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Reliability of sprinkler system in Australian high rise office buildings

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ABSTRACT

A comprehensive survey of sprinkler systems in high-rise office buildings was carried out to determine the reliability of various components of such systems in Australia. Based on the survey data, a fault tree analysis (FTA) has been used to estimate the overall reliability of these sprinkler systems. Data from 26 buildings were collected and are presented in this paper. In addition, data from overseas surveys has also been considered based on their relevance to the office buildings. The analyses are confined only to wet-pipe systems, as these constitute the vast majority of automatic sprinkler systems in Australia and New Zealand. To develop the fault trees, the designs found in usual practice are considered, rather than the designs just complying the Australian codes with the minimum requirements. A range of reliability for the sprinkler systems is estimated based on a number of considerations. Sprinkler zone shut off during tenancy changes and out of specification sprinkler head appear to be the main factors that may lead to a sprinkler system failure.

1. Introduction

Water is supplied to automatic fire sprinklers (or *sprinkler heads*) through a system of piping, and are arranged so that they are able to automatically distribute sufficient water directly to a fire to extinguish it or hold it in check until fire fighters arrive [1]. This is achieved by cooling the fire and wetting surrounding materials in order to make them harder to ignite. As a consequence of this application of water, there have been cases where the water interferes with the combustion process sufficiently to reduce the size of the fire and possibly extinguish it.

The effectiveness of a fire-safety system can be considered as the product of its *efficacy* and its *reliability* and this relationship was first introduced and discussed in [2]. Later the relationship was formulated in a rigorous manner in [3] and applied it to the analysis of smoke alarms. A research program [4] was undertaken to evaluate the *efficacy* (the degree to which a particular system achieves an objective, e.g. control or extinguishment of a fire, given that it operates and delivers the designed amount of water to the fire) of a sprinkler system in an office building. It was found that when small office fire occurs, the fire is suppressed almost instantly. In all open-plan office fire tests, sprinklers had no trouble in containing the fire, especially above the desk where it was adjacent to the fire initiation point. Furthermore, fire did not spread to adjacent workstations or associated combustibles.

During the time of automatic operation of the sprinklers, occupants of an open plan office area of similar dimensions did not suffer any significant distress or permanent harmful effects, provided they were not involved in the ignition and were reasonably mobile. The structure of the building was not damaged during the tests and carried the required loads without any signs of excessive deflection or other distress. The structural steel members and the composite floor slab suffered no measurable permanent deflection and would not have required any form of major repair before reoccupation if fire sprinklers had been incorporated in a typical office building.

Having established the *efficacy* of typical sprinkler systems experimentally, the purpose of the fault tree analysis herein is to estimate the *reliability* of a sprinkler system in a high-rise office building (60 storeys). The *reliability* of a sprinkler system is defined as the likelihood that it operates and delivers the designed amount of water to the fire. The likelihood that sprinkler operates was reported as nearly 92% by both Kim [5] from US statistics of high-rise building fires in 1988 and Rohr and Hall [6] from US statistics of store and office fires in 1999–2002; however it was reported as 96% by Hall [7] from US statistics of store and office fires in 2003–2007. It can be observed from [6,7] that between 1999–2002 and 2003–2007 period the likelihood that sprinkler operates, when sprinklers were present in fire area and fire was large enough to activate sprinkler, has improved from 92% to 96% for stores and offices. In this paper, the analyses are confined to the wet-pipe systems as these constitute the vast majority of automatic sprinkler systems in Australia and New Zealand. Wet-pipe systems are installations in which the sprinkler piping network is permanently charged with water under pressure and are therefore suitable for use in buildings in which freezing never occurs [8]. The effectiveness of the wet-pipe sprinkler system in stores and offices has been reported as 95% by Hall [7], which has been 96% for office buildings only.

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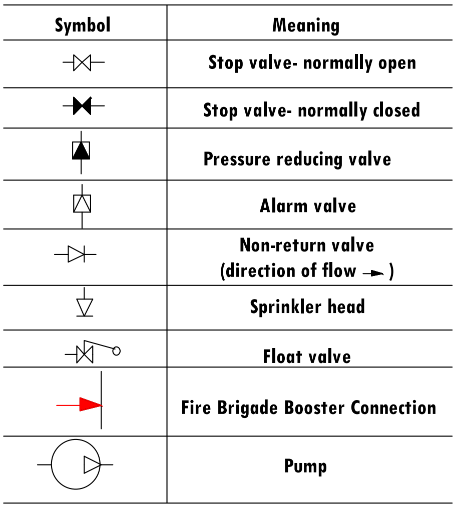

Fig. 1. Legend of symbols.

2. Description of automatic sprinkler system in a typical high rise building

This section describes the automatic sprinkler system that is used in a typical Australian high-rise building. A number of schematics are presented to assist this description. Fig. 1 shows legends of symbols for various components of a sprinkler system used in schematics.

2.1. Water supply

According to Building Code of Australia [9] and the sprinkler standard AS 2118.1-1999 [10], a building over 25 m of height is required to have water supply from two separate mains. Strictly, this requirement is difficult to meet and sometimes a concession is given. For example mains passing along two parallel streets are considered as separate mains, though strictly they may not be entirely independent. Alternatively, an automatic pump supply from private reservoirs (mainly located in the basement) and two elevated private supplies (mainly located in the rooftop) is also widely used.

According to AS 2118.1-1999 [10], an office building requires a light hazard sprinkler system with fast response sprinkler heads at about 4.6 m maximum spacing. The design criteria for a light hazard sprinkler system dictates that the water supply must be capable of flowing 48 l/min per sprinkler head at 100 kPa for the hydraulically most disadvantaged group of six sprinklers, for a minimum duration of 30 min. Given the different geographical locations of cities around Australia and variations in height above sea level, there are understandable variations in the supply pressures available in town main water supplies available to fire sprinkler systems. For the purpose of this study, it is assumed that a mean average town mains' pressure of 500 kPa is available. Given that a study case building of 60 storeys is being considered here and each storey has an average height of 3.7 m (the floor-to-floor height of office buildings varies from 3.6 m to 4 m, however it is typically around 3.7 m), the effective building height is approximately 222 m. When considering that gravitation/elevation head loss is 9.8 kPa/m and the operating pressure to operate the six most hydraulically disadvantaged sprinkler is 200 kPa (+friction losses), town mains pressure of 500 kPa can only supply water up to the eighth floor of the building. Therefore, town mains' pressure is required to be boosted by a set of pumps, to supply water to the sprinkler system for storeys above these lowest eight storeys. Therefore for sprinklers, water is drawn from town mains and either supplied directly to the pump or is stored in basement reservoirs/tanks and then is pumped to the riser (vertical pipes). Water flows through non-return valves, pump isolation valves, pumps, the main sprinkler valve and then alarm valves to the riser.

The pumps are operated from separate pressure switches. These pumps are either electric or diesel operated. The levels of charge in the batteries or/and the continuity of the electricity supply are usually monitored, and battery/power failure is indicated by a local alarm and at the fire indicator panel (FIP).

AS 2118.1-1999 [10] requires that in the case of a multi-storey building in excess of 75 m (approximately 21 storeys), the sprinkler system needs to be divided into stages so that the pressure on any sprinkler does not exceed 1 MPa (1000 kPa). Considering that gravitation/elevation head loss is 9.8 kPa/m and the operating pressure at the highest level (the most hydraulically disadvantaged sprinkler) is 200 kPa, then it is likely that the operating pressure at the lowest level is $200+(75\times 9.8)+\text{losses}\approx 1000$ kPa.

It is also important to mention that a typical riser usually supplies water to a floor area of up to 9000 m^2 [10] (usually seven or eight floors). Thus seven or eight floors comprises a zone. Thereby, each stage is divided into three zones; in each zone water is supplied by a separate riser. These risers are controlled by separate stop valves. At the interface of the stages, usually a plant room is located where multiple risers emanate from the main riser (manifold type; see Fig. 2) to supply water to the respective sprinkler zones within the stage.

For a 50 to 70 storey building, the system can be divided into the following stages in different ways as shown in Table 1. As discussed earlier, water can be supplied from the town main without a pump up to the lowest eight storeys. Therefore, the lowest stage usually consists of only eight storeys (see designs given in [12]) for high-rise buildings. For the purpose of this paper, Option I for a 60 storey building is considered in detail.

The building floors can be supplied with water in two ways:

- Upfeed system – by pump pressure only.
- Downfeed system – by gravity.

These systems are discussed now.

2.2. Water supply for upfeed system

Given the height of this building, there may be a need to have pump rooms for stage to stage pumping (plant rooms) or high pressure supply multi-stage pump along with high pressure riser. AS 2941-2008 [13] allows the use of both single-stage or multi-stage pumps. In either case, one electrical and one diesel pump should be used. Single-stage pumps deliver water at a single pressure only, multi-stage pumps deliver water at different pressures suitable for different stages of a sprinkler system. In surveyed buildings, the use of single-stage pumps has not been observed for the upfeed system, rather multi-stage pumps are used. In the latter system, two multi-stage pumps can supply water to the whole building. Risers are connected to various stages of the pumps that supply water to the different building stages with different pressures (see Fig. 3). Extra care needs to be taken when designing this type of system to ensure that enough elevation head and friction loss is allowed for the correctly pressure rated pipework valves and fittings, to ensure that there is no failure. Water is either directly drawn from the town main or reservoirs/tanks located in the basement. In these tanks, water is stored from town mains.

2.3. Water supply for downfeed system

A set of *very high pressure single-stage* pumps is usually used for a downfeed system covering the entire building. In this case