Feasible fire protection solutions for long underground cable tunnel in UAE; A case study

By

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1. Abstract

The present case study offers a detailed discussion on different active fire protection solutions for underground electric cable tunnels. These tunnels considered to house only MV (medium voltage, up to 11 KV) electrical and telecom cable trays while other building service such as gas, fuel, water (except for fire suppression use) etc. are not permitted inside these cable tunnels. These tunnels are usually found in connecting substations to different number of facilities.

A case study of such cable tunnel in perspective of Dubai, UAE is carried out. The technical and commercial aspects of different possible fire protection solutions are discussed for total 4 sample models of cable tunnels; with varying lengths of 1 km, 2 km, 4 km & 6 km while width and height are being constant to 3 meters.

2. Introduction & background

An electric cable tunnel plays a crucial role in maintaining functionality of any facility. Many past experiences of cable tunnel fires worldwide have demonstrated severe impact on the business and threat to people life safety. For example recent fire in Holborn (London) cable tunnel in April 2015 resulted in long business interruption and massive threat to life safety of local people. The present case study focus on different cable tunnels samples in UAE.

Usually a cable tunnel is a narrow tunnel through which medium or high voltage cables runs in large industries and facilities. The risk of fires in such cable tunnels is a growing concern for electric utilities and connected facilities. Any fire incident in these spaces can be numerous and serious.

The aftermaths of a fire in these systems may result in serious damage to installations as a whole, can cause disruptions to processes and business, leading to significant economic losses and, in the worst cases, even personal losses. A complete goal from the fire protection standpoint in this type of infrastructure is to prevent fires and stop them from spreading. This necessitate requirement of an active fire protection solution supplemented with passive protection systems.

Common causes of cable tunnel fires are:

Internal	External
Short-circuits	Maintenance
Sparks	Accumulation of dirt
Overloading	Environmental Conditions
Static electricity	Fuel concentration

Overheating	Fire spread from other fires

Though many fire suppression solutions are available and recommended by codes and standards, few solutions (especially one which uses heavy water discharge) impose potential damage to cable tunnels arrangement and post fire complications like long business shut off time, replacement of burned cables etc. Some technologies which are clean or using much lesser water are considered as very expensive and usually assumed that it will not be able to demonstrate better controlling of growing fire over other traditional options.

The fire protections requirements from local building code (UAE Fire & life safety code) are international codes are discussed in following sections.

3. Objective

The prime objective of cable tunnel fire protection is to meet the following conditions:

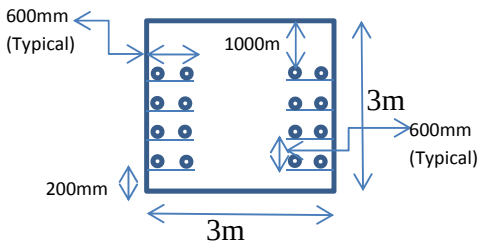
a. Prevent the premature collapse of the structure.
b. Limit exposure of the material to high temperatures.
c. Limit the toxicity of combustion gases.
d. Control the fire
e. Extinguish the fire (If possible)

The objective of this study is to discuss technical and commercial aspects of different applicable fire protection system for different cable tunnel models and select the most suitable one.

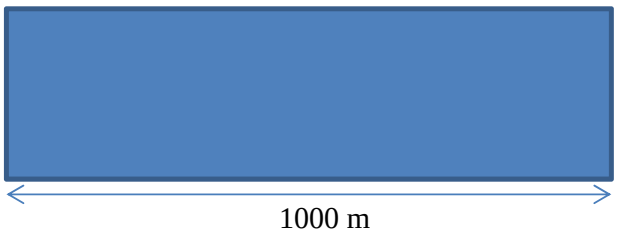
4. Sample cable tunnel models

To study the different aspects of fire protection for such cable tunnels, few models as described below are considered. Cross section of all cable tunnels are assumed to be same, only length varies between different tunnel models.

Model-1 (M1);

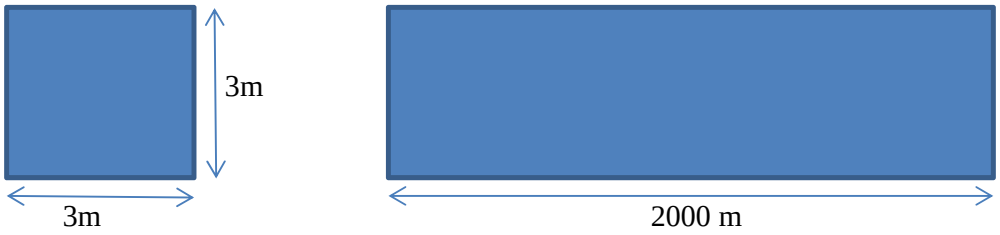


Cable tunnel cross section

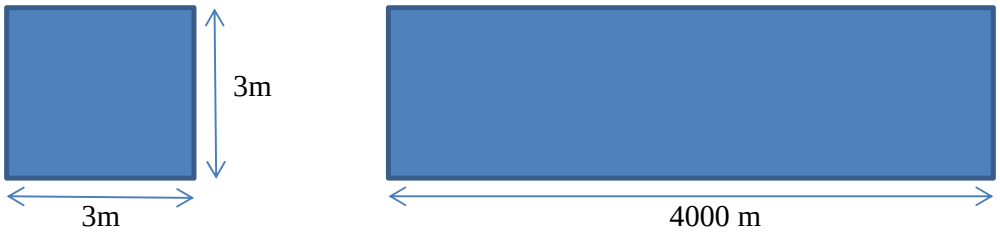


Cable tunnel plan view

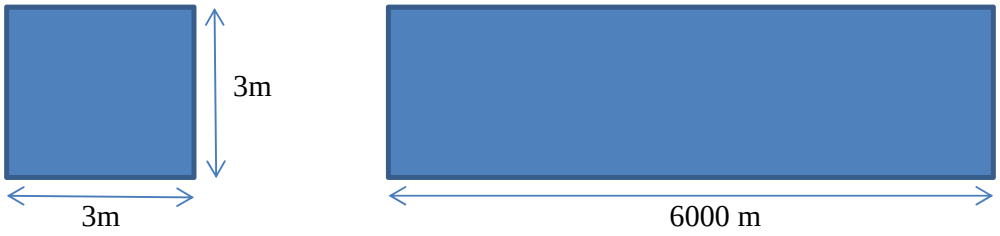
Model-2 (M2);



Model-3 (M3);



Model-4 (M4);



5. Assumptions

The below listed assumptions were made to conduct this study;

a. Cable tunnel cross-section is rectangular/Square.
b. Cable trays are mounted only on side walls of tunnels.
c. There are no additional confined spaces in tunnel, as sometime emergency power cables passing in such tunnels are provided within in 2 HR fire rated enclosures.
d. No obstruction between ceiling and cable tray arrangements.
e. No other services like fuel, gas, & water (except fire water) are passing through such tunnels. However incidental crossing at certain locations is not an issue.
f. No passive fire protection system requirement is discussed or considered during this study.
g. Life cycle costs of different fire protection systems are not accounted.

6. Fire protection solutions

6.1.Applicable codes and standards;

Applicable codes and standards pertaining to fire protection solutions for cable tunnels in UAE are as bellow;

a. UAE Fire & Life safety code, 2011 edition.
b. NFPA 13, "Standard for the Installation of Sprinkler Systems" 2016 edition.
c. NFPA 15 "Standard for Water Spray Fixed Systems for Fire Protection" 2012 edition.
d. NFPA 101 "Life safety code". 2016 edition
e. NFPA 750 "Standard on Water Mist Fire Protection Systems" 2015 edition.
f. NFPA 850 "Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations" 2015 edition.
g. NFPA 5000 "Building construction and safety code" 2015 edition.

6.2 Occupancy classification for cable Tunnels;

UAE fire & life safety code table 9.3 considers cable tunnels under industrial occupancy.

NFPA 5000, chapter 29 covers such areas under "utility chases" and considers under industrial occupancy.

6.3 Hazard classification for cable tunnels;

UAE fire & life safety code which is primary country code refers to NFPA 850, *"Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations"* for hazard classification of cable tunnels.

However the NFPA 850 doesn't classify cable tunnels into any hazards category, but the provided, applicable sprinklers density of 0.30 gpm/ft^2 allows us to assume it under "extra hazard 1" category as per density/area curves of NFPA 13. Hence this study assumes cable tunnels as ***"Extra hazard 1"*** category for further analysis, unless other modified requirements imposed by UAE fire & life safety code or any other mentioned NFPA codes/standards.

6.4 Fire protection requirements from different codes & standards for cable Tunnels;

As per table 9.3 from UAE fire & life safety code: Wet risers, Automatic sprinklers, and water mist system are recommended/required as fire protection system for cable tunnels.

NFPA 101, life safety code chapter 40, section 40.3.2 requires all high hazard industrial occupancies, operations, or processes shall have approved supervised automatic extinguishing systems.

The below table provide the possible choices of fire protection solutions for cable tunnels.

UAE Fire & Life safety codes	NFPA Codes/Standards
Water mist	NFPA-13; Automatic sprinklers
Automatic sprinklers (With high discharge density)	NFPA 15; Water spray (Deluge)
Water spray (Deluge)	NFPA 750; Water mist
Wet standpipe system	NFPA 850; Automatic sprinklers, Water spray (Deluge), Water mist Automatic gaseous extinguishing systems

In summary, UAE Fire & life safety code and NFPA both allows automatic sprinklers system (With high discharge rates), water deluge, and water mist system for protecting cable tunnels.

The wet standpipes system is the only requirement which is additional under UAE fire & life safety code compare to NFPA. However on the basis of past project experiences it is found that usually AHJ allows to omit wet standpipe from such areas since in many situations it's not practicable for a fire fighter to use such standpipes in cable tunnels. However current study also considers the wet standpipe as an option for fire protection of cable tunnels, as it's a requirement from local building code.

In the following sections a discussion on advantages and disadvantages of all listed fire protection systems are discussed in detail.

**Note: The comparison of above systems does not qualify a system to be selected as final, the final system selection is subjected to acceptance by Authority having jurisdiction (AHJ).*

6.5 Design density for sprinklers/ water spray applications;

UAE fire & life safety code table 9.7 requires 0.30 gpm/ft^2 of sprinklers density for a 232 m^2 of area.

The NFPA 13, Section 22.27.1.4.1 for advanced light water reactor electric generating plants, requires sprinkler systems shall be designed for a density of 0.30 gpm/ft^2 (12.2 L/min·m^2) for the most remote 100 linear ft. (30.5 m) of cable tunnel up to the most remote 2500 ft^2 (232.2 m^2).

The NFPA 15, section 7.2.2 requires for cable trays and cable runs, the system shall be hydraulically designed to impinge water directly on each tray or group of cables or tubes at a net rate of 0.15 gpm/ft^2 [6.1 (L/min)/m^2] on the projected plane containing the cable or tubing tray or run.

The NFPA 850, section 7.8.2 requires Automatic sprinkler systems should be designed for a density of 0.30 gpm/ft^2 (12.2 mm/min) over 2500 ft^2 (232 m^2) or the most remote 100 linear ft. (30 m) of cable tunnels up to 2500 ft^2 (232 m^2).

Hence a conservative approach with a **0.30 gpm/ft^2** of sprinklers density for a **232 m^2** of area is selected as a basis of design for sprinklers and water spray system.

6.6 Technical comparison of different fire protection systems;

A technical comparison of different fire protection systems for different cable tunnel models as discussed in section 4 of this report (lengths of 1 KM, 2 KM, 4 KM & 6 KM) is carried out in below table. While the commercial comparison to be discussed in coming sections.

Note-1: Any increase in width or height of tunnel above 3 meter may increase the nozzles and piping requirement for different systems discussed above.

Note-2: This study whenever specifies water mist system, it refers to high pressure (>80 bars), pumps based water mist system, with zoned application style and open nozzles. The design is intended to cater for at least 3 zones of such installation, one fire zone and two adjacent zones.
All the manufacturers of high pressure water mist systems are using their fire test model results, as a basis of their system design. Hence there is no standard design criteria are available as of now. This study considered engineering water mist system, as defined by 3.3.24.3 of NFPA 750. Thus all technical parameters accounted for comparison in below table are based on different manufacturer's recommendations and quotations. Slight changes in system design parameters are expected between different manufacturers/ suppliers.

Fire Fighting systems			
Water mist	**Automatic sprinklers**	**Water deluge**	**Remarks**
Installation			
Multizone installation	Single zone	Multizone installation	**All criteria for tunnel Model-M1; (L-1000m & W-3 m).**
Max zone length 24 meters (Based on manufacturer's recommendations and optimized pump sizes)	Max zone length 1 KM (1000 meters) (Based on extra hazard group 1 area limitations of 3716 m^2 from NFPA 13.)	Max zone length 80 meters (Based on 232.2 m^2 area NFPA 13, 22.27.1.4 & table 9.7 from UAE fire & life safety code)	
No of zone required-42	No of zone required-1	No of zone required-13	
Water demand			
Minimum active zones-3	Minimum active zones-1	Minimum active zones-1	
Minimum active nozzles-24 (8 nozzles per zone, nozzle selection, spacing and flow is based on different manufacturer's recommendations)	Minimum active Sprinklers-25 (Based on hydraulically most demanding area of 232.2 m^2 or 25000 ft^2 with sprinklers coverage of 9.3 m^2 or 100 ft^2.)	Minimum active nozzles-25 (Based on hydraulically most demanding area of 232.2 m^2 or 25000 ft^2 with sprinklers coverage of 9.3 m^2 or 100 ft^2.)	8 nozzles/zone for wms Water deluge; single zone activation is considered, while some designers prefers at least 2 or 3 zone activations.
Minimum water flow demand- 45 GPM (based on 2.0-2.5 (L/m)/m^2 or 1.8-2 .3 gpm/ft^2 density) (1.8 X 24=45)	Minimum water flow demand -750 GPM No of sprinklers X density X sprinkler coverage area (25 X 0.30 X 100=750 gpm)	Minimum water flow demand -750 GPM (based on 0.30 gpm/ft^2 density) (25 X 0.30 X 100=750 gpm)	

500 GPM for standpipe	500 GPM for standpipe	500 GPM for standpipe	Based on 2 connections of 65 mm flowing 250 each.
Total demand= **545** GPM	Total demand= **1250** GPM	Total demand= **1250** GPM	
Accidental (If any) water discharge from automatic fire suppression systems			
15 GPM (One zone)	30 GPM (1 Sprinkler)	750 GPM (1 Zone)	
Design duration (Minimum)			
10 mins (based on section 12.3 of NFPA 750 & minimum 2 times of manufacturer's test results for pre-engineered systems)	90 mins (based on table 11.3.1.2 from NFPA 13)	120 mins (based on section 6.2 of NFPA 850 Or based on table 11.2.3.1.2 from NFPA 13)	
Designed discharge (In case of fire)			
45X10=450 Gallons	750X90=67,500 Gallons	750X120=90,000 Gallons	
Drainage requirements			
450 gpm or None (Very minimal) As most of the water mist/fog is absorbed by structure and heat generated by fire itself	Moderate 67,500 Gallons	**Very huge** 180,000 Gallons (based on minimum 2 Zone's drainage as recommended by section 22.27.1.4.2 of NFPA 13)	
Other important highlights			
Very small pipe sizes	Huge pipe sizes	Huge pipe sizes	
Compact pumps and small water Reserve required	Huge pumps and huge water Reservoir required	Huge pumps and huge water Reservoir required	
Quick activation	Delayed activation	Quick activation	

	(As temp need to grow high)	(Considering linear heat detection is employed for obtaining signal for system activation.)	
Rapid cooling of fire (Water mist envelops the fire source and affected areas, and introduces the cooling effect due to its high surface volume & heat absorption capacity. Water mist also uses inerting effect by blocking additional available oxygen to the fire source)	Irregular cooling (Temperature needs to rise continuously, thus allows fire to grow significantly till it reaches the ceiling heads and activate the sprinkler heads. Sometime ventilation system also takes heat away from the immediate vicinity of fire and hence results in activation of wrong sprinkler heads.)	Rapid water discharge (This system uses a huge water to be flooded into space and thus results in cooling of entire space)	
No or very little drainage expected	High drainage expected	High drainage expected	
Post fire, no or little shut off time	Normal to heavy shut off	Heavy shut off time	
During extinguishment no or very little damage of cables Expected	Normal to heavy damage of Cables expected	Very heavy damage of facility is Expected.	

6.7 Performance of Water mist/ Automatic sprinklers/ water deluge system;

Automatic water sprinklers, water deluge, high pressure water mists all systems are capable of suppressing /extinguishment of cable tunnel fires. As this is a theoretical study we are not studying any actual cable tunnels. To compare the actual performance of said systems, an actual cable tunnel case must be studied to account for actual fire load, tunnel cross sections, ventilation arrangements and several other factors.

All above systems will perform differently in actual cable tunnel fire arrangements and it requires either to have a full scale fire tests to study performance of systems or to have a suitable computer model and possible fire scenarios to obtain such figures.

6.8 Commercial comparison of different fire protection systems WITH standpipes for M1 model;

The below table provides the commercial comparison (Capital cost, only) of the different fire protection systems for cable tunnels of 1 KM length.

High pressure Water mist			
System components	Quantity	Tentative Prices **AED**	Tentative Prices **USD $**
High pressure pump sets @ 140 bar	3	917,336	247680
GRP water tank	1		
Mist nozzles	334		
Zone valves	42		
controls			
Packing & Forwarding @ 10%		91,735	24,769
Duty @ 5%		50,454	13,623
Stainless steel piping, fittings, supports	2200 m	993,126	268,145
Installation & Commissioning			
Total		2,052,651	554,216
With standpipes			
Fire pumps	*1 set*	*800,000*	*216,000*
Fire water tanks	*1*	*200,000*	*54,000*
Piping & fitting	*1000 m*	*1,000,000*	*270,000*
Class III cabinets	20	136000	36720
Total		2,136,000	576,720
Total cost of tunnel protection (Water mist + standpipes)		**4,188,651**	**1,130,935**
Automatic Sprinklers			
System components	Quantity	Tentative Prices **AED**	Tentative Prices **USD $**
Sprinklers	350	70,000	18,900
Zone valves	2	5,000	1,350
Other controls @ 5%		43,750	11,813
Cost of standpipes with fire pumps & piping as calculated above under water mist section	1 No	2,136,000	576,720
Total cost of tunnel protection		**2,254,750**	**608,783**

Water Deluge			
System components	Quantity	Tentative Prices **AED**	Tentative Prices **USD $**
Nozzles	350	161,000	43,470
Deluge valve assembly	13	104,000	28,080
Other controls @ 5%		58,250	15,728
Cost of standpipes with fire pumps & piping as calculated above under water mist section	1 No	2,136,000	576,720
Total cost of tunnel protection		**2,459,250**	**663,997**
*Note: The above prices are tentative and taken from leading manufacturer of the systems. The prices for Water mist is from world leading manufactures for pump based pre-engineered water mist system. *The technical as well as commercial parameters for water mist may change considerably with different manufacturer; as most of the water mist manufactures are using their fire test data for designing the systems. However, an average costing from different manufacture is used for this study.			

6.9 Commercial comparison of different fire protection systems WITHOUT standpipes for M1 model;

High pressure Water mist			
System components	Quantity	Tentative Prices **AED**	Tentative Prices **USD $**
High pressure pump sets @ 140 bar	3	917,336	247680
GRP water tank	1		
Mist nozzles	334		
Zone valves	42		
controls			
Packing & Forwarding @ 10%		91,735	24,769
Duty @ 5%		50,454	13,623
Stainless steel piping, fittings, supports	2200 m	993,126	268,145
Installation & Commissioning			
Total		2,052,651	554,216
Total cost of tunnel protection (Water mist + standpipes)		**2,052,651**	**554,216**

Automatic Sprinklers			
System components	Quantity	Tentative Prices **AED**	Tentative Prices **USD $**
Sprinklers	350	70,000	18,900
Zone valves	2	5,000	1,350
Other controls @ 5%		43,750	11,813
Cost of fire pumps & piping As calculated in *section 6.8*	1 No	2,000,000	540,000
Total cost of tunnel protection		**2,118,750**	**572,063**
Water Deluge			
System components	Quantity	Tentative Prices **AED**	Tentative Prices **USD $**
Nozzles	350	161,000	43,470
Deluge valve assembly	13	104,000	28,080
Other controls @ 5%		58,250	15,728
Cost of fire pumps & piping As calculated in *section 6.8*	1 No	2,000,000	540,000
Total cost of tunnel protection		**2,323,250**	**627,276**

7. Quick commercial comparison for different tunnel models for different fire protection system

Below are the tables which show quick commercial comparison for tunnel models M2, M3 & M4 for different fire protection systems. These costs are calculated from reference of 1 km tunnel costs, some items are just multiplied by tunnel length factors, while other are accounted separately.

7.1 For 2 KM length of cable tunnel;

Water mist			
System components	Quantity	Cost With standpipes (USD)	Cost Without standpipes (USD)
Water mist system cost	1	1,080,000	1,080,000
Standpipe system (with fire pumps, piping, standpipes & fitting)	1 No	883,440	0
Total cost of tunnel protection		1,963,440	1,080,000

Automatic Sprinklers			
Sprinklers	700	37,800	37,800
Zone valves	4	2,700	2,700
With fire pumps, piping, & fitting	1 No	945,000	810,000
Total cost of tunnel protection		985,500	850,500
Water Deluge			
Nozzles	700	86,940	86,940
Deluge valve assembly	26	56,160	56,160
With fire pumps, piping, & fitting	1 No	945,000	810,000
Total cost of tunnel protection		1,031,940	953,100

7.2 For 4 KM length of cable tunnel;

Water mist			
System components	Quantity	Cost With standpipes (USD)	Cost Without standpipes (USD)
Water mist system cost	1	1,89,0000	1,89,0000
Standpipe system (with fire pumps, piping, standpipes & fitting)	1	1,496,880	0
Total cost of tunnel protection		3,386,880	1,89,0000
Automatic Sprinklers			
Sprinklers	1400	75,600	75,600
Zone valves	8	5,400	5,400
With fire pumps, piping, & fitting	1 No	1,620,000	1,350,000
Total cost of tunnel protection		1,701,000	1,431,000
Water Deluge			
Nozzles	1400	173,880	173,880
Deluge valve assembly	52	112,320	112,320
With fire pumps, piping, & fitting	1 No	1,620,000	1,350,000
Total cost of tunnel protection		1,793,880	1,636,200

7.3 For 6 KM length of cable tunnel;

Water mist			
System components	Quantity	Cost With standpipes	Cost Without

		(USD)	standpipes (USD)
Water mist system cost	1	2,970,000	2,970,000
Standpipe system (with fire pumps, piping, standpipes & fitting)	1	2,110,320	0
Total cost of tunnel protection		5,080,320	2,970,000
Automatic Sprinklers			
Sprinklers	2100	121,500	121,500
Zone valves	12	8,100	8,100
With fire pumps, piping, & fitting	1 No	2,295,000	1,890,000
Total cost of tunnel protection		2,416,500	2,019,600
Water Deluge			
Nozzles	2100	260,820	260,820
Deluge valve assembly	78	168,480	168,480
With fire pumps, piping, & fitting	1 No	2,295,000	1,890,000
Total cost of tunnel protection		2,555,820	2,319,300

7.4 Comparative chart for all tunnel models with associated system costs;

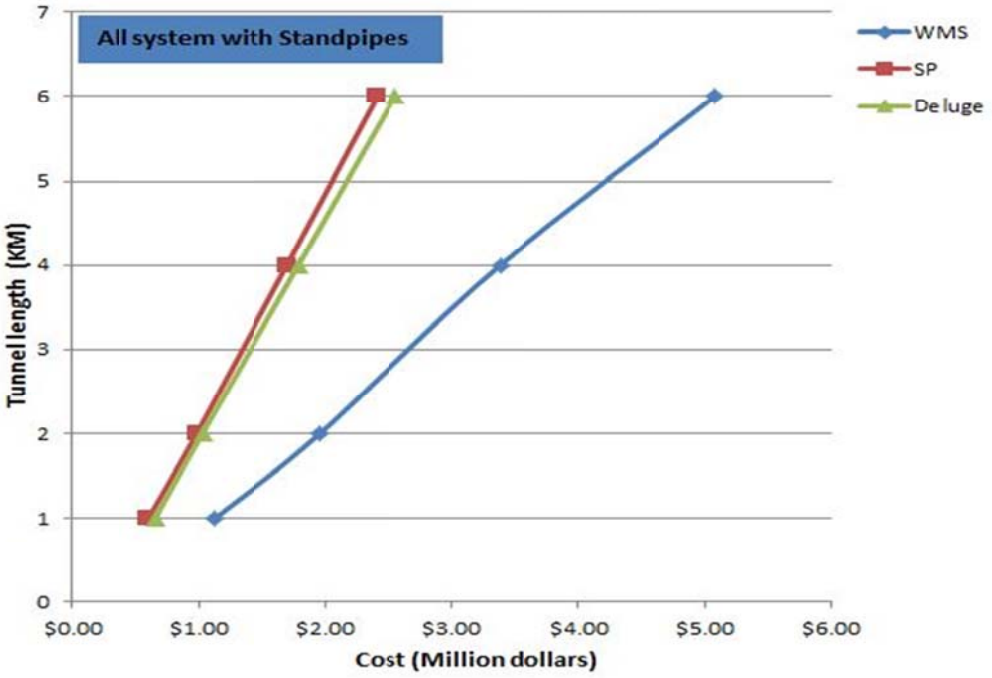
With standpipe system:

The below chart shows a very quick comparison of different tunnel models (M1, M2, M3 & M4) and associated fire protection system costs, with standpipe system;

WMS- High pressure water mist system

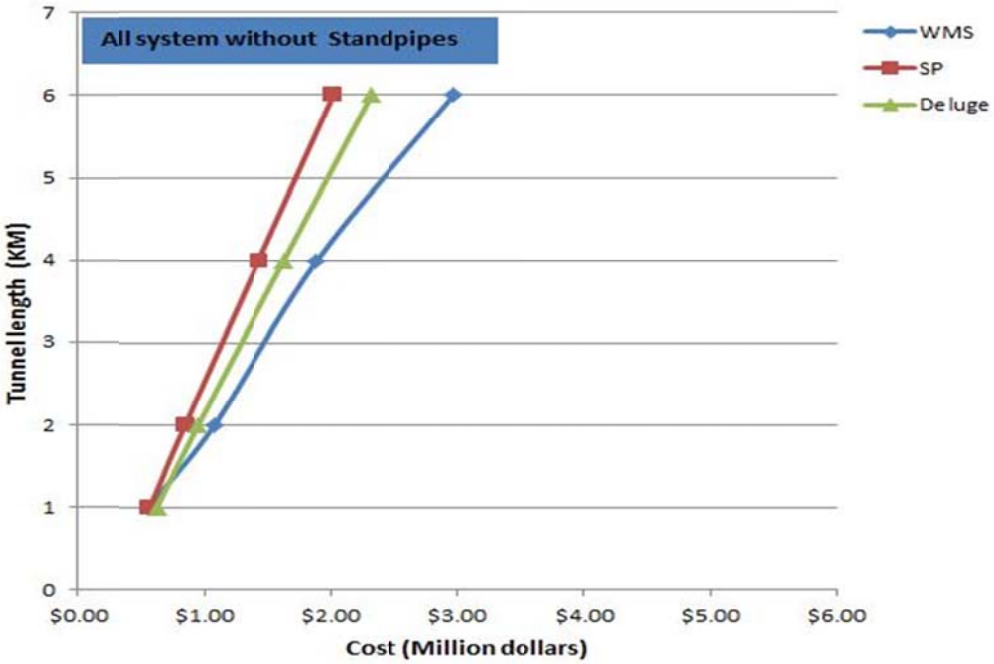
SP- Automatic wet sprinklers

Deluge- Water deluge system



With Out standpipe system:

The below chart shows a very quick comparison of different tunnel models (M1, M2, M3 & M4) and associated fire protection system costs, without standpipe system;



8. Conclusion

The study observes that if technical performance like cooling effects, system activation time, controlling of fire, post fire cleanup, drainage issues, and business continuity are the major concerns, water mist offers great advantages over sprinklers and deluge options.

However as described under commercial comparison section and cost comparison charts, wet sprinklers and water deluge are following a similar cost trend with very minimal variations over different tunnel lengths for with and without standpipe options.

The cost of WMS system is jumping to nearly double with standpipe option but for without standpipe option the WMS cost is following interesting curves as described below;

For 1 km tunnel: Water mist is the cheaper option than sprinklers and deluge.
For 2 km tunnel: Water mist is around 13% higher than water deluge.
For 4 km tunnel: Water mist is around 16% higher than water deluge.
For 6 km tunnel: Water mist is around 28% higher than water deluge.

Hence, water mist is most preferred option considering no standpipe requirement, while with standpipe requirements also water mist is a good choice over other system and subject to objectives of fire protection and subject to cost review.

9. References:

1. UAE Fire & Life safety code, 2011 edition.
2. NFPA 1, “Fire code” 2015 edition.
3. NFPA 13, “Standard for the Installation of Sprinkler Systems” 2016 edition.
4. NFPA 15, “Standard for Water Spray Fixed Systems for Fire Protection” 2012 edition.
5. NFPA 101, “Life safety code”.
6. NFPA 750, “Standard on Water Mist Fire Protection Systems” 2015 edition.
7. NFPA 850, “Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations” 2015 edition.
8. NFPA 5000, “Building construction and safety code” 2015 edition.
9. More than four commercial quotations from various international water mist system manufacturers (company names are not disclosed for maintaining this article as a general study and not promoting any commercial item/make).
10. Various technical information from google.com.