Create safer transportation tunnels based on extensive scientific research performed in a real tunnel environment, in order to verify and prove that installing an active water-based Fixed Fire Fighting System (FFFS) will prevent structural damage in tunnels.

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1. INTRODUCTION TO FIXED FIRE FIGHTING SYSTEMS (FFFS)

A Fixed Fire Fighting System (FFFS) is a system that in an active way fights a fire. Such systems are typically also called water based fire fighting systems or suppression systems. The most common FFFS for tunnels are either deluge (low pressure) or watermist (in high or low pressure).
Both technologies work in deluge operation, dividing the tunnel into fire zones typically 20-30 m of open nozzles activated by opening a section valve. Both technologies are using some of the same fire fighting methods.

Japan was the first country to installing a FFFS more than +50 years ago together with Australia by default install FFFS in all their tunnels.

1.1 Growing awareness for active fire fighting

Water based active fire fighting or suppression technology is growing globally as a mean to mitigate risks and to protect humans and the asset against structural collapse, all serious vendors in the market have their system tested in full scale tunnel fire tests for large HGV fires.

2. TUNNEL FIRES

Typically fires in a tunnel are normally deep seated solid (Class A) fires or flammable (Class B) fires, and as such very difficult extinguishing. It's important to understand that a tunnel fire is very different to a building fire, due to the nature of the fire load, typically a HGV`s covered with tarpaulin and as such the water have limited access to the seat of the fire until the cover has opened up due to the exposure of flames or temperatures/heat.

Typically a modern tunnel safety strategy operates with the idea or concept that rescue workers or fire fighters are able quickly to access the tunnel in case of a fire, meaning that back-layer and temperature should be controlled prior to access the tunnel.

2.1. Stand-alone ventilation system Vs. design HRR fires

The vast majority of road or train tunnels today are typically protected or depends on a stand-alone ventilation system is able to make tenable conditions for evacuation and access for rescue workers and fire fighters to quickly enter the tunnel and evacuate and/or extinguish the fire. However in several cases in recent time and in the past this strategy hasn't been sufficient and coursed substantial loss of life and tremendous damage and costs to the tunnel structure and close down in significant period of time, up to months or years of highly important infrastructure network. The reason for those incidents and/or the ventilation system inability to handle such bigger fires with substantial high HRR output is due to the fact that in many cases, consultants or tunnel operators has underestimated the HRR output or development of an unsuppressed fire in a tunnel environment during the risk analysis.

The table shown below are international accepted HRR output which consultants uses for reference during the risk analysis as a help tool to determine design fires. Often in specifications for concrete tunnel projects we see design fires e.g. 30, 50 or 100 MW, however with below table in mind, and if the tunnel is allowed for mixed traffic, then one shouldn`t wonder why a ventilation system get overwhelmed and not able to handle the fire situation.

HRR MW			Road vehicles	Fire boundary
Lives at risk		5	1 – 2 cars	ISO 834
		10	Small van, 2 – 3 cars ++	ISO 834
		20	Big van, public bus, multiple vehicles	ISO 834
		30	Bus, empty HGV	ISO 834
	Construction at risk	50	Combustible load on truck	ISO 834
		70	HGV load with combustibles (4 tons)	HC
		100	Average HGV	HC
		150	HGV loaded with easy comb. (10 tons)	RWS
		>200	Limited by oxygen, petrol tanker, multiple HGVs	RWS

Table 2.1 HRR outputs in road tunnels

2.2. Facts to be considered

So even if a ventilation system is correct dimensioned to handle a large fire with a major HRR peak, even then the ventilation system can fail, because also the ventilation velocity has a great impact on fire growth rates (1) and temperatures, velocities above 2,5 m/s will increase the rate or speed at which a fire or the HRR will rise by 50% compared to moderate or lower ventilation speed – higher ventilation velocities are normally applied, when a back layer has to be controlled/removed!
The production of CO - CO_2 and toxic substances rise linearly with the increase of the HRR.
The FGR of a large fire increases dramatically when it is not controlled at approximately 5 MW – beyond that the FGR accelerated rapidly at 16,4–26,3 MW/min and a fire can quickly get out of control and easily exceeds the capacity of a standalone ventilation system and an overwhelming ventilation system can`t neither prevent a back-layer upstream, neither control or reduce temperature and as such

not prevent fire spread and such scenario`s will not enable rescue-/fire fighting teams to access the tunnel .
If a HRR of 75 MW fire is reached, temperatures downstream make self-evacuation impossible.

2.3 Some examples of catastrophic fires with a stand-alone ventilation system

CATASTROPHIC TUNNEL FIRES W/O (FFFS)		
Fire cause	Location	Loss/damage
A HGV (Truck) with flour and margarine caught fire	Montblanc Tunnel Italy/France	• 41 people died • €350-450 mio + €500 mio in transport system downtime
A HGV (truck) crash caught fire	Gotthard Tunnel Switzerland	• 11 people died • €6 mio in repair costs
Fire in a chemical hauling HGV (truck)	Euro Tunnel UK/France	• €60 mio in repair costs • €200 mio income losses

Ref.: 2.3 Catastrophic Tunnel fires, SP Report 2004-05

2.4 Calculated estimated maximum HRR Qmax MW (2) including some of the above catastrophic

Accident, year	Vehicle type	Tunnel cross-section (m^2)	Estimated total heat content, E_{tot} (GJ)	Estimated maximum HRR, Q_{max} (MW)	Estimated time to Qmax	Estimated fire duration, t_2	Fuel or ventilation-controlled tunnel fire
Baku 1995	2 metro coaches	28	80-100	70-90	10-15 min	30-50 min	Fuel controlled
Kaprun 2001	Funicular train	9-10	20-30	15 - 20	15-20 min	45-60 min	Fuel controlled
Channel tunnel 1996	10 HGV	45	2200	370	1 h	2.5 (3.4) h	Ventilation controlled
Mont Blanc 1999	15 HGV, 9 cars*	50	5000-7000	300 – 380	2-3 h	9-13 h	Ventilation controlled
Tauern 1999	16 HGV, 24 cars	45	4000-4500	300 – 400	2-3 h	7-10 h	Fuel controlled

Ref.: 2.4 Catastrophic Tunnel fires, SP Report 2004-05

2.3 Some examples of catastrophic fires with a Fixed Fire Fighting System

CATASTROPHIC TUNNEL FIRES W/ (FFFS)		
Fire cause	Location	Loss/damage
3 HGV`s and 4 cars crashed (resulted in an explosion +fire)	Burnley Tunnel Australia	• 3 people died • Very limited damage and repair cost

Ref.: The Impact of Fixed Fire Fighting Systems on Tunnel Safety – The Burnley Incident in a Current Theoretical Perspective, Dix, A

(No Fixed Fire Fighting System)
N B . : Road surface and tunnel walls and infrastructure damaged after the fire

MONT BLANC TUNNEL

(With Fixed Fire Fighting System)
N B . : Road surface and tunnel walls and infrastructure are intact after the fire

BURNLEY TUNNEL

The Burnley tunnel fire in Australia in 2007 had a potential higher HRR than some of the other named catastrophic tunnel fires showed at 2.3, but due to the ventilation-/ Fixed Fire Fighting Systems interaction and quick activation and operation the fire was suppressed and controlled, so that the HRR peak was never reached and casualties (due to the fire) was prevented and the tunnel structure was intact, the tunnel was opened in less than 3 days after the fire.

3. PASSIVE FIRE PROTECTION VS. INSTALLING A FIXED FIRE FIGHTING SYSTEM

The debate about conventional passive fire protection versus an active Fixed Fire Fighting System or suppression system is an on-going debate, however active fire fighting are getting traction, especially on sub-sea tunnels, currently all sub-sea tunnels being projected, are all planned with an active fixed fire fighting system.

PLANNED MAJOR SUB-SEA TUNNEL		
Name	Country	Lengths
FEMERN	Denmark/Germany	18,0 km`s
COPENHAGEN HARBOUR TUNNEL	Denmark	1,0 km`s
3-DECK TUNNEL BOSPORUS	Turkey	6,5 km`s
SILVERTOWN	UK	1,7 km`s
LOWER THAMES CROSSING	UK	4,5 km`s
SWINIUJCE TUNNEL	Poland	1,5 km`s

3.1 Reduce or avoid passive tunnel fire protection or lining
Due to a Fixed Fire Fighting System ability to offer immediately temperature reduction and control after activation, enable tunnel owners or consultants to either reduce or avoid protective fire protection layer or insulation/lining when installing a FFFS.

3.2 Disadvantages by passive fire protection
The installation of passive fire protection in an existing tunnel have a massive impact on a number of things e.g.;

- A very time consuming and labor intensive and costly procedure
- Construction intervention in the tunnel, will reduce the tunnel cross section volume
- Will inevitably lead to the closure of the tunnel and major traffic problems for the public

3.3 Disadvantages by passive fire protection (Fire safety)
Although the tunnel walls are protected against temperatures for a limited period, it will not solve any incidents which happens regular e.g.;

- Multiple collisions by vehicles HGV`s and other vehicles, creating rapid FGR and high temperatures, preventing fire fighters from entering the tunnel
- A catastrophic fire scenario as per table 2.4 with a fire duration of ≥ 2,0 hours
- The more reflective surface of passive protection will have a negative effect on radiation of heat and as such it will have a self-reinforcing effect on the size of a fire and its potential rapid development.
- Passive fire protection will not in any case improve safety for human`s or evacuation, on the contrary

4. STRUCTURAL PROTECTION BY A FIXED FIRE FIGHTING SYSTEM

4.1 The mechanisms of a FFFS or fire suppression system
After activation of a FFFS/Suppression watermist system it will affect the fire through(3);

- Pyrolysis inhibition through cooling and oxygen deprivation
- Smothering of combustion with liquid and water vapour
- Cooling the hot plume through latent heat of evaporation
- Prevention of fire spread through cooling of neighboring surfaces

Fire Heat Release Components;

- Convective
- Radiative
- Latent
- Water heating
- Superheating

Without Fire Suppression	With Fire Suppression
Convective 70 % of fire heat release rate Radiative 30 % of fire heat release rate	Convective 50 % of fire heat release rate • Radiative • Latent • Water heating • Superheating 50 % of fire heat release rate

4.2 Example Resulting Fire Heat Release Rate

- Unsuppressed HRR = 100 MW
- Suppressed HRR = 40 MW
- Suppressed convective HRR = 50% of 40 MW = 20 MW

4.3 Full scale tunnel fire testing

Due to a Fixed Fire Fighting System ability to offer immediately temperature reduction and control after activation, enable tunnel owners and consultants to either reduce or avoid protective fire protection layer or insulation/lining when installing a FFFS.

We were asked in a recent actual case by a tunnel owner to prove or verify our Fixed Fire Fighting System ability to protect against a structural collapse as per NFPA 502.

Fig. A HGV fire in a tunnel

With reference to the above verification of structural collapse protection, which only was a single element in one of the largest and most comprehensive full-scale tunnel fire test program done recently and performed at the San Pedro de Anes "Experimental Center" 600 m test tunnel in (Asturias) Spain in 2018.

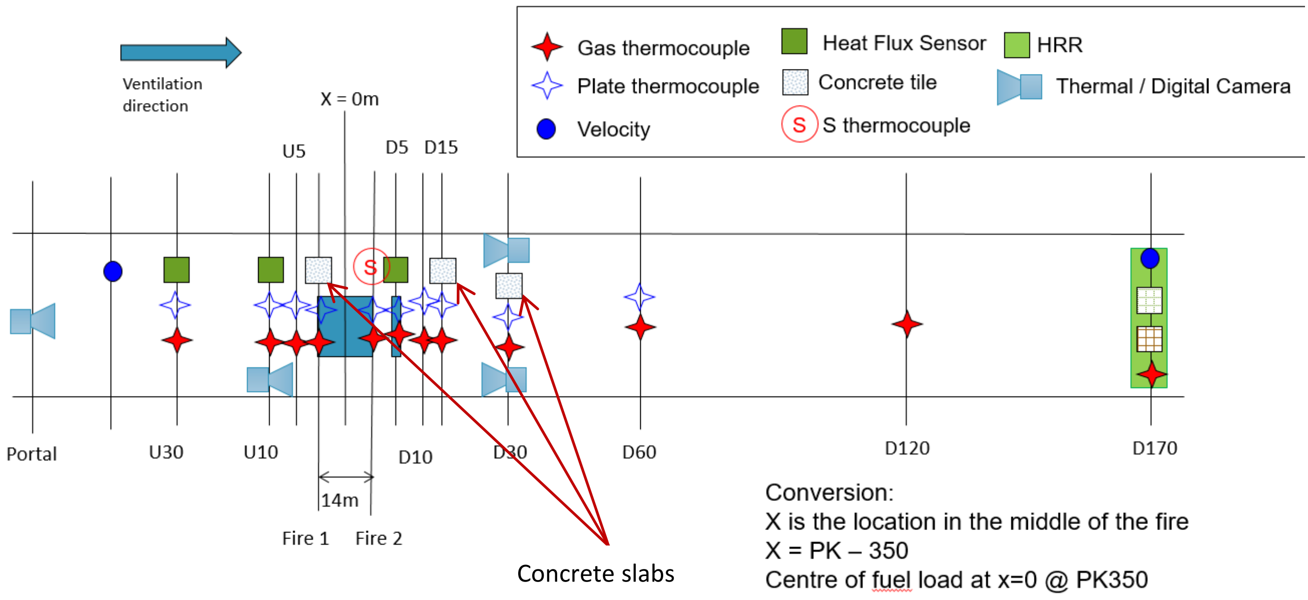

Fig. 1. Actual test set-up

<u>The client criteria`s for the actual structural fire test recently performed:</u>

- Ceiling surface temperature shall not exceed 380°C
  (As per NFPA 502 recommendation), to demonstrate that there is minimum spalling, which may lead to progressive tunnel collapse
- Temperature of steel reinforcement within the concrete shall not exceed 250°C
  (As per NFPA 502 recommendation)
- To demonstrate that there is minimum spalling, which may lead to progressive tunnel collapse.

The full scale tunnel fire test was simulating a large HGV fire ≥ 200 MW, concrete slabs with inserted thermos couples at 3 depths were mounted to the existing tunnel ceiling at 3 locations, location F1 is shown on below temperature curve.

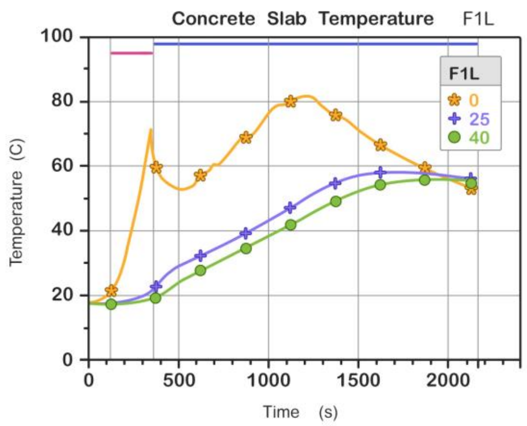

Fig. 2. Temperature curve

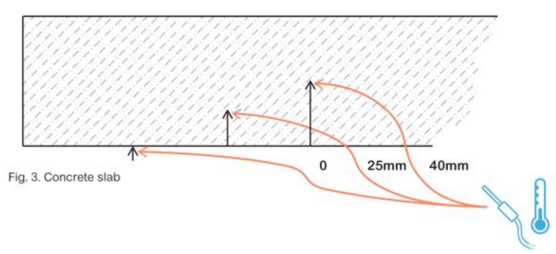

Fig. 3. Concrete slab

The full scale tunnel fire test was simulating a large HGV fire ≥ 200 MW, concrete slabs with inserted thermos couples at 3 depths were mounted to the existing tunnel ceiling at 3 locations, location F1 is shown on fig. 2 temperature curve.

CONCLUSIONS

Fixed Fire Fighting Systems generally have undergone numerous full scale tunnel fire tests, which particular is performed by the European vendors.
So there is a substantial amount of fire test data and research results available which can be evaluated proving and witnessing FFFS ability to minimize risks and protect the asset

5. REFERENCES

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