RELIABILITY STUDY ON SPRINKLER SYSTEM TO BE INSTALLED IN OLD HIGH-RISE BUILDINGS

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ABSTRACT

Reliability study on a sprinkler system based on the new proposal for old high-rise buildings in Hong Kong was carried out. Fault tree analysis was used to analyze the reliability of the sprinkler system. The mean fractional dead time representing the failure probability of the sprinkler system on demand was calculated. It is found that the design is not so promising because of using smaller tanks due to space constraints. Two alternative system designs are recommended. The study was repeated and those designs are found to be more reliable.

1. INTRODUCTION

About 25,000 high-rise non-residential buildings constructed before 1972 are classified as old high-rise buildings [1] in Hong Kong. Consequent to several big fires in those old high-rise buildings since 1996 [2-5], the SAR Government is now reviewing the fire safety aspects required in those buildings. Out of all alternatives, regulations are imposed on installing sprinkler systems [6-8] with a consultation paper [6] issued in 1997.

The Hong Kong Polytechnic University (PolyU), with the mission of offering "Quality Teaching", i.e. teaching supported by research, is very active in carrying out applied research projects useful to the society. 'Sprinkler systems for old high-rise buildings' is one of the key projects with preliminary results published in the literature [10,11]. It is found that there are many problems in installing the system in old high-rise buildings. Of which, inadequate space for housing the water tanks, pumps and pipes is of most concern. Therefore, sizes of the water tank were changed to give different operating water discharge flow rate and pressure from common sprinkler installation, leading to unsatisfactory performance of the system. By fault tree analysis (FTA) and calculation of the mean fractional dead time of the sprinkler system, the system is found to be not so reliable. Therefore, two alternative designs are proposed with their overall reliability tested.

2. ALTERNATIVE DESIGN

In an earlier study at PolyU, failure in the water supply to the sprinkler system as shown in Fig. 1 was found to be one of the major problems. Therefore, two alternative schemes were proposed to improve the reliability of the water supply to the sprinkler system.

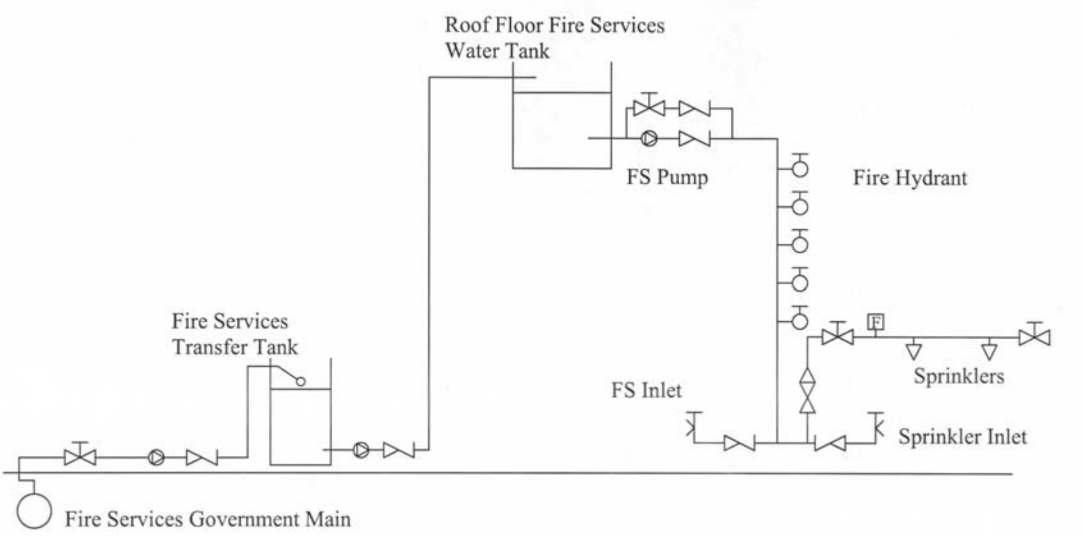

Fig. 1: Schematic diagram of a typical gravity system

Scheme A

An interlocking arrangement is proposed with the existing fresh water up-feed system by the motorized control valve as shown in Fig. 2. The fresh water transfer pump would be operated if the water level in the roof fire services (FS) tank drops to a low level. The motorized control valve would be fully opened when a fire is detected. The existing fresh water up-feed system acts as a duplicate water supply system to the roof FS water tank.

Scheme B

A smaller water tank is proposed to be installed with a sprinkler pump as shown in Fig. 3. Such a water tank of capacity 2 m^3 would be sufficient to maintain the operation of the six operated sprinklers for Ordinary Hazard (OH) class fire for six minutes. This is supported by statistics that 83.7% of building fires in USA (in 1925-1964) and 93.4% fire in Australia and New Zealand (in 1886-1986) [25] were controlled by six sprinkler heads. The sprinkler pump would be operated if the water level of the roof FS tank is low. The sprinkler systems would be isolated from the Fire Hydrant/Hose Reel (FH/HR) systems by a motorized control valve. Water would be supplied by the standby sprinkler pump.

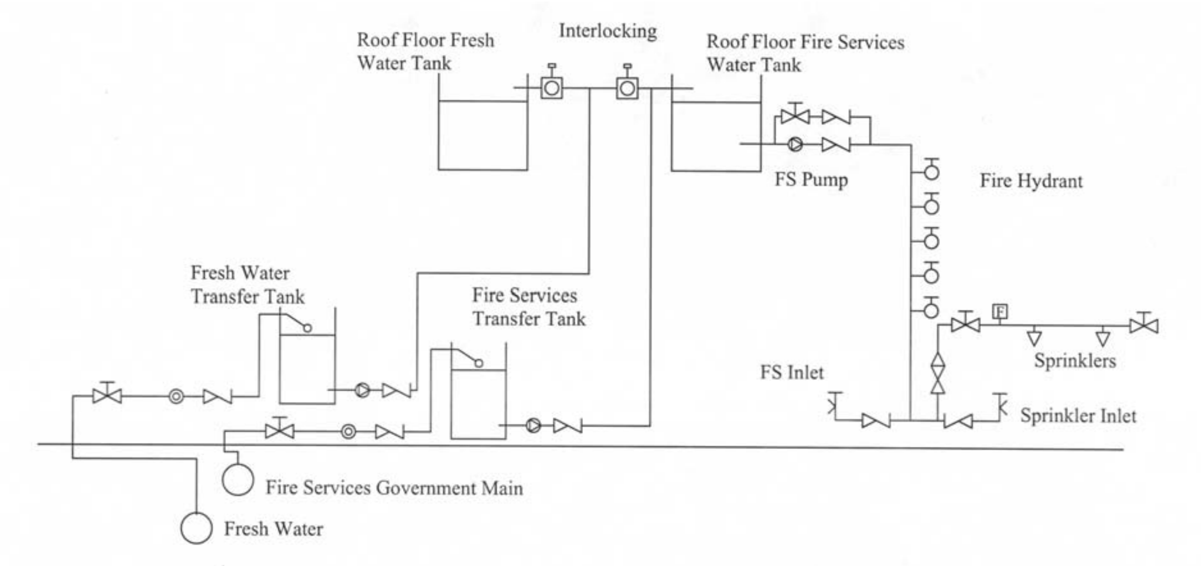

Fig. 2: Schematic diagram for system with interlocking device connected to fresh water supply

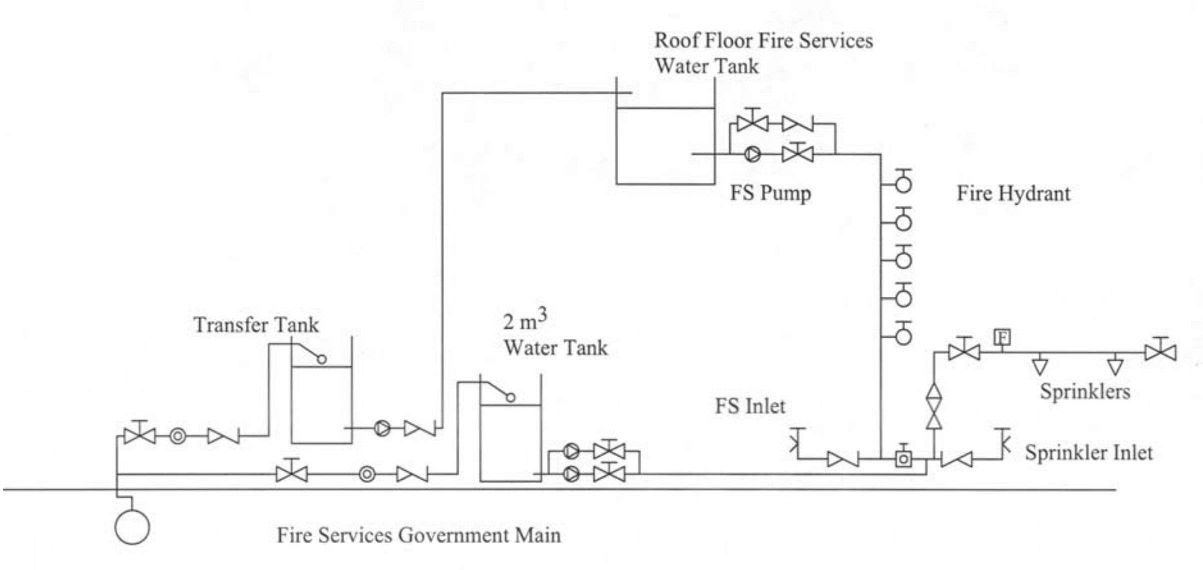

Fig. 3: Schematic diagram for system with additional 2 m^3 water tank and sprinkler pump

3. RELIABILITY ANALYSIS

The technique of FTA was adopted in the reliability assessment for the improvised sprinkler system. FTA is a method to identify all possible causes of a particular system failure mode, and it provides a basis for which to calculate the probability of occurrence of each system failure mode [18]. The fault tree diagrams of the sprinkler systems with the original design and the proposed designs (schemes A and B) shown in Figs. 4 to 6 were studied. The reliability of the original design and of schemes A and B can be determined. The total system failure in this study refers to no water is discharged from the activated sprinkler head in the design period of the system operation.

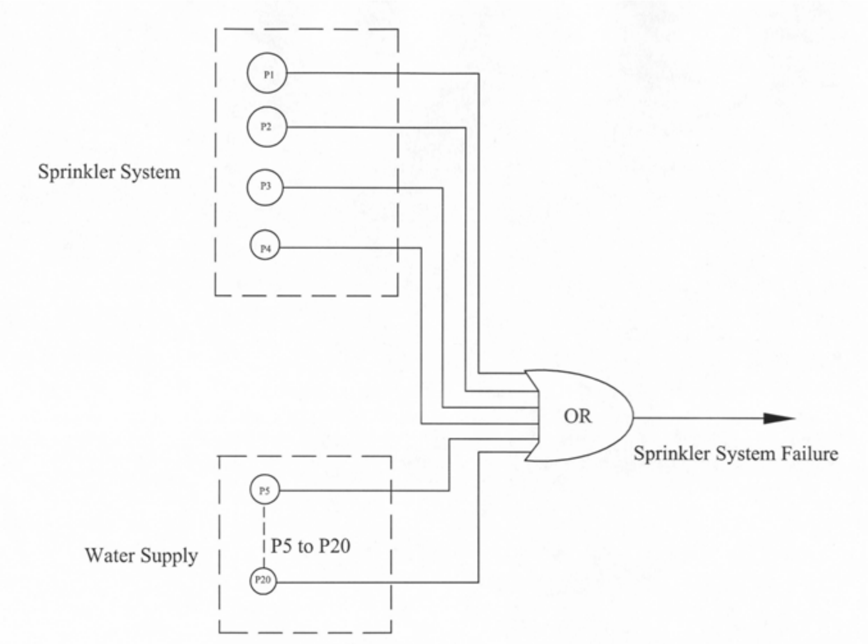

Fig. 4: Fault tree diagram for a typical gravity system

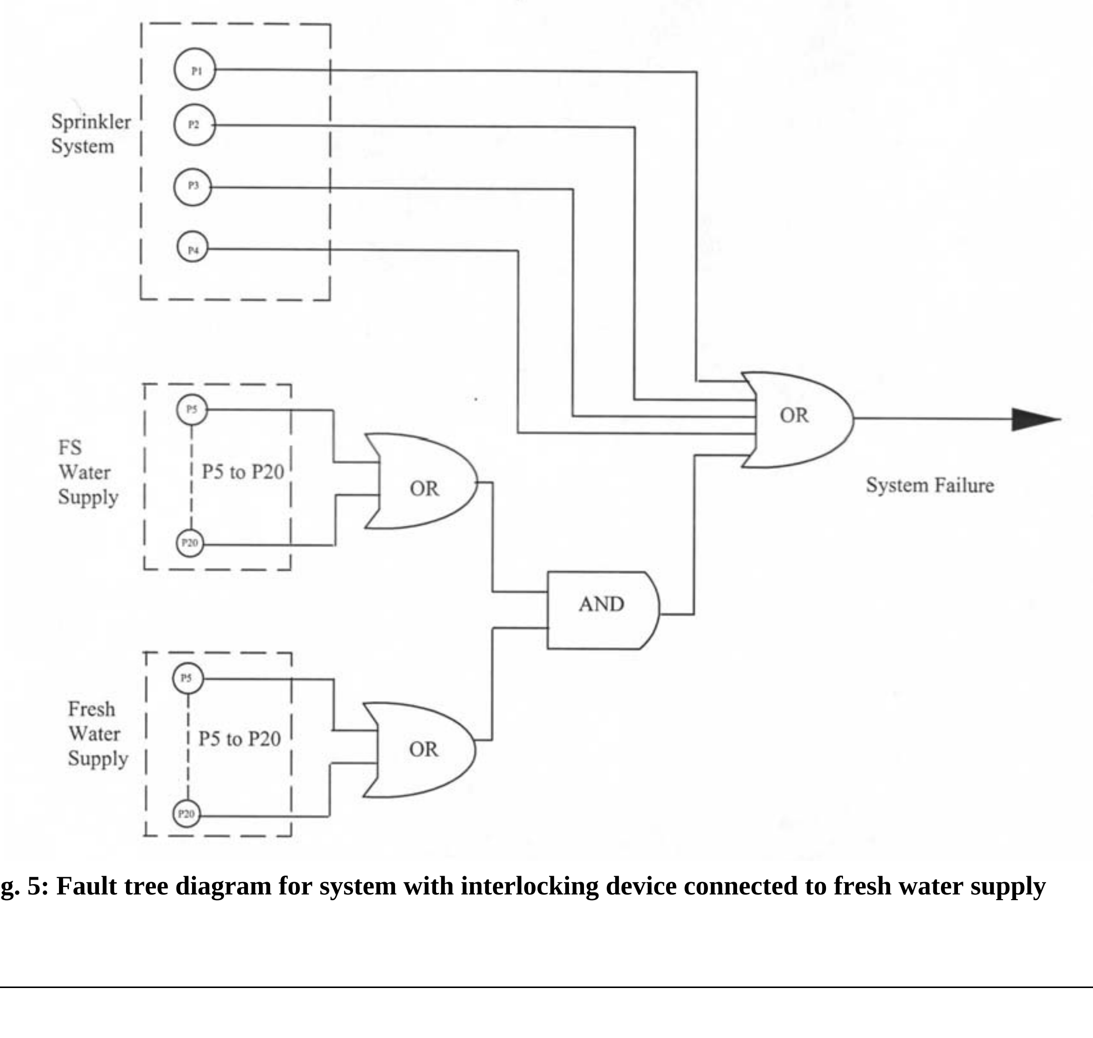

Fig. 5: Fault tree diagram for system with interlocking device connected to fresh water supply

The failure rates λ (per 10^6 hours) suggested in the literature [19] for the system components (P1 to P24) as shown in Figs. 4 to 6 were used to study the system reliability. The surveyed failure rates were classified as minimum, mean and maximum for the system components as shown in Table 1. Pump failure might be due to corrosion, deterioration, plugging, bearing worn out, electrical faults or improper stresses on the rotor shaft. The failure rate of water pump was found to be varied from 0.68 to 200 ($\times 10^{-6}$). The fault tree diagrams for the improvised sprinkler system of the original design, of schemes A and B were shown in Figs. 4 to 6 respectively and the system failure rates shown in Table 1.

Since most fires occur accidentally, the need for a sprinkler system is equally probable at any instant over the proof test interval of the system. Therefore, the failure probability of the sprinkler is referred to the fractional dead time of the system. The mean fractional dead time (FDT) is the average failure probability of the system over a given period of time known as the proof test interval τ [18]. The FDT based on an exponential distribution of failure rate is given by:

$$\mathrm{FDT} \cong \frac{1}{\tau}\int_0^{\tau}\left(1 - e^{-\lambda \cdot t}\right)dt \qquad (1)$$

For λt <<1.0, then:

$$\mathrm{FDT} \cong \frac{1}{\tau}\int_0^{\tau}\left(1 - [1 - \lambda t + \frac{(\lambda t)^2}{2!} + ...]\right)dt = \frac{\lambda\tau}{2} \qquad (2)$$

The FDT is plotted against the proof test interval in Fig. 7.

Proof test interval is normally expressed in terms of years or per million hours and refers to a periodic function test for evidence of continued system capability. It assumes that at the end of each test, the system is fully restored to its initial fault-free state [14]. The proof test interval is one year (8760 hours) for the fire protection system in Hong Kong. According to the Fire Services Department requirement, the test interval is that every fire service system shall be checked and tested every year [15].

Table 1: Failure rate for sprinkler systems

Components		**Failure Rate** (10^{-6} hr^{-1})		
		λ_{min}	λ_{max}	λ_{mean}
P1	Sprinkler head	2	9.02	4.43
P2	Sprinkler pipework	0.2	0.2	0.2
P3	Subsidiary stop valve	0.33	2.63	1.48
P4	Sprinkler control valve	0.02	30	7.6
P5	FH/HR riser	0.2	0.2	0.2
P6	Non-return valve at the bypass circuit	1.14	8	4.57
P7	Gate valve at the bypass circuit	0.1	15	6.85
P8	FS water tank at roof	0.1	10	5.05
P9	Float type water level sensor	187	187	187
P10	Up-feed water pipe	0.2	0.2	0.2
P11	Non-return valve at transfer pump discharge	1.14	8	4.57
P12	Gate valve			
P13	Transfer pump	0.68	200	107
P14	Gate valve			
P15	Transfer pump	0.1	10	5.05
P16	Ball valve in the transfer tank	0.5	10	4.5
P17	Non-return valve at the town main	1.14	8	4.57
P18	Gate valve at the town main	0.1	15	6.85
P19	Water pipe from the town main	0.2	0.2	0.2
P20	Town main	500	500	500
P21	Motorised control valve	0.5	20	10.3
P22	Non-return valve at the sprinkler pump	1.14	8	4.57
P23	Sprinkler pump	0.68	200	107
P24	Gate valve at the sprinkler pump	0.1	15	6.84

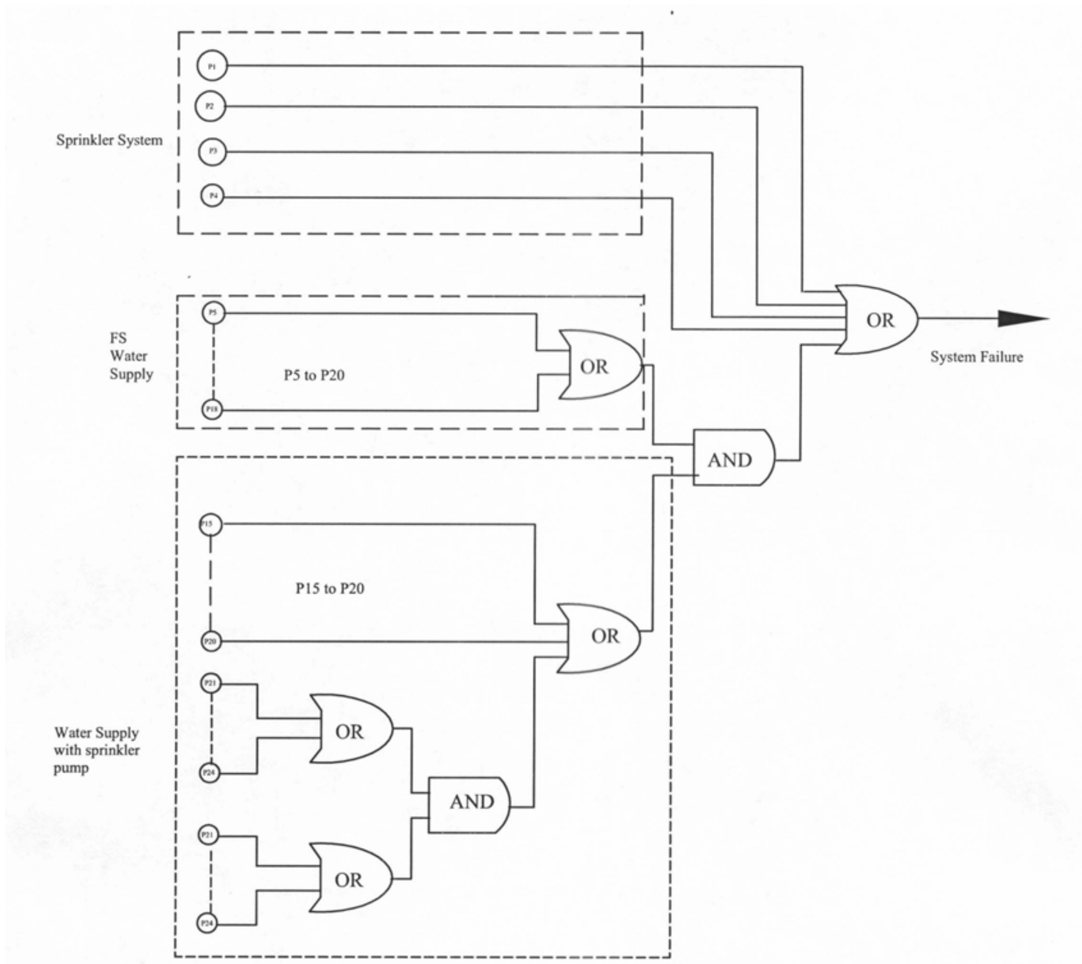

Fig. 6: Fault tree diagram for system with additional 2 m^3 water tank and sprinkler pump

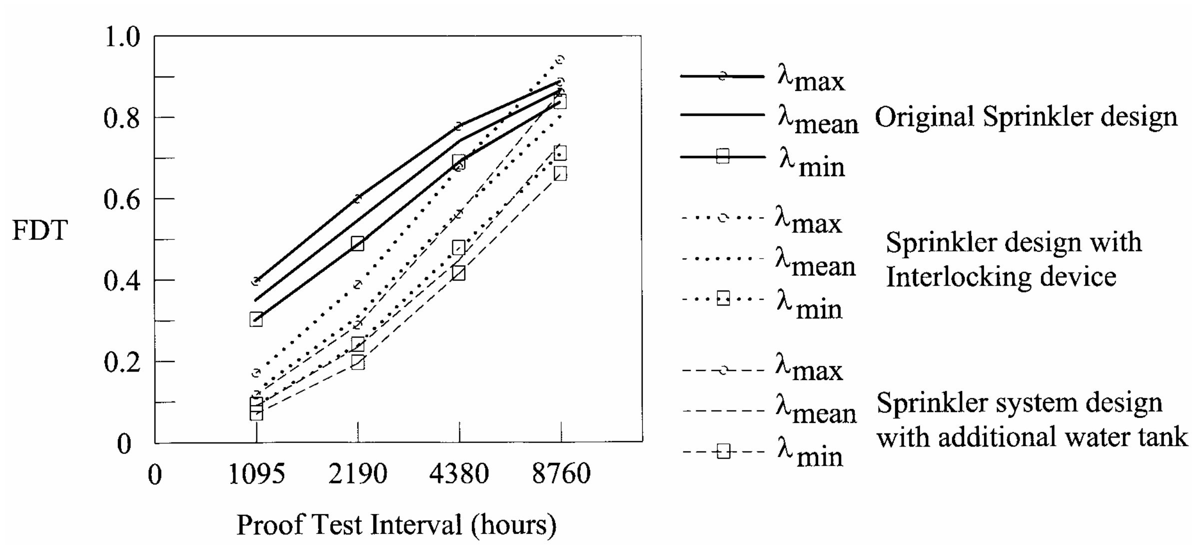

Fig. 7: FDT of the sprinkler systems vs proof test interval

4. RESULTS

In order to compare the system reliability, FDT is evaluated on the gravity system and the two alternative systems. The overall failure rates of the three systems were compiled in Table 1 based on the diagrams in Figs. 1 to 6. By inserting the failure rates and the proof test interval ($\tau = 8760$) into equation (2), the mean FDT of the whole system was calculated. Distribution on the mean FDT with respect to the proof test interval is plotted in Fig. 7. A summary of the mean FDT for proof test interval of one year and the improvised sprinkler system failure probability in every thousand process demand is illustrated in Table 2. In addition, the failure rates for the two alternative systems are less than that of the gravity system. This is due to the alternative designs adopted the redundancy design. If the proof test interval is shortened to half year, the failure probability would be improved significantly. As the water supply is the major cause of sprinkler system failure, appropriate electrical supervisory equipment can be adopted [24]. Additional methods for improving the reliability of a system include stock spares and performing preventive maintenance.

5. CONCLUSION

This study revealed that the reliability of sprinkler system in old high-rise buildings is very low. Hence, how to maintain the system in good condition and enhance its reliability is critically important. From the reliability assessment results, the proof test interval shall be kept as short as possible. The improvised sprinkler system shall be periodically proof tested in order to reveal any faults and maintain the system in fault free conditions. Besides, a better building management can also help to increase the overall system reliability. In a recent survey, the water supply for the improvised sprinkler system was shut down by one of the building management staff in order to save water. This shows that providing fire safety education to the public (especially for the building management team) is very important.

In this paper, only the gravity system in Prescribed Commercial Premises (PCP) was studied. Pumping system and direct town mains connection should be further studied. On the other hand, only two alternative methods are introduced. Further improvement and other alternative methods should also be investigated.

Table 2: Estimated FDT for different sprinkler system designs

Estimate the FDT using the original design				
Proof test interval (hr)	8760	4380	2190	1095
Failure probability (FDT) for λ_{min}	0.836155	0.687203	0.486456	0.299925
Failure probability (FDT) for λ_{max}	0.887375	0.77738	0.598401	0.395932
Failure probability (FDT) for λ_{mean}	0.865828	0.737979	0.546413	0.349286
Estimate the FDT using Scheme A				
Proof test interval (hr)	8760	4380	2190	1095
Failure probability (FDT) for λ_{min}	0.709248	0.476472	0.238372	0.090838
Failure probability (FDT) for λ_{max}	0.941676	0.676659	0.387858	0.170362
Failure probability (FDT) for λ_{mean}	0.80359	0.568324	0.308155	0.126583
Estimate the FDT using Scheme B				
Proof test interval (hr)	8760	4380	2190	1095
Failure probability (FDT) for λ_{min}	0.658992	0.414334	0.193726	0.070398
Failure probability (FDT) for λ_{max}	0.861489	0.561642	0.287796	0.117247
Failure probability (FDT) for λ_{mean}	0.734174	0.474764	0.233497	0.089616

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