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Proposed evacuation tunnels for wide-area disaster

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ABSTRACT

The present paper proposes a safe evacuation method using underground evacuation tunnels for urban area evacuation owing to a wide-area fire disaster that may occur in the aftermath of a major earthquake. To survey the effectiveness of the evacuation tunnels, evacuation completion time was estimated using wide-area evacuation simulations. It was discovered that evacuation completion time for underground tunnels was one hour faster than that of evacuation above ground (even with the widening of the surface roads) if tunnel usage was appropriately controlled so that vulnerable people (i.e., elderly people and children) used it while others evacuated above ground. Moreover, an estimation of the construction cost of evacuation tunnels in a metropolitan area indicated that one could be built at the same, or even lower, cost than that of the road widening above ground.

1. Introduction

Japan is one of the most earthquake-prone countries in the world because tectonic plates collide just off its coast. The Japanese have experienced the loss of human lives as well as economic loss caused by a significant number of major earthquakes, such as the Great Kanto Earthquake in 1923, the Great Hanshin Earthquake in 1995, and the Great East Japan Earthquake, which recently occurred in 2011. Fig. 1 shows the causes of death of people killed in these earthquakes—most of them were classified as burned, crushed, or drowned (Cabinet Office, 2011). Many studies have been undertaken and much money invested in equipment to prevent death by fire and compression. In the Tokyo metropolitan area, where the probability of a magnitude 7 earthquake occurring within 30 years is predicted to be 70% (Working Group on Measures to Tokyo Inland Earthquake, 2013), mitigation of road blockages caused by building collapse and people falling victim to fire following an earthquake (which generally occurs because of wooden houses) is an urgent issue. Improvements to the resilience of buildings to quakes and fires, and the redesign of the city, including road widening and the creation of vacant spaces for firebreaks, have therefore been proposed. However, such changes will not be easily accomplished because of their high estimated costs and the complex coordination of interests required. While these solutions conventionally assume evacuation above ground, in this paper, we propose a new evacuation system using evacuation tunnels constructed in an urban underground space. With the assumption that an underground tunnel is integrated in an evacuation plan in the case of an urban earthquake and major fire, we investigated the characteristics of an evacuation tunnel through an evacuation simulation. The tunnel's feasibility is studied with a focus on its construction cost and the utilization of existing infrastructure.

The following terms are used in this paper:

Wide-area refuge site: a large park or school that has sufficient capacity to hold a lot of people being evacuated from a major fire or tsunami following a major earthquake.

Primary refuge site: a small park or school where people can temporarily stay for safety purposes before moving to a wide-area refuge site. Its safety is not guaranteed for a prolonged amount of time, as it may be surrounded by fire or other hazards.

Vulnerable people: people who are particularly vulnerable in a disaster, such as elderly people, children, pregnant women, disabled or ill people, all of whom may require more time to evacuate.

Evacuation completion time: time necessary for 97% of evacuees to reach a wide-area refuge site.

Evacuation completion ratio: the ratio of the number of people who have reached a wide-area refuge site to the total number of evacuees.

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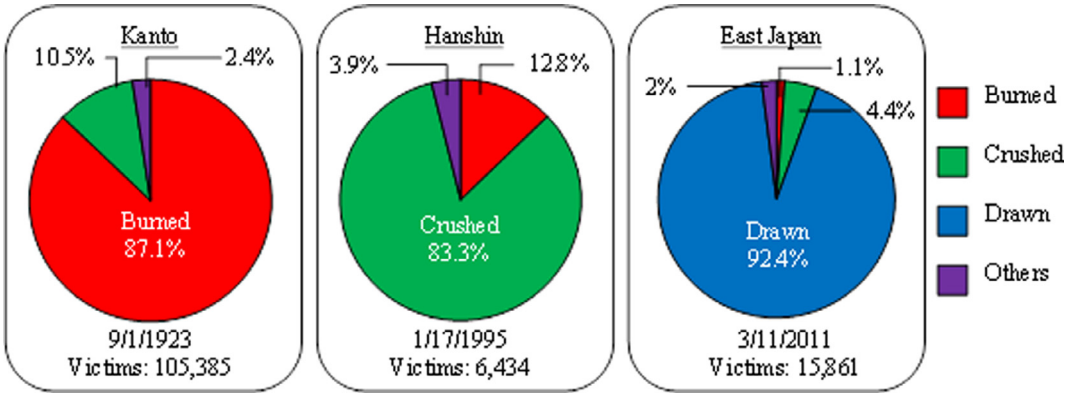

Fig. 1. Causes of death during major earthquakes in Japan.

2. Wide-area disaster

2.1. Existing problems

In a major earthquake followed by a fire, which may be caused by electric leakage or failure of initial extinguishing activities and subsequent fire spread, people who require an extended period of time to evacuate to a safe place are in danger of being trapped by the fire. In the Great Kanto Earthquake, which occurred in the Kanto area (including Tokyo) in 1923, almost 90% of its victims were killed in a fire, as shown in Fig. 1. A recent report on a potential disaster caused by an earthquake under Tokyo predicts a maximum of 16,000 victims losing their way, caught in fires that simultaneously occur in several locations or in fire whirls.

Therefore, maintaining the evacuation routes to reduce the number of such victims caught in fire after a major earthquake in an urban area is important. However, it is financially difficult to be accomplished with only above-ground plans.

2.2. Key features of planning for wide-area evacuation

Present and future considerations in planning evacuations in the case of a wide-area fire in Japan are: (1) taking vulnerable people, such as elderly people, into account; (2) security of evacuation and rescue routes; (3) large refuge sites for holding a lot of evacuees; and (4) security of infrastructure (electricity, information/-communications network, and water supply/sewage). The Japanese population is rapidly aging, as shown in Fig. 2; hence, wide-area evacuation plans should expect vulnerable people to make up as much as half of refugees in the near future (Statistics Bureau, 2011).

2.3. Wide-area evacuation plan above ground

Evacuation during a major earthquake planned by the local government (Tokyo Metropolitan Government, 0000; Ministry of Land, Infrastructure, Transport and Tourism, 2007). Also see Appendix A begins with behavior to avoid initial damage followed by information inquiry at a safer space within a building. Then, evacuees move from the initial site of evacuation to primary refuge sites, i.e., officially designated schools, public halls, or parks. If the scale of the fire increases such that it threatens a larger area owing to the merging of several fires, evacuees are further expected to move to the officially designated, wide-area refuge sites, i.e., large parks, apartment complexes, or colleges that are sufficiently large (over 10 ha) for a large number of evacuees to avoid the radiant heat generated by the fires. However, creating such large refuges (or find ones that are adequate) in urban areas is difficult since they are already crowded and urban land is expensive. The evacuation distance is therefore often very long, leading to evacuees being exhausted and increasing the possibility of evacuation routes being disrupted. In some areas, the roads designated for use in wide-area evacuation scenarios are currently being reconstructed to widen them (Ministry of Land, Infrastructure, Transport and Tourism, 2007). Therefore, large refuge sites and appropriate routes that enable quick evacuation are scarce.

2.4. Objectives of the present work

The use of underground space, compared with the use of surface routes, can improve safety during evacuation and mitigate the physical and financial problems of current evacuation plans for urban areas. Therefore, we propose a new evacuation system that utilizes underground spaces. The concept of a wide-area

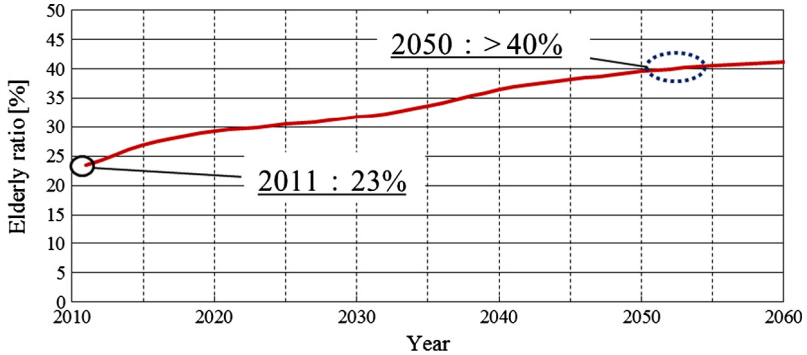

Fig. 2. Change in the proportion of people over 65 years of age for Japanese population over time.