides of the track.

6. Discussion

The results are based upon one single instantaneous release test. Yet, similar tests would likely result in similar pool shapes and size areas.

We realize that most rail tanker leakages are continuous. In general, continuous releases have a smaller release volume but last longer. Therefore, it would be interesting to determine what the pool shape and size would be in case of a continuous release from the rail tanker near a noise shield, for example 100 l/min as prescribed in the transportation risk analysis guidelines in the Netherlands [3].

In this study, the rail tanker was positioned before a (closed) door in the noise shield. Substantial amounts of liquid flowed underneath the door frame. It would be interesting to determine when locating the rail tanker away from the door hence only for the noise shield, if the liquid will also wash out the earth underneath the door frame. The same doors provide railway personnel the opportunity to escape from the track and emergency responders to reach the track. That is why doors in the shield are absolutely necessary.

Acknowledgement

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