Use of Fire Suppression Systems in Underground Stations and Metro Tunnels

Steven K.H. LAI[a], Tim K.W. CHO[a], William Y.M. XIE[b], Hadi WIJAYA[c], K.W. ANG[c]

[a] WSP (Asia) Limited, Hong Kong, [b] WSP Consultant Pte Limited, Singapore,

[c] Land Transport Authority, Singapore

ABSTRACT

To control or suppress a fire, fire suppression systems such as fire hydrant, hose reel, sprinkler, water mist, etc. are commonly used for buildings. In an underground metro station, it is common to have fire hydrant and hose reel to serve the public areas (e.g. platform, concourse, adits or long subways, etc.). For metro tunnels, it is also common to have fire hydrants along the tunnels. To enhance the fire and life safety, some countries have reviewed their regulations and have considered to provide additional fire suppression systems (e.g. sprinkler system, water mist system, drencher system) for underground metro facilities.

For a commercial building where there are lots of people, sprinkler systems are provided to control or suppress a fire, which has become a standard provision in most cities. In a busy underground station, however, where there will be lots of people in the station during the morning or evening peak periods, in the event of a fire, it will be a challenge for the operator to control the safe evacuation and arrange a path for the emergency services to arrive at the scene. Therefore, some cities have revised their regulation to include the use of sprinkler system for the public area in their underground metro system. Also, in order to reduce the pipe size and the spatial provision for the sprinkler system, Shanghai has considered to use water mist system instead of sprinkler system in their metro stations. This paper will discuss the use of sprinkler systems and water mist systems for station public areas from various points of view including operation and maintenance etc.

For road tunnels, the design fire heat release rate is normally from 5MW (passenger car) to over 150MW (goods vehicle). In recent years, sprinkler systems, water drencher systems and water mist systems have been used in road tunnels. Although they may not able to extinguish the fire, they can suppress and control the size of the fire especially when they are activated during the initial stage of the fire. Therefore, there is a suggestion to install sprinkler systems, water drencher systems or water mist systems in metro tunnels, where the fire heat release rate range from 5WM to 20MW. Some believe that such systems can assist in fire department intervention, protect the asset and protect the emergency services by for example, mitigating the risk of explosive spalling in the event of a huge fire. This paper will discuss the use of these systems for metro tunnels from various point of view with the consideration of the tunnel environment during the evacuation.

This paper will summarize the current practices in different cities including Hong Kong, Singapore, Hangzhou, Shanghai, Beijing, Middle East, etc. on the application of various water suppression system in underground stations and metro tunnels. The paper will also provide an overview on the upcoming trends on the use of fire suppression system in underground stations and metro tunnels.

KEYWORDS

Sprinkler System, Water Mist System, Drencher System, Fire Heat Release Rate

INTRODUCTION

Fire suppression system installed in a building will activate when a fire occurs in order to suppress or control the fire in the building. Its purpose is to enhance the life safety and lower the possible damage by fire. Usually it consists of fire hydrant, hose reel and other water based fixed firefighting system (FFFS), such as sprinkler system, water mist system, etc.

For water based FFFS, there are various types but they share a similar operation principle. Basically it consists of a water ejection nozzle, water distribution pipework, pumps, control valve and water tank. When there is a fire, the heat from fire will activate the system by melting the fire sensitive element in the nozzle or trigger the heat detector, then water will be pumped from the water tank to the nozzle which distributes water droplets to the fire. These water droplets will suppress or control the fire by (i) lowering the fire temperature to below flame point by water evaporation, (ii) put out the fire by isolating the fire from oxygen with evaporated and expanded water steam, and (iii) control the fire spread by wetting the surface of fuel and nearby combustible material.

In commercial buildings, fire hydrant, hose reel and other water based FFFS, such as sprinkler systems, are standard provision in most countries in order to suppress or control the fire and lower the fire damage when a fire occurs. According to Ahrens [1], properties with sprinkler system have 87% lower death rate per 1,000 reported fires than those properties without any automatic extinguishing system in USA. Also, the dollar loss per fire in properties with sprinkler system is reduced by 30%. These facts indicate that the sprinkler system can effectively enhance safety and reduce loss due to fire.

As the fire risk for station public areas in an underground station is expected to be lower than commercial building (see **Table 1**), water based FFFS is not commonly required. Some cities have provided water based FFFS (e.g. sprinkler system) for station public areas. The concern on installation of water based FFFS is mostly from its possible adverse impact on the evacuation path.

Table 1: Commercial Building vs Station Concourse/Platform

	Commercial Building (e.g. shopping mall)	**Station Public Area (e.g. Concourse/Platform)**
People Density & Characteristic	• Can be high during holiday or special events (e.g. Chinese New Year)	• Can be high during morning / evening peak hours or special events (e.g. Chinese New Year) • High passenger density
Likely Cause of Fire	• Shop fire • Rubbish bin fire	• Baggage fire • Rubbish bin fire (1)
Fire Heat Release Rate	• Shopping mall (5MW) • Atrium (7MW) [15]	• Baggage (not more than 2MW)
Overall Fire Risk	• Higher, no control for goods in the building	• Lower, as stricter requirement on building material and goods in the area
Impact to general public	• Minor, building closed	• Huge, interruption or suspension of metro services

Note:
(1) There are no rubbish bins in public area in Singapore metro station.

In road tunnels, currently fire hydrants are required to be provided along the length of the tunnel, while some tunnels have additionally installed sprinkler systems, water mist systems or drencher systems to protect the tunnel structure, though this is not a common practice. The comparison of fire risk between metro tunnel and road tunnel is summarized in **Table 2**. The concern on the installation of water based FFFS is due to the impact of water based FFFS to the tunnel facilities and evacuation path, the effectiveness of water based FFFS in metro tunnel, and the combined effect of water based FFFS with tunnel ventilation system.

Table 2: Road Tunnel vs Metro Tunnel

	Road Tunnel	Metro Tunnel
People Density & Characteristic	• Little control of the combustible inventory (vehicles and its contents) • For 1km, 2 lanes, all passenger cars, 5 persons per car ➔ 1600 people	• Better control of the combustible contents (rolling stock furniture, occupants, luggage) • 2000~3000 people per train
Likely Cause of Fire	• Cable • Vehicle	• Cable • Train
Fire Heat Release Rate	• Overall combustibility can be very high (5~300MW)	• Overall combustibility is low (e.g. 5~20MW)
Overall Fisk Risk	• Higher chance of fire (based on previous experience)	• Lower chance of fire
Impact to general public	• Tunnel closed	• Relevant tunnel closed • Service interruption for at least a few stations
Remark		• Avoid collision effectively • High level of control of traffic

CURRENT PRACTICE

The current practice of water based FFFS provision is summarized in **Table 3**.

Table 3: FFFS for Different Underground Metro Projects

	Hong Kong [6]	Singapore [13]	Mainland China [16][17]			UAE [5]	NFPA 130 [9]
			Shanghai	Hangzhou	Beijing	Dubai	
System	PSD	PSD	PSD (new station)	PSD (new station)	PSD (new station)	PSD	Not applicable
Station Concourse	• HR • FH • SP (New station)	• HR • FH (Dry Type)	• HR • FH • SP / Water Mist System(1)	• HR • FH • SP	• HR • FH • SP (2)	• HR • FH • SP	• HR • FH • SP (3)
Station Platform	• HR • FH • SP (New station)	• HR • FH (Dry Type)	• HR • FH • SP / Water Mist System(1)	• HR • FH • SP	• HR • FH • SP (2)	• HR • FH • SP	• HR • FH • SP (3)
Tunnel	• FH	• FH (Dry Type)	• FH	• FH	• FH	• FH	• FH

Abbreviations:
FH – Fire Hydrant
HR – Hose Reel
PSD – Platform Screen Door
SP – Sprinkler
Notes:
(1) Water mist system is installed in station platform and trackway for station in Shanghai metro line 11 phase 1.
(2) Sprinkler system for commercial area.
(3) Sprinkler system for area with combustible loadings.

USE OF WATER BASED FFFS IN STATION PUBLIC AREA (CONCOURSE / PLATFORM)

In station public area, installation of fire hydrant system and hose reel system is considered as standard provision. However, as shown in **Table 3**, the use of water based FFFS is still subject to local practice. Currently, there are not many experiment or test to substantiate the use and the effectiveness of water based FFFS in underground metro station. Based on the experience of application of water based FFFS in buildings, it seems that the use of FFFS in station public area could suppress the fire or control the fire spread and protect the underground structure. The major concerns of using water based FFFS in underground metro station are discussed below:

Concern 1: Visibility along Evacuation Path

When water based FFFS is activated, the visibility of the environment will be reduced due to cool down of hot smoke and steam near the fire site. Poor visibility may prolong the time the passengers take to evacuate from the station.

From experience in commercial building, when water based FFFS is activated, the visibility at the fire site is reduced. However, the reduction in visibility is only significant around the area of the fire site.

In most cases, the water based FFFS allows the people to move away from the fire site and move to the exit.

In addition, the smoke extraction system installed in the station will be activated when there is a fire. It will improve visibility by extracting smoke and steam from the fire, thus allowing the passengers to escape along the evacuation paths. Therefore, the concern of visibility can be mitigated.

Concern 2: Steam

There is also a concern about steam from evaporation of water discharged onto the fire by water based FFFS. The hot steam would cause scald to the passengers.

Some research [2] suggested that the activation of water based FFFS could cool down the temperature around the fire site, and blocking the radiant heat transfer from the fire. Hence, if passengers will get scald due to the steam from the water based FFFS, they may also suffer scald injury by radiant heat transfer from the fire if there is no water based FFFS.

It is also argued that the smoke extraction system would extract the smoke and steam, such that high temperature steam are less likely to spread away from fire site. Therefore the concern of scald from steam may need to be further studied and evaluated.

Concern 3: Slippery Evacuation Path

Another concern is that when water based FFFS is activated, the floor will be wetted by water and become slippery. This will increase the risk of injury during evacuation due to slippery floor or slippery handrail. Also, spraying water on the passengers may make them feel uncomfortable especially if the station air temperature is low.

The activation of water based FFFS usually only affects the area around the fire, most part of evacuation path are not affected. For passengers close to the fire when the fire starts, protecting them from radiant heat of fire and stopping the fire spread could be more important than keeping the evacuation path dry. In addition, suitable selection of floor finishes and handrail finishes can reduce the impact of slippery floor or slippery handrail. Therefore this concern can be mitigated.

Concern 4: False Activation

Another concern for installing water based FFFS in station public area is its impact to metro operation when the water based FFFS experienced a system fault. The fault maybe due to quality of the system components, wear and tear or inappropriate maintenance. The accidental activation of the water based FFFS may lead to interruption of the metro service and water damage to equipment such as escalator. Such equipment damage (e.g. breakdown of escalator, etc.) may in turn results in safety concern to the passengers.

Concern 5: Cost effectiveness

As the station public area is well controlled by the operators and a lot of mitigation measures (e.g. use of construction material with low fire risk, only activities with low fire risk are allowed in the station, etc.) have been implemented to reduce the fire risk, the chance of fire in the station is very low. Thus, it may not be cost effective to install and maintain the water based FFFS in a station.

Comparison of Sprinkler System and Water Mist System

In the following, two type of water based FFFS will be considered: (i) Sprinkler System and (ii) Water Mist System. They share similar equipment and operation principle but work in different ways. For sprinkler system, its working pressure is around 2MPa [7]. While for water mist system, its working pressure is over 3.5MPa [7]. The difference in working pressure lead to different droplet size. For sprinkler system, the droplet size is around 700 to 800 microns, while for water mist system, the droplet size is around 30 to 100 microns. The different droplet size results in major differences in the firefighting mechanisms for the two systems. For sprinkler system, as the water droplet is larger in size, they will not be completely evaporated by flame and will reach the fuel surface, wetting it and suppressing the fire. For the water mist system, as the small droplet has high surface area to volume ratio, most of these droplets will be evaporated by the flame, and the steam produced by evaporation would block the fire from oxygen, thus extinguishing or controlling the fire. Both systems will cool down the air around the fire, blocking the radiant heat transfer and prevent fire spread by wetting the surrounding surfaces.

Considering the cost of two systems, sprinkler system will have lower installation, operation and maintenance cost since it is working at lower pressure. As higher system pressure will require more expensive piping and fitting, and hence more expensive operation and maintenance cost.

For water mist system, skillful workers are required to install the system to ensure the system can work properly. Also, regular cleaning is required to avoid the nozzle from being blocked by dust as they are exposed to station open area. Technically, these issues can be resolved as water mist system has been used in road tunnels where the environment is dirtier.

The advantage of water mist system over sprinkler system is that it uses less water. Typically the sprinkler system would use 3 to 5 times more water than water mist system [7]. Smaller water flow implies smaller pumps and pipes.

A summary of comparison between Sprinkler System and Water Mist System is shown in **Table 4** below:

Table 4: Comparison of Sprinkler System and Water Mist System

	Sprinkler System	Water Mist System
Major Fire Fighting Mechanism	• Wetting the fuel surface	• Heat Absorption • Blocking fuel from oxygen
Water Flow Rate	• Higher (3-5 times of Water Mist System) [7]	• Lower
Installation Cost	• Lower	• Higher
Operation and Maintenance Cost	• Lower	• Higher
Impact to operation when falsely activated	• Only area near faulty head affected	• Only area near faulty head affected
Tank Size	• Larger	• Smaller

Trend to install FFFS in underground station public area

Currently, provisions of water based FFFS in underground station public areas is not widespread yet, due to the inherent concerns mentioned above. In Hong Kong, sprinkler system has only been installed in a few new underground stations (e.g. Kennedy Town station opened in 2014) public area. It is envisaged that more studies and research on sprinkler system are still required before it can gain wider acceptance for application in underground station public areas. At the same time, the effectiveness of water mist system in semi-open area is still uncertain and more research and development is required before it can be implemented.

USE OF FFFS IN METRO TUNNEL

For road tunnels, attitude of various countries around the world on the water based FFFS varies. Countries like Australia choose to make it mandatory to install water based FFFS (Deluge System) in all road tunnels, while some countries choose not to consider water based FFFS or only consider installing water based FFFS on a case by case basis [11]. The difference of fire heat release rate between road tunnel and metro tunnel is listed in **Table 5** below:

For metro tunnels, generally the heat release rate is lower than road tunnel due to fire resistant train and strict control of materials inside the tunnel. Currently, only fire hydrant is installed in the metro tunnel and no other water based FFFS is installed in metro tunnel.

Table 5: Fire Heat Release Rate for Various Tunnel

	Hong Kong	Singapore	Mainland China	NFPA [10][11]
Road Tunnel	20 – 100 MW	100 – 300 MW	20 – 100 MW	5 – 300 MW
Metro Tunnel	5 – 22 MW	10 – 15.2 MW	5 – 10.5 MW	Full Scale Test: 13 – 52.5 MW

The purpose of water based FFFS in tunnel is to (i) assist in fire department intervention, (ii) protect the assets in the tunnel, especially the tunnel structure, and (iii) protect the fireman. In Delhi Metro, deluge system has been installed at platform trackway. In Shanghai Metro, water mist system has been installed at platform trackway for some stations to reduce the amount of smoke entering the station

platform via platform screen door. In general, there is no additional water based FFFS installed inside metro tunnel.

Although the environment of road tunnel and metro tunnel differs (refer to **Table 2**), most of the experience of water based FFFS for road tunnel can be a good reference for metro tunnel.

From the experience in road tunnel [11], the automatic water based FFFS is able to provide early suppression on fire, retard the fire growth rate, remove heat from the environment, limit the fire spread between the vehicles and extend the available escape time for tunnel users and lower the possible damage to tunnel structure, system and equipment. But there are some concerns regarding installation of water based FFFS in metro tunnel as discussed below.

Concern 1: Shielded Fire

In road tunnel, where the fire is within or under a vehicle (i.e. a shield fire), water from FFFS cannot applied directly on the source of fire. This is similar to the case of a fire within or under a train.

In case fire occurs in the train or below the train, the fire can still spread to other carriages. In this situation, multiple experiment with covered fire mentioned in [2] shown that water based FFFS can prevent the spread of fire to another train, lower the heat release rate and tunnel ceiling temperature, but not able to extinguish the fire.

Concern 2: Steam Generation

Another concern for installation of water based FFFS is the steam generated from evaporation may cause more harm to the people during evacuation and emergency service personnel during rescue and fire control. This concern is discussed for fire scenario in station public area. However, the fire heat release rate for tunnel fire is much larger than station fire. Hence, this concern requires revisiting.

According to Leucker [8], for water mist system, the heat flux in the downstream air will decrease from dangerous $2kW/m^2$ to $0.5kW/m^2$, which is a safe level for occupant based on information given by SCDF [14]. This shows that the water mist system is effective on blocking radiant heat transfer from the fire, and sprinkler system would have similar effect.

Another studies [12] suggested that water mist system would lower the tunnel air temperature 35m downstream from fire decrease significantly from nearly 600°C to around 30°C after 10 minutes.

The blockage of radiant heat transfer and cooling down of tunnel air temperature is due to the evaporation of water droplet from the water based FFFS. For road tunnel, the large cross section area allows hot steam to spread and mix with cold air. The hot steam will be cool down to a safe level for people and emergency service personnel to move. However, as the cross section area of metro tunnel is limited, there are possibilities the hot steam may remain in high temperature and cause scald to the people. Further research and development shall be carried out to determine the system requirement for water based FFFS to be used in metro tunnel.

Concern 3: Maintenance Cost and Access

Although the installation of water based FFFS only requires small diameter water pipe running along the tunnel at high level, maintenance for the system will be a concern for metro operators. Usually the metro tunnel is compact with a cross section area of around 25m^2. Thus, it is difficult to get access to the high level of the tunnel and may require special works train for the installation of the pipes.

In case of leakage from the water based FFFS, it may be difficult to detect during normal train operation. For safe access of water based FFFS installed at the tunnel ceiling, termination of train services in the associated tunnel is needed. If the metro system is using overhead line as power supply for the train, the maintenance process will require special caution to avoid damage of power line or electrocution of workers.

Concern 4: Electrocution and Short Circuit

In metro tunnel, power supply for the train is either by overhead lines at high level or by third rail near rail level. In both cases, there will be non-insulated conductor exposed in the tunnel environment. When water based FFFS is activated, large amount of water will be distributed in the tunnel, which may create an electrified environment

To avoid this, the water based FFFS needed to be interlocked with the traction power supply system i.e. the water based FFFS can only be activated when the traction power supply system is off. However, it may take a long response time (~10 minutes) against fire as time is needed to shut down the traction supply system after a fire is confirmed by the operator. In particular, shutting down of the traction supply system cannot be done in short time as there may be another train in the incident tunnel, and non-incident train needed to be driven away from the incident tunnel section before the traction power supply can be shut down.

From Singapore Sprinkler Test 2012 [3], the effectiveness of deluge system in road tunnel would be greatly reduced with activation time after fire is detected. Therefore, the effectiveness of water based FFFS in metro tunnel may be greatly reduced due to the long response time.

Concern 5: Combined Effect with Tunnel Ventilation System

During a fire, tunnel ventilation system will be activated to exhaust the smoke from tunnel and protect the evacuation path from smoke. In this situation, the combined effect of tunnel ventilation and water based FFFS needed to be considered.

The major concern of combined operation of tunnel ventilation system and water based FFFS is related to the impact on the hot smoke layer. The smoke layer may be disturbed due to the cooling effect of the water based FFFS. The disturbance of smoke layer may draw down hot smoke layer onto the evacuation passengers, reducing the visibility level. In addition, the water released would make the walkway more slippery. The concern related to visibility and slippery surface is already discussed earlier.

For this phenomenon, according to English [4], FFFS can reduce the fire heat release rate, which may improve the effectiveness of the tunnel ventilation system.

Concern 6: False Activation

There is concern of false activation of water based FFFS. For road tunnel, spurious activation of water based FFFS will lead to service interruption and risk of collision as drivers may stop their vehicles suddenly when the FFFS is activated.

For metro tunnel, the problem would be more severe as activation of FFFS during metro operation may cut down the traction power supply system due to the system interlock. Train will loss the traction power suddenly and metro service will be terminated. Despite the risk of electrocution and circuit damage, the recovery of traction power supply would take some time as a detail check is needed after the removal of water from the tunnel.

CURRENT PROVISION

Response of Metro Train Fire in Tunnel

When a metro train on fire in tunnel, "Drive through concept" is commonly adapted today. The incident train should continue to the next station to facilitate egress and firefighting process. By parking the incident train in station, passengers would leave the train and evacuate from the metro system more quickly, and it is easier for emergency service personnel to approach the train. In addition, possible fire damage to the tunnel structure and equipment inside the tunnel is avoided.

Fire Services Provision in Train and Metro Tunnel

Summary of typical fire services provision in train and metro tunnel is summarized in **Table 6** below:

Table 6: Fire Services Provision in Train and Metro Tunnel

	Train	Tunnel
Fire Detection	• Smoke detector • CCTV	• Aspirating type smoke detector (1) • Linear heat detector (2)
Warning	• Train communication systems such as break glass, intercom phone, and public address system	• Intercom phone
Manual Fire Suppression	• Potable fire extinguishers	• Fire hydrant
Smoke Control	• Close the intake of the train air-conditioning unit	• Tunnel ventilation system
Egress Path	• Side door • Detrainment device at first / rear car (optional)	• Cross passage between tunnels • Escape staircases
Fireman access		• Fireman staircases • Special vehicle (long tunnel)

Notes:
(1) Aspirating type smoke detector has been used for a project in Hong Kong.
(2) Linear heat detector has been used for projects in Hong Kong and Singapore.

CONCLUSION

To enhance fire safety in metro system, water based FFFS installation has been provided for underground station public area in some cities. There are concerns on the effectiveness and risks related to the water based FFFS and therefore, some cities have not installed water based FFFS in underground station public area. For metro tunnels, experience of water based FFFS in road tunnel can be referred, but due to special features in metro tunnel, more research and experiments are needed to study (i) the impact of water based FFFS to large fire in metro tunnel, (ii) how to activate the water based FFFS and the associated overall reaction time and (iii) the effectiveness of the water based FFFS in metro tunnel.

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