A DISCUSSION ON ENHANCING WATER FIRE FIGHTING SYSTEMS FOR TALL BUILDINGS WITH AN ANTI-TERRORISM PERSPECTIVE

K.P. Cheung
Department of Architecture, The University of Hong Kong, Pokfulam Road, Hong Kong

H.W. Chan
Hinkey Technical Services, Hong Kong

ABSTRACT

This paper affirms the prime importance of automatic sprinklers in tall buildings and the importance of ensuring operating sprinklers/ fire hydrants/ landing valves in the farthest building corners can be provided with undisturbed water supply of sufficient flow/ pressure. In the worst scenario, all fixed fire pumps inside the building may fail to operate, and the smaller header tank at roof can run out of water. This issue has not been resolved worldwide in normal fires as well as those caused by terrorist and arsonist attack. (6)

Portable pumps will be delivered to refuge floors for relaying water into building's fire fighting systems. It is proposed to install mains for compressed air and water to supply portable/ fixed impulse fire extinguishing devices, to supplement the ordinary fire fighting systems and enable the most effective choice when water shortage becomes critical. These can greatly enhance fire safety of the tallest buildings against attacks from terrorist/ arsonist.

INTRODUCTION

Current codes and standards in USA (8), UK (8), Australia (9) and Hong Kong (10) specify pumping, water flow and pressure requirements for tall buildings, all relying on the successful operation of fixed pumps installed in the building for immediate fire fighting and for relaying water from the fire engines to hydrants of the fire hydrant system located at the high rise floors (2, Fig. 1), because the pumping capacity of currently used fire engines is not capable of providing adequate flow rate/pressure to high rise floors by boosting water directly into the fire service inlet/fire brigade connection located at street level. In Hong Kong (10) fir engine pumps are generally capable of supplying water to fire hydrants /landing valves located within 60 m from ground level, and to sprinklers located within about 80 m from ground level.

There are proposals (1,11) of installing additional fire department connections at certain high rise floors, together with portable fire pumps to be brought along by firemen, enabling water from fire engines at street level to be satisfactorily relayed to any hydrant/landing valve at high rise floors. However when the fixed fire pumps installed in the building fail to operate (2, Fig. 2), portable fire pumps will take at least a few more minutes for setting up satisfactorily after the fire engine arrives at the building. Furthermore the system reliability decreases as the number of portable pumps increases. There is also an increase demand of man power for operating and controlling the portable pumps.

Furthermore existing codes used in Hong Kong follow the US and UK practice, (8,12) relying on the successful operation of fixed sprinkler pumps installed inside the building to achieve successful operation of sprinkler systems in tall buildings. Once these pumps fail, sprinklers in high level floors will have no water. Therefore there is a need to re-rationalise the basic design principles of sprinkler systems and fire hydrant systems in tall buildings, especially in planning for fires safety against terrorist attack and arsonist attack.

Considering the effectiveness of fire fighting of impulse fire extinguishing technology (7), there is a need to make provisions for future use of these devices in tall buildings, especially when water is running out during terrorist attack, because these devices consume very little water. These devices will supplement the existing water fire fighting systems.

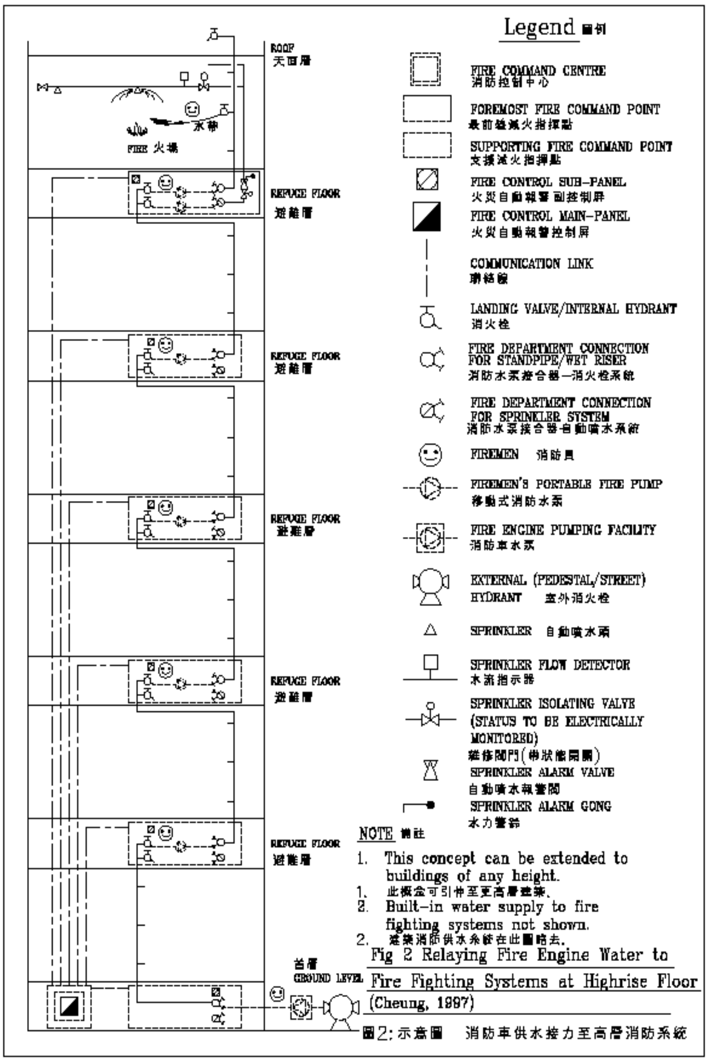

Fig 2 Relaying Fire Engine Water to Fire Fighting Systems at Highrise Floor (Cheung, 1997)

圖2: 示意圖 消防車供水接力至高層消防系統

EXISTING ENHANCEMENT PROPOSALS OF SPRINKLER WATER SUPPLY

To overcome these time and manpower constraints, enhancement proposals were put forward for introducing high pressure pumps in fire engines for boosting water from ground level into sprinkler systems and standpipe/wet riser/hydrant systems for tall buildings of about 270 m high, (2) thus supplying water directly to the highest sprinklers and hydrants and landing valves, without relying on fixed pumps installed inside the building.

Realising the numerous successful operation records for automatic sprinkler systems in controlling fires, it was proposed that (2, fig. 3) independent and reliable back up water to be boosted from fire engines, for achieving the design flow rate and pressure, even for the highest and most remote sprinklers. Sprinklers are seen as the basic and first line automatic fire fighting system that controls the fire and supports other fire safety measures. (10,1) including smoke control systems, (13) evacuation and manual fire fighting by firemen. It is recognised of course that immediate water discharge is essential for sprinkler system to be effective, before the fire is getting uncontrollably large.

Because the storage of sprinkler water is commonly above 50 cubic meter, and even above 100 cubic meter, (12,14) sprinkler tanks are and pimps are commonly installed at low level of tall buildings.

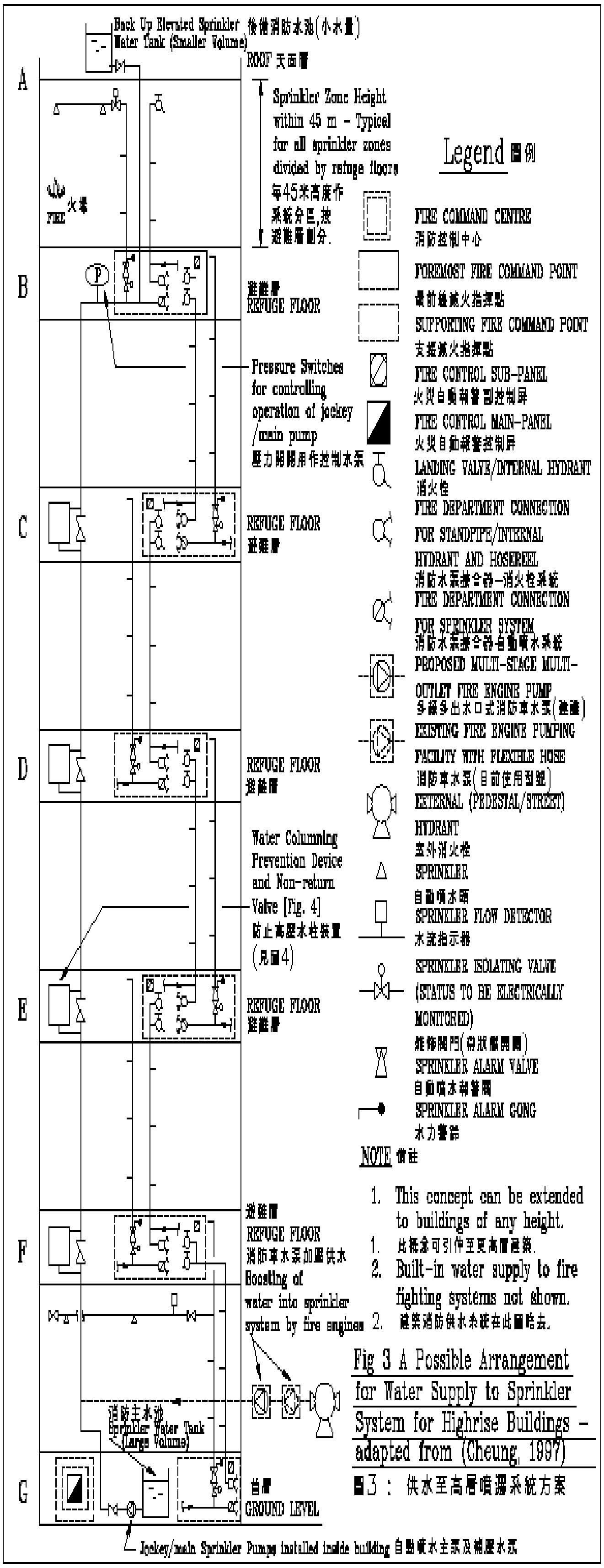

Fig 3 A Possible Arrangement for Water Supply to Sprinkler System for Highrise Buildings – adapted from (Cheung, 1997)

圖3：供水至高層噴灑系統方案

Sprinkler pumps will pump water up to all sprinklers, including the highest sprinklers. This benefits structural loading, but not fire safety.

To back up sprinkler water supply in case of up-feed pumping failure in the initial stage of a fire, an elevated supplemental sprinkler water tank (15,3,4, fig. 3) is proposed as an enhancement, with one sixth of nominal water capacity (Table 1) i.e. ten minutes of nominal flow (12).

For supplying sprinklers in lower floors, the gravity-fed water has to be reduced in pressure by pressure reducing valves or/and pressure break tanks.

The elevated tank can be about 10m above the highest sprinkler, provided water pipe size is appropriately selected. If 10m cannot be achieved, then a pneumatic booster system has to be provided to serve the top very floors.

The proposal for back up storage to be one sixth of nominal water storage is justifiable because target attendance time for firemen in Hong Kong is 6 minutes. That is, firemen are targeted to arrive at the fire floor 6 minutes after receiving a fire alarm which is now automatically transmitted to Fire Services Department for tall buildings. Another 4 minutes should be allowed for connecting fire engine pumps to fire department connections for sprinkler system and to street fire hydrants with flexible hose for drawing water.

EXISTING ENHANCEMENT PROPOSALS OF WATER SUPPLY TO HYDRANT SYSTEM

Fire department connections installed at ground level for boosting water to standpipe/wet riser system in tall buildings are essential and need no elaboration. In addition to supplying firemen hose lines and nozzles, water boosted into this system, with an increase in the boosted water amount, can be used to supply water-foam systems, water mist/spray/fog systems as required (2).

Because proposals for a new generation of fire engine pumps have been made for effective relaying of fire engine water at ground level to very tall buildings (2, Fig. 5), emphasis here is placed on co-ordinating for an optimum use of the refuge area (16) for both people evacuation and fireman operation, including using firemen's portable pumps for vertical water relaying at refuge floors, should the fixed fire pumps installed in the building fail to operate and the proposed new generation of high pressure fire engine pumps are not yet available. (2)

The refuge floor (3, fig. 6) should be added with a designated area of dimensions sufficient for firemen operation of the sprinkler system and fire hydrant/standpipe/wet riser system, and for carrying out other fire service operations (1, fig. 6) including rescue operations.

TABLE 1. Proposed supplemental elevated water storage for Ordinary Hazard Group II Occupancy (e.g. Office) for a 270m (886 ft) high building (fig. 3, Table 22 of BS5306: Part 2: 1990, LPC, 1990) (from Cheung, 1997a)

Group	Height of highest sprinkler above lowest sprinkler not exceeding m	Nominal design water capacity (for one hour operation)	Proposed supplemental elevated water storage tank (for 10 minutes operation, i.e. one sixth of nominal capacity)
II	15	105	17.5
	30	125	20.8
	45	140	23.3

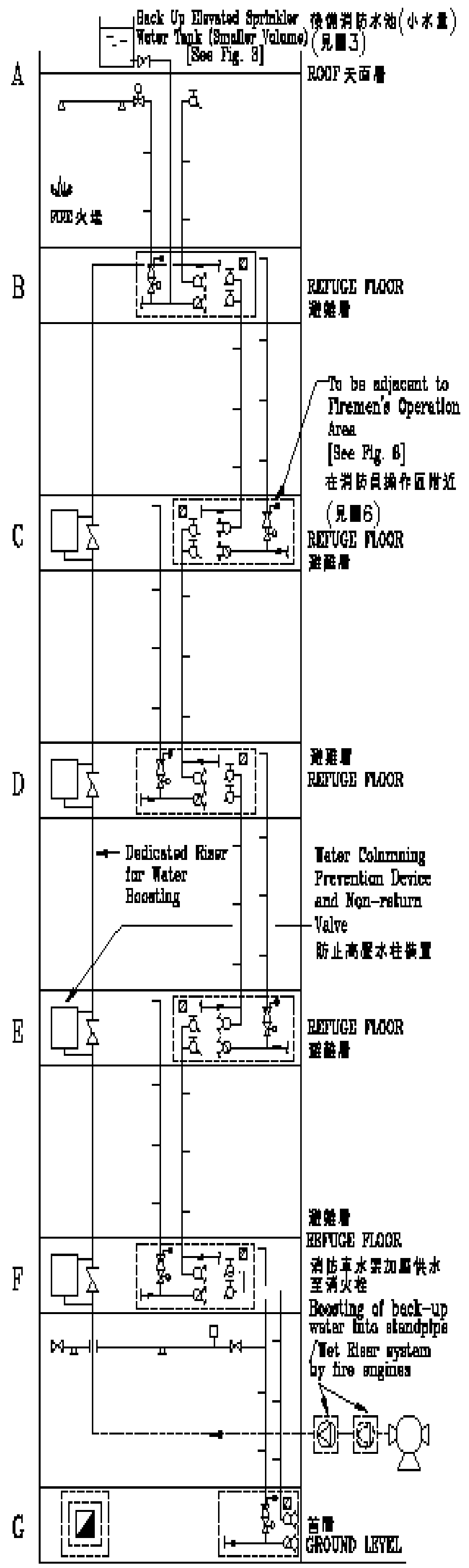

Fig 5 Relaying Fire Engine Water to Standpipe/Wet Riser Systems at Highrise Floors -adapted from (Cheung, 1997)

圖5: 消防車接力供水至高層

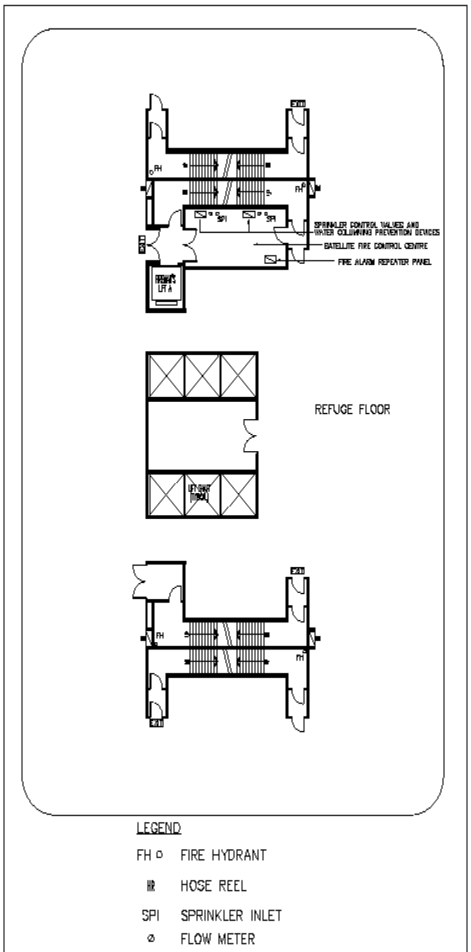

FIG.6 REFUGE FLOOR LAYOUT PLAN

RE-RATIONALISING THE BASIC PRINCIPLES FOR WATER FIRE FIGHTING SYSTEMS FOR TALL BUILDINGS

It has been establishing that:-

- Sprinkler water (1,2,3) and hosereel water (3) shall be available at all times for automatic fire suppression and control and for first aid manual fire fighting
- Refuge floors are requirements for very tall buildings (16,1) and they shall be integrated into fire fighting operations of sprinkler systems and fire hydrants (1,2,3,4), besides offering other uses.
- Impulse fire extinguishing technology (7) should be considered as a supplementing fire fighting means, or used as the only means especially when water shortage becomes critical during terrorist attack or otherwise. The existing back pack impulse devices have to be adapted for connecting to mains of compressed air and water to ensure continuous operation. The existing completely mobile set ups (7) have to adapted to mobile devices connected to supply mains via flexible tubes, for continuous operation say for 1 hour.

The action of firemen

The action of the firemen can be considered as follows (Fig. 7):-

Firemen Team 1 (associated with Time T1, T1a, etc.) will arrive at the fire floor, (T1) and the affected areas if needed; then to assess the situation for conducting people evacuation and rescue, and for fighting the fire (T1a), etc.

Firemen Team 2 will bring portable pumps to strategic locations such as the water relaying and communication posts at refuge floors (1, 2,3,4) and to set up the portable equipment to ensure continuous water supply to the sprinkler system to as far up the building as needed (T2).

Firemen Team 3 will act similarly as Team 2 above, but for ensuring continuous water supply to the fire hydrant system (T3).

Firemen Team 4 will bring hose, nozzles and other equipment such as impulse fire extinguishing devices to the fire floor to fight the fire (T4).

Firemen Team 5 are other firemen and officers and related people carrying out collaborative actions. Time is not assigned to them for the consideration in this paper, because their action is not in the critical work path, comparing with other teams.

If all fixed fire pumps and other fire services installations work well, the effort and time duration for firemen to direct evacuation and to fight the fire would be much less than when certain fire services installations and pumps in the building fail to work. In considering the fire fighting operations by firemen, the worst situation of having all fire pumps failing is taken into consideration.

This will demand pre-planned installation of an elevated roof tank (Table 1) and a pneumatic booster unit if the elevated tank is not high enough to give by gravity the pressure needed to supply sprinklers to the top floors. Small break tanks will be installed at selected strategic floors, which can be refuge floors, to reduce pressure of water supplied from the elevated rood tank, to supply sprinklers to the lower floors, because it takes some time for the back up mobile and portable equipment and pumps to be set up by firemen (see the action of Firemen Team 2 described above) to ensure continuous water supply to the sprinkler system. **This is the first priority** of water supply, because successful and efficient fire fighting and rescue and people evacuation for tall buildings relies on successful fire control by automatic fire sprinklers.

To make sure hosereel water supply is (3) available at all times for automatic fire suppression and control and for first aid manual fire fighting, it is proposed to installed a hosereel water tank of 4.5 cubic meter at roof, which will be capable to supply one hosereel of 15 litre per minute for 30 minutes or 2 hosereel for 15 minutes, or 2 hosereels for 10 minutes, before hosereels and hydrants/landing valves are boosted with water by fire engines and portable fire pumps.

Considering the effectiveness of fire fighting of impulse fire extinguishing technology (7), it is also proposed to install mains for compressed air and water to supply portable or fixed impulse fire extinguishing devices, which have to adapted for such mains back up. This provision will supplement the existing water fire fighting systems. This provision will also enable the most effective choice of fire fighting technology when water shortage comes to a critical situation under terrorist attack. The related mains should be backed up by fire brigade boosting devices similar to backing up sprinkler systems.

It is proposed to install a separating water tank of 1200 litre on the roof for feeding the lower floors for impulse fire fighting devices. Assuming a shot of 0.1 litre every 3 seconds by one impulse fire fighting device, (7) this water tank will supply 10 such devices for 1 hour operation. In additional a compressed air tank has to be installed, which has to be backed up by a diesel-operated compressor motor. A diesel-backed up water pump has to be installed to supply these impulse devices for protecting the floors at the top 70 m of the building, because these devices have to operate above 6 bars of pressure. (Fig. 8) The existing completely mobile impulse set ups (7) have to adapted to mobile devices connected to supply mains via flexible tubes, for continuous operation say for 1 hour.

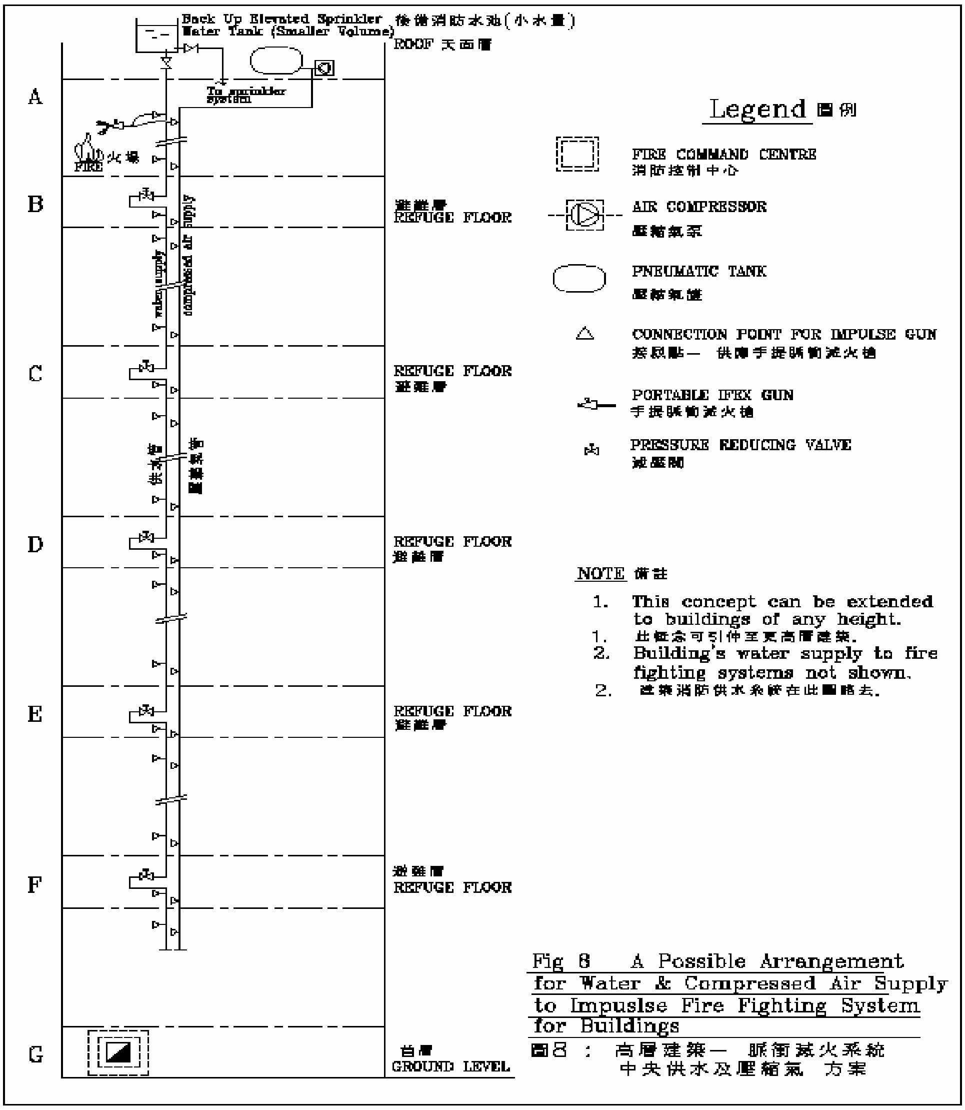

Fig 8 A Possible Arrangement for Water & Compressed Air Supply to Impuslse Fire Fighting System for Buildings

圖8 : 高層建築— 脈衝滅火系統 中央供水及壓縮氣 方案

Considering the 4 teams of firemen described above, the action of Team 1 and Team 2 take equally the first priority.

Depending on manpower and equipment availability and fire station location, Team 3 can be allowed to take the second priority. Team 4 has to keep in pace with Team 3 if the fixed fire hydrant pumps of the building fail, and if the elevated tank for hosereels is not leaving water for hydrant operation before the portable pumps can relay water from ground floor fire engines. If the fixed fire hydrant pumps operate satisfactorily, of course Team 4 can work independent of Team 3. Depending on manpower availability and fire and evacuation situation, Team 4 can start work earlier because the earlier the fire is extinguished the better, although its action is recommended to be of 2nd priority, compare to the work of Team 1 and Team 2.

Team 5 consists of various types of firemen and other related personnel (e.g. ambulance teams) and equipment, and their actions are not in the critical time path as compared with Teams 1 and 2, their actions are not discussed further.

Factors affecting the action of various Firemen Teams

T1 and T1a vary with:-

- the location of the building relative to the nearby fire stations
- the equipment and manpower available in these fire stations
- the traffic conditions and traffic thoroughfare available
- the availability of mechanised emergency access (e.g. firemen's lift opening to protected lobbies backed up by emergency power) to the fire floor
- the fire growth and the extent of its spread and control (e.g. Is the staircase smoke logged? Has the fire spread to other floors?)
- the evacuation conditions of the occupants (Are the occupants trapped in the staircase which may be smoke-logged, or in other places, requiring firemen’s help, who are then delayed from arriving at the fire floor)
- the height of the fire floor above ground
- other unforeseen circumstances such as heavy rain and bad weather, road works, etc.

T2 vary similarly with the items of consideration of T1, T1a above. For example, if a new generation of high pressure fire pumps are available (2) T2 may be reduced substantially.

Times T3 and T4 are similarly affected by the factors stated above.

In one hypothetical building having one refuge floor every 45m up the building (Fig 2, 3, 5, 6), T1, T2, T3, T4 (Fig 7) could be expected to vary (Table 2) respectively from 5.5 min. to 8 min., 8 min. to 13 min., 8 min. to 15 min., 8 to 12 min. If conditions are not favourable, these T1, T2, T3 and T4 may be longer.

This brings in reconsideration of the size of the elevated water tank(s) for the sprinkler system and the fire hydrant system. The size should be larger as the building goes taller. This will ensure the sprinkler system, and the hosereels are continuously and sufficiently supplied with water before the firemen's portable pumps can operate, assuming the worst condition of failure of all fixed fire pumps in the building. [Note however the size of these elevated water tanks need not be enlarged if the sufficient security guards in the building are trained up to take up part of the job of firemen Team 2 and Team 3 – See section on anti-terrorist and anti-arsonist considerations below.]

Similarly, as the fire floor in the building goes taller, the number of firemen, fire engine, portable fire pumps to attend the fire will increase. The actions of the related fire stations, the firemen, the fire engine and equipment, have to be pre-planned.

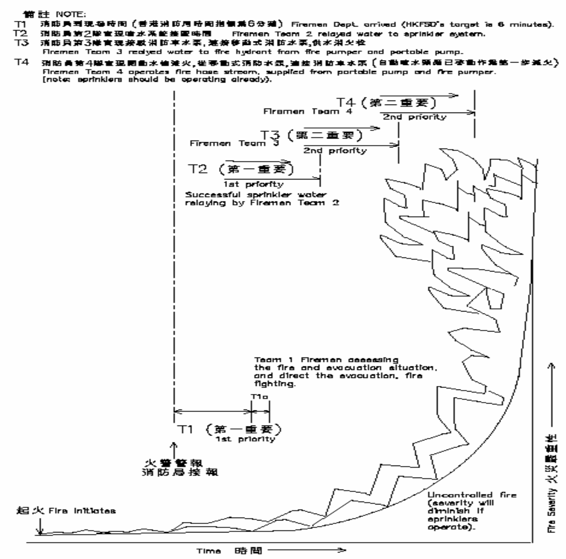

Fig 7 Operational Times for Fireman Teams (Cheung, 1997)
圖7 消防員隊伍行動時間

TABLE 2. A hypothetical building (Fig. 2, 3, 5, 6) with T1, T2, T3, T4 estimated

Building height (m)	45	90	135	180	235	270
Number of refuge floors	0	1	2	3	4	5
Expected No. of portable pumps (to be located at refuge floors) for supplying sprinklers (Related to T2)	0	1	2	3	4	5
Expected No. of portable pumps (to be located at refuge floors) for supplying fire hydrants (Related to T3)	0	1	2	3	4	5
Time counted from the moment the fire station receives a fire call (in minutes)						
T1	5.5	6	5	7	7.5	8
T2	8	9	10	11	12	13
T3	8-9	9-10	10-12	10-13	11-14	12-15
T4	8-10	9-11	10-13	10-14	11-16	12-17

Notes:

1. The above estimation is based on complete failure of all the fixed fire pumps in the building and that fire engine pumps can supply up to 8 to 10 bar (i.e. 100m)
2. Portable pumps can deliver 450 l/min at 6 bar (i.e. 60m) or 360 litre/min at 8 bar (i.e. 80m), each weighing about 26kg, to be carry on the back of one fireman (Cheung, 1995, 1997a).
3. T1, T2, T3, T4 are estimated on smooth and efficient operation under favourable conditions. If conditions are not favourable T1, T2, T3, T4 will be longer and more portable pumps will be needed.
4. With a proposed new generation of fire engine pumps (Cheung, 1995) T2, T3 would be reduced.

ANTI-TERRORIST AND ANTI-ARSONIST CONSIDERATIONS

To encounter these scenarios successfully, this paper endorses the previous proposals of keeping sufficient portable pumps in nearby fire stations, (1,4) and taking them to the refuge floors for relaying water to be boosted by existing fire engines into the sprinkler system and fire hydrant/standpipe/wet riser system of the building. Such water relaying processes take certain minutes to set up. (4,5, Fig. 7)
If existing fire authority cannot provide portable pumps as needed for water relaying for normal situations and situations of terrorist attack and arsonist attack, this paper recommends the owners of nearby tall buildings to unite together to purchase the related portable pump, to recruit suitable security employees such as recently retired fire fighters. The existing sprinkler systems and the fire hydrant/standpipe/wet riser systems have to be modified to provide additional fire brigade inlets at refuge floors or similar locations (1, Figs. 2 to 6), to drill fire fighting together with the local fire brigade, and to help each other to deal with all sorts of fires that could occur under all circumstances.

A sufficient security guards in the building have to be trained up to take up part of the task, and preferably all of the task, of firemen Team 2 and Team 3. This will ensure quick and efficient supply of fire fighting water to the all sprinklers and hydrants/landing valves as needed, even those at the tallest part of the building. The fire engines will boost water into these systems at ground level as currently practised, and the boosted water can reach the highest devices at say about 460 m above ground for the tallest group of buildings as needed as quickly as is they were buildings of about 60 m high, because the trained security guards already take up the task of firemen Team 2 and Team 3 and they are ready to execute the water relaying task successfully when the firemen arrive at the very tall building and the tallest building. This will provide a strong hold against terrorist and arsonist attack.

To nullify the setting up time for portable pumps for water relaying for very tall and tallest buildings, this paper further proposes a new series of super high pressure fire pumps, to be installed in a new generation of high power fire engines to pump water directly from ground to the highest corners of the fire fighting systems as needed. Pumps normally known as boiler feed pumps used in power stations, capable of supplying a large amount of water commonly up to 500 m to 600 m pressure, can be selected for this purpose. This will complementarily demand super high pressure pipes to be installed in bottom parts of the tallest building. The fire engine manufacture may take a few years to make this proposal work. This proposal greatly ensures fire safety of the tallest group of buildings against terrorist attack and arsonist attack.

The higher the building goes, the longer it will take to set up the water relaying process and equipment from ground and up the building. So the speedy use of water efficient impulse fire fighting devices may take the lead in initial fire fighting, since a small water storage of 1200 litre will be sufficient to supply 10 such devices to operate for 1 hour, as described earlier.

Since impulse fire fighting devices are found to fight oil fires of certain sizes successfully (Chang 2003), they can be developed into fixed systems to fight certain flammable liquid fires right at the spot upon fire initiation when terrorists or arsonists use flammable liquids to start the fire, which is not uncommon. This area is recommended for separate investigation for use in fires of very tall buildings (6) or normal tall buildings. (17)

CONCLUSION

The rationale and the basic principles of designing a fire hydrant system and a sprinkler system for tall buildings having refuge floors have been discussed, with an emphasis on considering firemen operation with portable pumps to ensure continuous water supply to sprinklers and first aid fire fighting hosreels as the first priority. It calls for a reconsideration of increasing the size of the elevated water tank as the building height increases. It also calls for suitable locating and deploying of firemen and portable pumps and other equipment in the related fire stations.

The demand of increasing the capacity of elevated sprinkler water storage can be eliminated if security guards are trained to take up the water relaying task of firemen. This proposal has the significance of providing a strong hold on fire safety against terrorist and arsonist attack.

The principles presented are primarily discussed for new tall buildings with refuge floors, but are however equally relevant to existing tall buildings, which should be upgraded with the proposals discussed in this paper.

The use of impulse fire fighting devices to be supplied by fixed water and compressed air mains are seen as a potentially effective supplement or complement to fire fighting, subject to more investigations and adaptation from its completely mobile set ups to mobile devices connected to supply mains via flexible tubes.

REFERENCES

1. The Council on Tall Buildings and Urban Habitat, Fire Safety in Tall Buildings, McGraw Hill, pp. 47-60, 1992.
2. Cheung, K.P., “Design for Effective and Reliable Boosting of Water from Fire Engines to Water-based Fire Fighting Systems in tall Buildings”, Proceedings of 5th World Congress, Council on Tall Buildings and Urban Habitat, pp. 775-789, 1995.
3. Cheung, K.P., “Enhancement Proposals on Sprinkler System and Standpipe/Wet Riser/Hydrant System in Tall Buildings”, Building Journal Hong Kong China, February 1997, 66-69, 1997.

4. Cheung, K.P. and Chan, H.W. "A Discussion on the Design Principles of Fire Hydrant Systems and Sprinkler Systems in Refuge-floor based Fire Safety Design in Tall Buildings", National Fire Conference, Chinese Association for Advancement of Science and Technology, Zhuhai, China, Oct. 1997.
5. Cheung, K.P. and Chan, H.W., "High Water – Discussion on Methods of Improving the Water Supply to Sprinkler and Hydrant Systems in Tall Buildings", Fire Prevention - Fire Engineers Journal, Fire Protection Association, UK, May 2003, 65-67, 2003.
6. WTC Fire 2001. http://911review.org/Wget/www.nerdcities.com/guardian/wtc/WTC_ch1.htm
7. Chang, J.C., Chen, S.S., and Lin, C.M., "The Experimental Study on Fire Extinction by High Speed Water Spray", Journal of C.C.I.T. Chung Cheng Institute of Technology, Taiwan, 32:1, Nov 2003. http://www.ccit.edu.tw/~jccit/pdf/32-1/p59.pdf
8. National Fire Protection Association, National Fire Code 14, Standpipe and Hose Systems, USA, 1993.
9. Australian Standard, AS2419:1 - 1988: Fire Hydrant Installations, PART 1 - System Design, Installation, and Commissioning, 1988.
10. Hong Kong Fire Services Department, Code of practice for Minimum Fire Service Installations and Equipment, 1993.
11. Australian Ordinance, Australian Ordinance No. 70, Specification 10, 1992.
12. The Loss Prevention Council, High Rise Sprinkler Systems, Technical Bulletin, TB13:1990:1, UK, pp. 4, 1990.
13. Morgan, H.P. and Gardner, J.P., Design Principles for Smoke Ventilation in Enclosed Shopping Centres, HMSO, UK, 1990.
14. British Standard, BS 5306: 1990: Fire Extinguishing Installation and Equipment on Premises, Part 2 – Specification for Sprinkler System, British Standards Institution, Clause 17.4.6, 1990.
15. Chinese Code 1995. 中华人民共和国国家标准 . 高层民用建筑设计防火规范. Code for fire protection design of tall buildings. GB 50045-95 (2001 年修订版）主编部门: 中华人民共和国公安部. 批准部门: 中华人民共和国建设部 . 施行日期: 1995 年 11 月 1 日.
16. Hong Kong Buildings Department, Code of Practice for the Provision of Means of Escape in Case of Fire, 1996.
17. CARACAS Fire 2004, Fire Sweeps through Caracas High-Rise, Associated Press. 17 Oct. 2004. http://abcnews.go.com/International/wireStory?id=173446