Vertical Evacuation Against Debris Flow and Effective Vertical Evacuation Areas

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INTRODUCTION

Few reports have studied effectiveness of vertical evacuation to second floor of wooden residential structure against debris flow. This study assesses a case of debris-flow disaster in Hiroshima city on August 20, 2014, and evaluates effectiveness of vertical evacuation in view of actual preparedness and evacuation situation of affected residents. Furthermore, calculated hydrodynamic force values are categorized to determine effective vertical evacuation areas based on debris-flow depth accounting for ground-level heights of wooden residential structures (hereinafter referred to debris-flow effective depth).

METHODS

Questionnaires were distributed in the lower area of Yamate River (80 houses, and 41 households, 89 respondents) in Asaminami-ku, Hiroshima city to gather information on evacuation locations, time, triggers for evacuation, and reasons for debris flow awareness. In addition, the following information was gathered and assessed: residential locations where mass media indicted human casualties, degree of damage to residential structures.

The following classification of damage to wooden residential structures was used: “loss of structure”, “horizontal shift”, “complete destruction”, “partial destruction”, “openings damaged”, and “openings no damaged”. Using data of 81 wooden residential structures damaged of the recent debris-flow disasters (Kiho town, Mie in 2011; Aso city, Kumamoto in 2012; and Hiroshima city, Hiroshima in 2014) in our research, relation between hydrodynamic force and degrees of damage to wooden residential structures were studied. Debris-flow effective depth used to calculate hydrodynamic force was obtained by deposit depth and flow trace height of residential structures walls and fences. Mean velocity of debris flow was calculated by the Manning formula (roughness coefficient: 0.03) and adjusted according to distance of residential structure from the center line of debris flow based on cross-sectional velocity distribution. Then, effective vertical evacuation areas were investigated.

RESULTS

Only 28(32%) of the 89 respondents indicated that they were aware of debris flow hazard, whereas 61(68%) residents were not. For residents who were aware of debris flow hazard, main reason of awareness was “they had never experienced such torrential rain and thunder” (7(28%) of the 25 respondents). For residents who were not aware of debris flow hazard, main reason of no awareness was “never imagined a debris flow could occur” (27(50%) of the 54 respondents). There are also some who lived without any doubts about their safety, and provided responses such as “I heard this

area was safe". Just over half (44(48%) of the 90 respondents) reported that they evacuated to second floor of their own house. Among the evacuees to second floor, 22(50%) of the 44 respondents reported already being on second floor and remaining there. 4(9%) of the 44 residents reported evacuating from first floor to second floor. Locations of the remaining 18 residents were unknown. Among the 22 residents who remained on second floor, only 2 residents indicated that they intentionally stayed; among which 1 resident reported "outside was dangerous" and other resident reported "second floor is always safer". Thus, only 6 (14%) of 44 residents intentionally evacuated vertically. As for the evacuation time, only 2(6%) of the 31 respondents evacuated between 2 a.m. and 3 a.m. before the debris flow occurrence. No death was reported among those who stayed in wooden residential structures with partial destruction, all those who evacuated to second floor survived. Out of 17% of complete destroyed wooden residential structures, deaths were reported in 33%. 33% of them were on first floor, 67% of them are unknown. Among the loss of wooden residential structure, deaths were reported in 44% of them, 56% of them were unknown. These results indicate that vertical evacuation can be considered highly effective except in cases with loss of structures.

Figure 1 shows the distribution of hydrodynamic force categorized by degrees of damage to wooden residential structures. Hydrodynamic Force less than about 130 kN/m did not result in loss of wooden residential structures. Hence, vertical evacuation to second floor is effective when hydrodynamic force is less than about 130 kN/m.

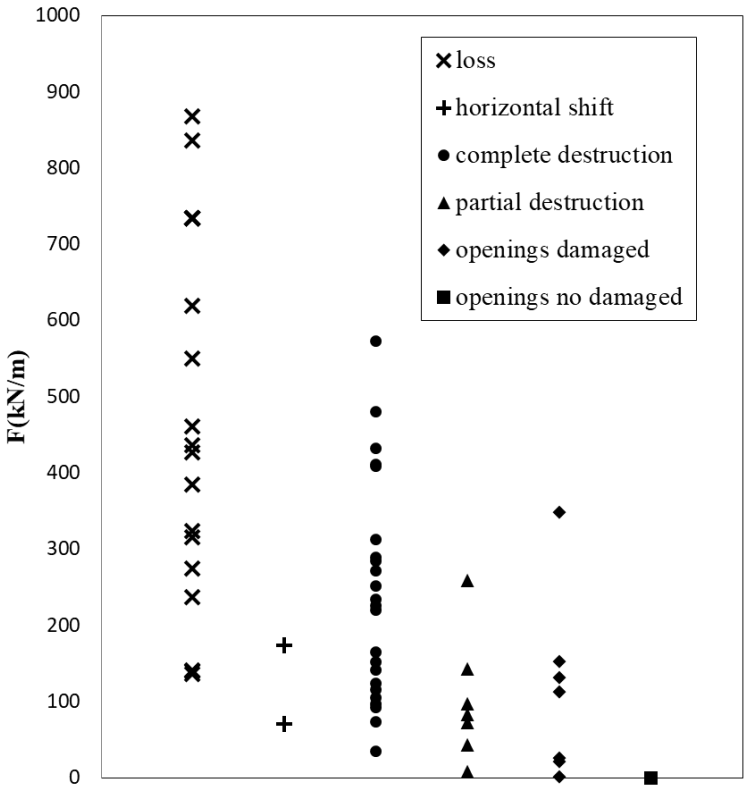

Fig. 1 Distribution of hydrodynamic force(F) categorized by the degrees of damage to wooden residential structures

CONCLUSIONS

1) Many residents were not aware of debris flow. Few residents evacuated before the debris flow occurrence. Although many residents evacuated to second floor, only 14% evacuated vertically recognizing debris-flow hazard.
2) Many residents who evacuated to second floor survived in outside areas of loss of wooden residential structures.
3) Vertical evacuation to second floor is effective when hydrodynamic force is less than about 130 kN/m.

Keywords: debris flow, vertical evacuation, questionnaire, hydrodynamic force