Environmental water supply systems and the protection of wooden cultural heritages and historic urban areas from post-earthquake fire

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Abstract: People have traditionally obtained water using simple management systems such as open channels, wells and rainwater tubs. These environmental water devices are losing their function in urban areas, replaced by the waterworks and sewerage systems of the modern industrial period. In the Great Hanshin-Awaji (or "Kobe") earthquake of 1995, serious damage to modern infrastructure restricted the water supply, making it difficult to extinguish fires triggered by the earthquake. These shortages were partly met by making use of the naturally occurring water to be found in neighborhoods. This paper argues that the potential natural water usage in urban areas must be improved to develop an "environmental water supply system (EWSS) for disaster prevention". Such uninterrupted water supply systems could be used to protect from fire cultural cities that have a substantial number of wooden structures and preserve the urban water environment. The concept of EWSS opens up possibilities for a sustainable water environment and the restoration of historical cities, maintaining beauty and safety for the benefit of future generations. EWSS project proposals have the potential also to increase safety measures in developing countries in line with regional capabilities and the need for low-cost development.

Keywords: project proposal in Kyoto, wooden cultural heritage, fire disaster prevention, water environmental preservation, citizen participation.

Introduction

Wooden cultural buildings and historic urban areas are irreplaceable cultural and social resources and vast storehouses for carbon sequestration – in Japan's case, absorbing or sequestering around 18 per cent of the carbon output of the country's forests. Japan's culture of unique wooden buildings has traditionally been supported by the abundance of timber resources provided by the forests that cover almost 66 per cent of Japan's highly mountainous landmass. In Japan, as elsewhere, the process of modernization has been accompanied by the building of a great number of structures from manufactured materials such as concrete and steel. Recently, these modern structures are raising concerns with regard to their impact on the global environment. In contrast, the characteristics of wooden materials are argued to have comparatively low negative impacts on the environment.[1]

Wooden cultural heritages and historic urban areas are:

- human treasures that contribute to the maintenance of cultural diversity;
- huge storehouses for carbon sequestration, which slow down the build up of carbon dioxide concentration in the atmosphere;
- built by sustainable and restorable natural materials.

However, they are a fire hazard that poses a grave threat in countries that have a strong culture of building with wood. The highest risk of destruction comes from an earthquake, when innumerable fires break out over a scattered area in a very short time while road blockages hinder the efforts of fire engines. Consequently, lives and irreplaceable wooden heritages are lost. In the case of Japan, which was created by movement in the earth's crust, earthquakes have shaken the archipelago periodically across the centuries. In the Kobe earthquake of 1995, the final death toll of 6,433 included 559 people killed by fire. The 67,421 buildings that collapsed from the earthquake's impact were added to by a further 6,965 buildings destroyed by fire: some 285 fires occurred in the immediate aftermath of the earthquake.[2] The destructive power of earthquake fire was exacerbated by the serious damage to modern infrastructure, which restricted the supply of water for fire fighting. In Kobe, citizens were forced to rely on naturally occurring sources of water in their initial efforts to fight the fires.

Citizens have long relied on naturally collected water for drinking, washing, transportation and agricultural use, creating simple management systems such as open channels, wells and rainwater tubs to conserve and distribute water. These environmental water devices have been all but lost to the modern urban landscape; replaced by modern waterworks and sewerage systems. The lessons of Kobe indicate that the combination of urban natural water and citizens' power offer great potential – currently neglected – to maintain the safety of wooden cultural cities from fire and preserve the urban water environment. From this premise, the concept of an uninterrupted environmental water supply system for disaster prevention (EWSS) was developed; a product of cooperation between the Kyoto City Fire Department and the Global Environmental Architecture laboratory at Kyoto University[3] (see the Kyoto City Fire Department 2002).

This paper accordingly argues the importance of returning the natural water environment to our urban areas. We should use EWSS to create a safe and pleasant environment in which wooden cultural heritage structures are preserved among the modern buildings of our urban landscapes. Wooden buildings are indeed flammable but it would be an immeasurable loss for human culture and the global environment if they were eliminated purely on the grounds they pose a fire risk. To save our wooden cultural cities, it is more important to create an environment in which citizens can fight fire easily and quickly than it is to change all the historical buildings into fire-proof structures. The most essential safeguard when fighting an earthquake fire is to maintain an adequate supply of water at the neighborhood level and make it accessible to citizens.

Throughout history in the monsoon temperate zones that include much of Asia, the climate has nourished wooden cities rich in water. Cultures with a wood and water environment share an obligation to preserve and pass on the irreplaceable treasure of "wood culture" to the future benefit of not only their future citizens but a diverse and sustainable global environment.

The EWSS concept

Emerging from the experience of the Kobe earthquake, the concept of EWSS advocates building up the potential of various water resources to ensure an uninterrupted water supply at all times. The supply should be sufficiently large enough to provide water to fight fire in all its phases – from small through to spreading fires.

The three fire-fighting phases summarized in Figure 1 were defined with the cooperation of the Kyoto City Fire Department in 2002 (Ibid). The first phase is that of a small fire, fought by citizens armed only with small amounts of water. The

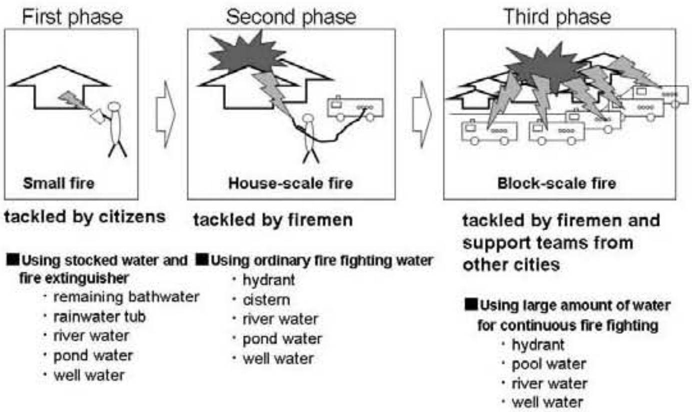

Fig. 1 Multiple phases of fire fighting
(Source: Kyoto City Fire Department 2002)

accessibility of water is most important in this phase. The second phase defines a standard house-scale fire, fought by professional firemen. In this case, the amount of water must be sufficient for professional use. The third and final phase is block-scale fire; this is tackled by various support teams for fire fighting, usually from other cities. Continuous and ample amounts of water are particularly vital in this last phase.

To uphold the fail-safe performance requirements of its safety measures, the EWSS must be designed to incorporate diverse water resources and be effective in any of the fire-fighting phases. The objectives of EWSS performance are as follows:

- easy operation by citizens;
- safe and continual water supply;
- environmental contribution;
- back-up system for usual fire prevention methods;
- low-cost development by utilization of existing water.

With its emphasis on water sustainability and the conservation of wooden buildings, it is evident that the concept of EWSS has far-reaching benefits. These are not only practical in environmental terms but aesthetic, in terms of preserving traditional wooden buildings, and communal, as citizens will participate to protect the local community. In addition, it is conceivable that the reintroduction of water environments into our cities may help stabilize the "heat island" phenomenon in urban areas. Likewise, the ramifications of EWSS in regenerating a wood-based building industry are vast in terms of safety and beauty.

Post-earthquake fire hazard projections in Kyoto, Japan

Kyoto city in Japan was selected as the location for two EWSS case studies on account of its diverse wooden cultural heritage. Kyoto is home to a countless number of wooden structures, including 14 world heritage sites – the highest number of any city in Japan. In addition, there are five historical preservation districts that have been declared national treasures. Kyoto city is also at risk from a serious earthquake. There are three major fault lines that run to the east, west and north-east of the city through high density residential areas. These were responsible for the formation of the Kyoto basin. The city's next periodic earthquake is expected to take place this century.

A simple survey to estimate earthquake fire risk was carried out in order to choose appropriate sites for the case studies (Okubo et al. 2002). The characteristics of the city area were analyzed in terms of the risk of fire occurrence and the risk of fire spreading. Statistical data from the Kobe earthquake[4] was used in an analysis of the percentage of people of advanced age (over 65 years old) and the average number of people in each family, to index the risk factor of fire occurrence. Next, a study of the density of flammable structures in a given area was used to index the risk factor of fire spreading.[5] The collated data indicated that areas sharing a high density of flammable structures with over 15 per cent of elderly people and fewer than 2.8 people in each family on average bore the highest risk of outbreaks of fire resulting in fire spreading. The data was used to identify a number of hazardous areas across Kyoto city, divided into two risk area categories: seriously and semi-hazardous. These can be seen in Figure 2.

In addition, the risk of isolation for any area caught in an earthquake was analyzed according to the width of the roads around the area. In the Kobe earthquake, most road blockages occurred in streets that were less than 12m wide (Tsukaguchi 1995). All of the roads in Kyoto were examined, and those that measured more than 12m in width were checked for the passage of fire engines. In most cases, the prospect of fighting a fire depends on its distance from the fire engine that acts as the water resource. The typical length of a fire hose in Japan is 400m, making the minimum radius of the fire-fighting circle approximately 250m (some loss in radius is caused by twisting roads). Projections were made of the area available for fighting fires using conventional methods such as fire engines and pumps, within 250m of all the major roads which fell into the estimated earthquake related fire-risk hazard areas described above.

The combined data was used to estimate which of Kyoto's cultural heritage buildings and districts were most at risk from post-earthquake fire hazards. Dai-houon-ji temple and the Sannei-zaka historical preservation district proved to be the most in danger

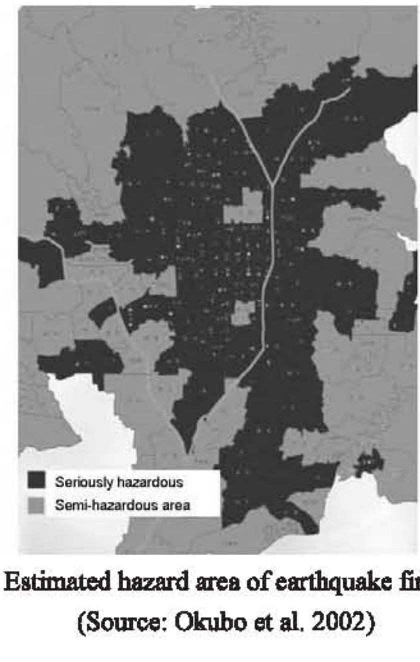

Fig. 2 Estimated hazard area of earthquake fire in Kyoto

(Source: Okubo et al. 2002)

because they are within the estimated hazard areas but outside the available fire-fighting areas. They were accordingly selected as specific case study sites for EWSS-based proposals.

EWSS case study proposal 1: Dai-houon-ji temple area

Dai-houon-ji temple is a wooden national treasure surrounded by a high density of wooden houses in close proximity. The temple was built in 1227 and is one of the oldest wooden buildings in Kyoto city. The temple's *hondō* or main building has an area of 453.15 square meters and measures 12.86m from ground level to roof-top. The building has 42 wooden columns, the largest of which has a diameter of 0.61m. Its wooden roof is made from a large number of small cypress roof tiles (Figure 3).

The Tenjin River lies within 250m west of Dai-houon-ji temple. In the planning stages for the case study, the river was examined for use as a water resource and a route designed to lead water from the river to the temple (Figure 4). In creating an open channel, it was important for water security to create a natural and endless water flow independent of any mechanical system. For this reason, a water circulation route was designed in accordance with principles of geographical altitude. Because the Tenjin River's source comes from a mountain side within 1km of Dai-houon-ji temple, the quality of water is appropriate for both fire fighting and daily usage. However, the difference of altitude between the river and ground level is approximately 7m at the

Photo by Okubo Takeyuki

Fig. 3 Dai-houon-ji temple

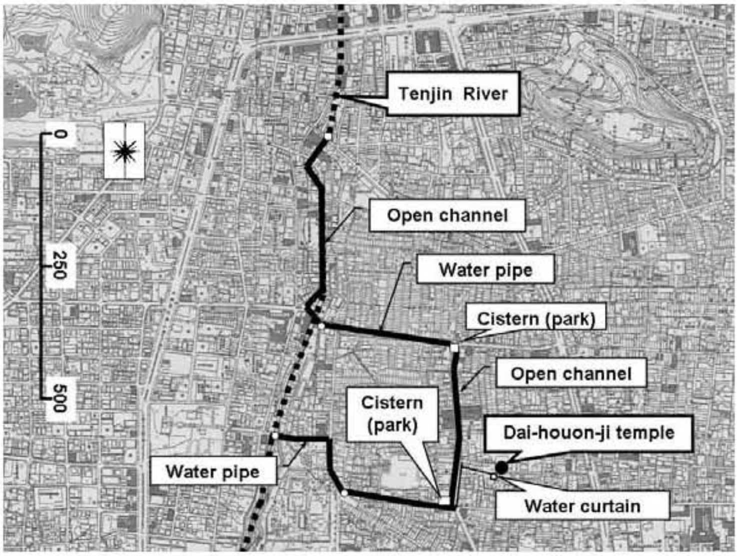

Fig. 4 Water route planning for EWSS case study proposal 1.
(Source: Toki et al. 2002)

Fig. 5 A scooping pit for citizen's use (1st fire-fighting phase)

point where the river flows to the west of the temple. To assist the water flow, the open channel has accordingly been designed to feed directly from the water current further upstream where the river's altitude is higher, in order to keep the water level at ground level. The natural force of the current pushes the river water through the open channel, therefore eliminating the need for mechanical aids in diverting water towards the temple.

Scooping pits are located at regular 250m intervals in the open channel. Citizens are able to use buckets to scoop fresh water at these points, despite the shallow water depth (Figure 5). The pits are useful for the citizen-led phase of fire fighting during the crucial early stages of tackling a fire. Specially designed cisterns (Figure 6) combine large underground reservoirs with open water parks at ground level. Together these maintain an adequate supply of water for the first and second fire-fighting phases, as well as for citizens' daily use. People's daily use of the cisterns is a very important point of the EWSS because it enables them to commune closely with the water. The surface of the water is kept uncovered for easy access, not only for daily use but also in case of an emergency.

The third and final phase of fire fighting incorporates the use of a water curtain system. This is necessary because the distance between the temple and neighboring houses is so close (around 6m) that a spreading fire would easily reach the wooden eaves of the temple without some kind of fire wall. The amount of water held in the cistern should be calculated to meet the needs of the water curtain system, since it is in this phase that the greatest supply of water is needed. Field research assessing the

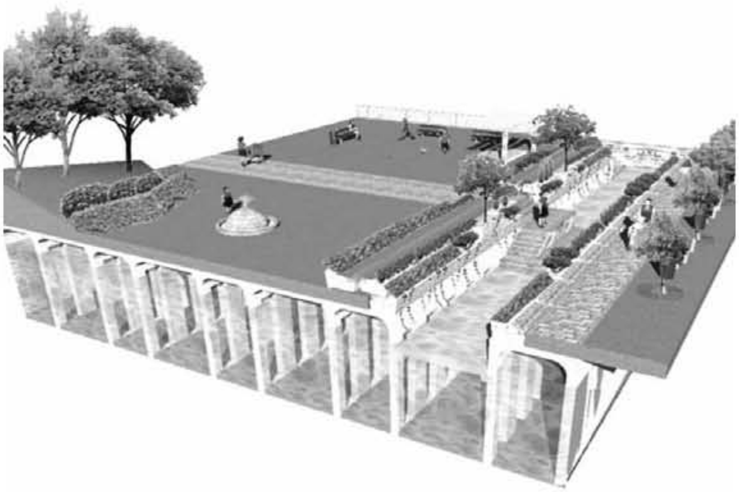

Fig. 6 Planning of cistern (park with water) for 1st and 2nd fire-fighting phases
(Source: Toki et al. 2002)

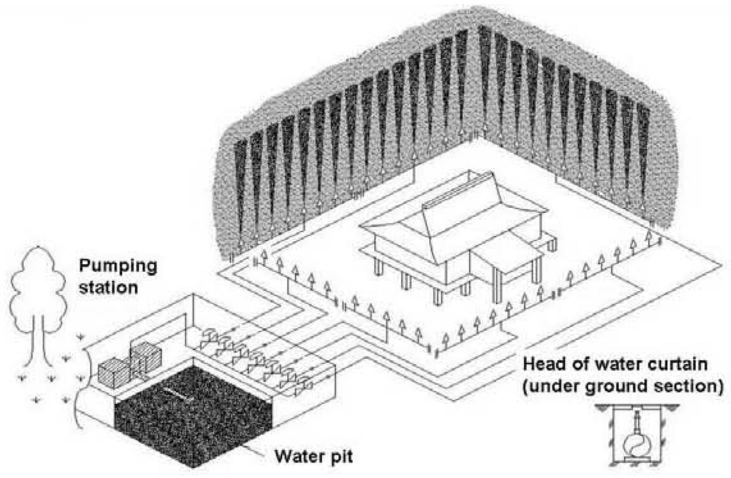

Fig. 7 Planning of dual pumping stations and water curtain
(Source: Toki et al. 2002)

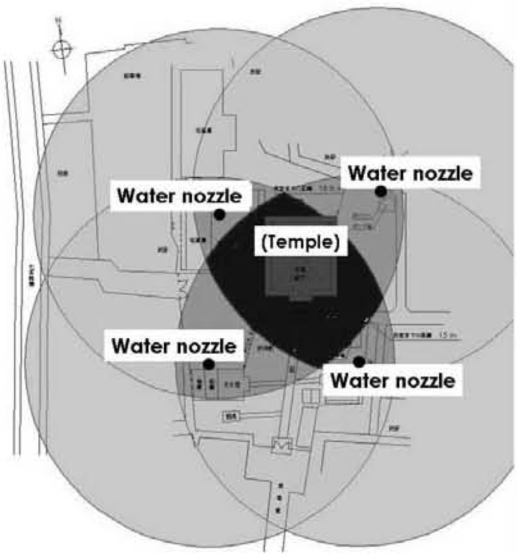

Fig. 8 Planning of water nozzle system for neighborhood fires (2nd phase)
(Source: Toki et al. 2002)

nature of the building structures around the temple enabled simulations of worst case scenarios in which the temple became caught up in a fire spreading from outside the temple environs. For this, five major areas where fire could spread around the temple were considered. The specification of the water curtain system is set to keep the temperature of radiant heat below 200 degrees at the edge of the wooden heritage structure to protect the temple from a block-scale fire. It was estimated that at least 3000 tons of water would be needed in the cistern to provide two hours of use to fight a fire. Dual pumping stations for the water curtain were designed to retain its fail-safe quality (Figure 7).

For the second fire-fighting phase, four water nozzle systems, capable of covering a 50m radius circle, were designed as an additional provision (Figure 8). This measure would ensure that not only the temple but also the neighborhood in the temple's vicinity would remain safe in the event of a fire.

EWSS case study proposal 2: Sannei-zaka area

The second case study deals with the Sannei-zaka historical preservation district – an area within the Kiyomizu temple world heritage area.

Research into the geographical characteristics of this site was particularly important in developing a practical EWSS proposal to meet this district's needs. Lying alongside the Higashiyama mountains on Kyoto's eastern flank, the district includes the two high-density areas of wooden structures that make up the picturesque Sannnei-zaka and

Fig. 9 Sannei-zaka and Ishibe-kōji

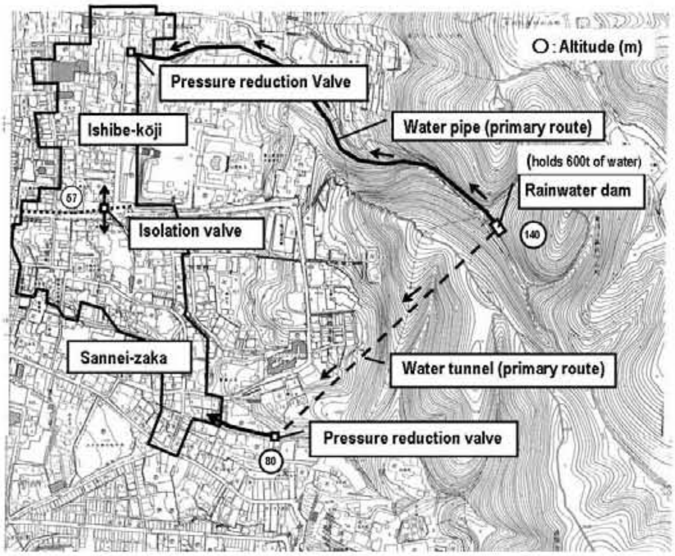

Fig. 10 Water route planning for case 2 area
(Source: Toki et al. 2002)

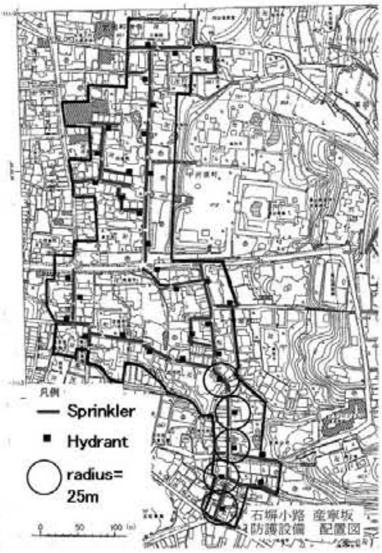

Fig. 11 Site planning of hydrants and sprinklers
(Source: Toki et al. 2002)

Ishibe-kōji neighborhoods. Each area is pinched between bare wooden buildings and is well-known – and much frequented by tourists – for its winding and narrow streets and twisting stone steps (Figure 9). Unsurprisingly, route blockages would present great difficulties to firemen trying to enter the district to extinguish a fire in the event of an earthquake. The EWSS in this case must therefore be designed with the easy operation of citizens, as well as professional fire fighters, in mind.

An existent rainwater dam on the mountainside close to the case study site holds 600 tons of water. Alternative water supply routes were designed to function as reciprocal backup in case of emergency (Figure 10): one pipeline above ground and another underground. An isolation valve is located between the Sannei-zaka and Ishibe-kōji neighorhoods. This will be closed to sustain water pressure if the water delivery network serving each of the two neighborhoods is broken at any point. The altitude difference between the rainwater dam level and the preservation area level makes it possible to sustain enough water pressure to keep the fire-fighting systems supplied with water. Here, it is important to use simple, natural forces, without complex systems such as pumps, to keep the system fail safe.

This pressurized water can be used for fire-fighting instruments such as hydrant and sprinkler systems. Hydrants located along the district's narrow streets are capable of reaching all the wooden structures within a 25m radius (Figure 11). They are designed for citizens to use easily, without the need for any specialized or professional knowledge, in the first phase of fire fighting. Care is used in their location and design in order to maintain the scenic appeal of the neighborhoods in which they are located (Figure 12). The hydrants are available not only for use in emergencies: people are able

Fig. 12 Image of hydrant system for citizens (1st fire-fighting phase)

Fig. 13 Image of sprinkler system for narrow street (2nd fire-fighting phase)
(Source: NPO for Protection of Cultural Heritage from Disaster, 2004)

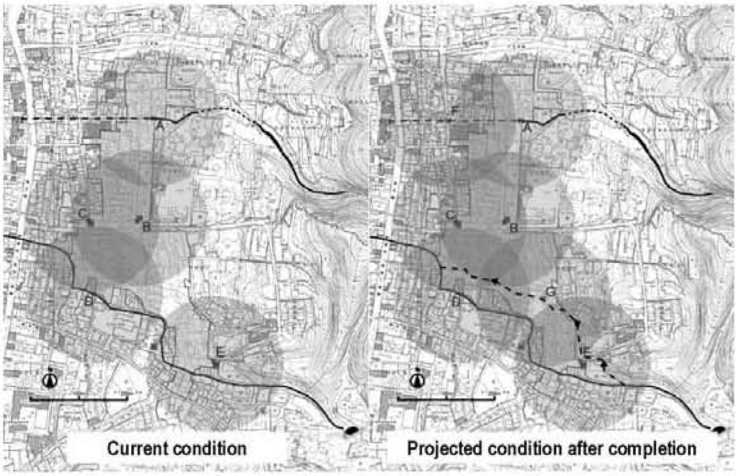

Fig. 14 Cisterns and channel network system: provisions for back up
(Source: Toki et al. 2002)

to use them in their daily lives, for example for *uchi-mizu* watering (a traditional Japanese custom of wetting the surface of the road early in the morning to settle the dust, or during hot summers to cool baking streets). The sprinkler system along narrow side streets is likewise designed for citizens to operate easily to slow down the speed of fire spreading at the second phase of fire fighting (Figure 13). Keeping surfaces wet by using the sprinkler system is an effective way of stopping a fire from advancing from the second to the third stage. Should the first phase of fire fighting fail, the second phase would require the citizens to simply turn on the sprinkler taps and then keep a safe distance.

Cisterns and channel networks are designed to back up these pressurized water systems to keep the whole system's performance fail safe. At present, there are still a number of areas that are inaccessible to fire fighters because they lie outside the supported fire-fighting circles fed by existing cisterns. It is planned that small rivers around this district that have been covered or sealed off will be regenerated as open channels and the resulting new water flow led into two more cisterns to cover the rest of the area (Figure 14). In addition, scooping pits built into the open channel where the water level is shallow will make it possible either for citizens to scoop out water with buckets, or for pumps to be applied manually or mechanically to pump out water without air inclusion interfering with the performance of a vacuum pumping system. In each case, it is important to adapt the design of the water environment to provide easy and safe access for the citizens who will use it.

Conclusion

This paper has argued the importance of returning a natural water environment to our urban areas. A regenerated water environment would create a safe, natural environment that assures the preservation of historic wooden buildings in communities.

The EWSS is a leading system of practical water management, which offers protection against the most dangerous instance of fire – earthquake fire – that threatens wooden structures in cultural cities around the world. As a concept, EWSS emphasizes both the necessity of a sustainable water environment and the preservation of historical cities. In each case, the beauty and security aspects underpin its basic principles. This kind of project also has the potential to reinforce safety systems for developing countries, bringing benefits both at the regional level and in terms of low-cost development.

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Notes

1 The environmental benefits of wood are reduced radically in cases where the wood used in the building industry is not produced domestically or from sustainably managed forests. Unfortunately, Japan's self-sufficiency in wooden materials has fallen to under 20 per cent since 1997 (Ministry of Agriculture, Forestry and Fisheries of Japan 1999). Clearly, the regeneration of a sustainable Japanese wood industry and an increase in the use of so-called "Fair Wood" materials are essential if an environmental case for wood is to be argued in Japan.

2 See the *Report on the Hanshin-Awaji Earthquake Disaster* (Architectural Institute of Japan 1998).

3 The author – one of three full-time staff members in the laboratory – worked closely with the Kyoto City Fire Department from 2001 to 2002 in developing the EWSS concept under the leadership of Professor Masami Kobayashi.

4 See the Architectural Institute of Japan (Ibid: 322)

5 The risk of fire spreading in Japan is usually indicated by the percentage defined as non-flammable (ie., composed of non-wooden and non-flammable buildings) in a given area. Most local governments define regions with a non-flammable area of under 60 per cent as being at risk from fire spreading (see Tokyo city government's 1997 report: *Promotion Plan for Cities with Disaster Prevention*).

References

Architectural Institute of Japan (1998) *Report on the Hanshin-Awaji Earthquake Disaster*, Tokyo: Architectural Institute of Japan.

Kyoto City Fire Department (2002) *Kyoto City Water Supply System Vision for Disaster Prevention*, Kyoto: Kyoto City Fire Department.

Ministry of Agriculture, Forestry and Fisheries of Japan (1999) *Statistics Report of Agriculture, Forestry and Fisheries*, Tokyo: Ministry of Agriculture, Forestry and Fisheries of Japan.

National Institute for Land and Infrastructure Management (1982) *Report of Method Development for Protection of Urban Area from Fire*, Tokyo: Ministry of Construction (Ministry of Land, Infrastructure and Transport).

Fire Institute of Japan (1981) *Handbook of Fire Prevention*, Tokyo: Kyoritsu Publishing.

Okubo Takeyuki (2003) 'Proposal: Environmental Water Supply System (EWSS) for Protection of Cultural Heritage from Earthquake Fire – Kyoto'. A presentation delivered at the 3rd World Water Forum on "Water and Cultural Diversity" on 17 March 2003 (Summary papers: pp. 44-45) at the Kyoto International Conference Hall.

Okubo Takeyuki, Iida Yuya and Toki Kenzo (2002) 'Study on Disaster Prevention and Water Maintenance with Regional Characteristics in Kyoto City', *Proceedings of the Annual Conference of Civil Engineers*, Osaka: JSCE Kansai Chapter.

Toki Kenzo, Okubo Takeyuki and Izuno Kazuyuki (2004) 'Protection of Cultural Heritages from Post-earthquake Fire (Paper No. 2781)', *Proceedings of the 13th World Conference on Earthquake Engineering*, Vancouver BC: Canada.

Toki Kenzo, Kobayashi Masami, Okubo Takeyuki et al. (2002) 'Research and Development on Environmental Water Supply System for Protection of Wooden Cultural Cities from Earthquake Fire', *Report of Construction Technology R & D Grant 2001, Ministry of Land, Infrastructure and Transport.*

Tokyo city government (eds.) (1997) *Promotion Plan for Cities with Disaster Prevention,* Tokyo: Tokyo Metropolis.

Tsukaguchi Hiroshi (1995) 'Research on Road Width', *Journal of JSTE,* 30(18), Tokyo: Japan Society of Traffic Engineers.

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