EXPERIMENTS OF EARTHQUAKE EARLY WARNING TO EXPRESSWAY DRIVERS USING SYNCHRONIZED DRIVING SIMULATORS

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Abstract: To reduce casualties due to earthquakes, Japan Meteorological Agency (JMA) has introduced earthquake early warning (EEW) to general public on October 1, 2007. However, the possibility that EEW causes traffic accidents exists because EEW through car radio may not be transmitted to all the expressway drivers. Hence, the effects of early earthquake warning were investigated using plural driving simulators, connected together by a server. In the virtual experiments, three driving simulators were used, simulating three cars running together on an expressway. When EEW was transmitted to all the cars, the drivers reduced speed slowly and no trouble occurred. On the contrary, when EEW was transmitted to only one car, some drivers reduced speed suddenly, and accidents occurred in 2 cases out of 14 tests. These experiments show the necessity of public education how to react EEW on expressways. Turning on the hazard lights after receiving an EEW and then reduce speed gradually is suggested to avoid accidents.

1. INTRODUCTION

The Japan Meteorological Agency (JMA) started to provide the earthquake early warning (EEW), which contains the arrival time of S-wave and the intensity of seismic motion estimated by the P-wave detection near the hypocenter (Doi, 2001). It is expected that the preparations for strong shaking and tsunami can start based on an EEW and thus, emergency responses can be performed rapidly and efficiently.

The EEW has been under operation on a trial basis since August 2006. The EEW is transmitted to construction sites, railway companies and so on, where the EEW is expected to be utilized properly without confusions. Based on the results of trial operations, the JMA started to issue the EEW to general public through radio and TV on October 1, 2007 (JMA, 2007). On the other hand, it is pointed out that some troubles may be caused when the EEW is issued to the general public. For example, it is anticipated that many evacuees may go down like ninepins at the exits of theaters and department stores.

The JMA compiled dos and don'ts after receiving the EEW (JMA, 2007). The proper behaviors during automobile driving are mentioned in the dos and don'ts. The possibility that EEW causes traffic accidents exists because the EEW through car radio may not be transmitted to all the expressway drivers. Maruyama and Yamazaki (2004) showed the effects of EEW to drivers on an expressway using a driving simulator. In the study, no other vehicles were considered except for examinee's. It is important to consider the interaction among vehicles on an expressway when the EEW is issued. In this study, the effects of EEW are investigated using three driving simulators, connected together by a server. The reactions of drivers are observed under various receiving conditions of EEW.

2. OUTLINE OF THE DRIVING SIMULATOR EXPERIMENTS

Figure 1 shows the driving simulators used in this study (Honda Motor Co., Ltd., 2001). Two regular driving simulators and one simple driving simulator that consists of only a steering wheel, brake and accelerator pedals were employed in the virtual tests. Figure 2 shows the scenario course in the experiment and the front view from the rear vehicle. The examinees were instructed to drive at the speed of 80 km/h in the left lane. In the right lane, the simple driving simulator, driven by a trained person, was assigned as a pace maker during the experiment.

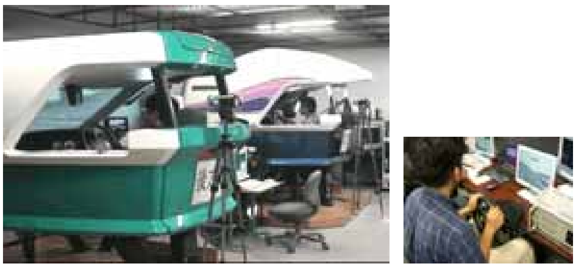

Figure 1. Synchronized driving simulators used in this study. Two regular simulators (left) and simple simulator (right).

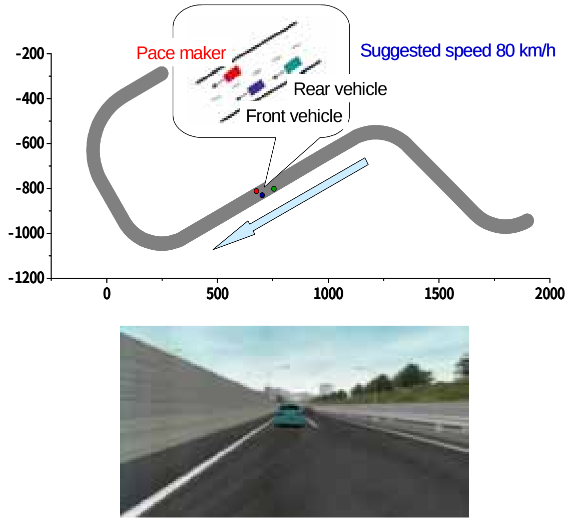

Figure 2. Scenario course in the experiment and the front view from the rear vehicle

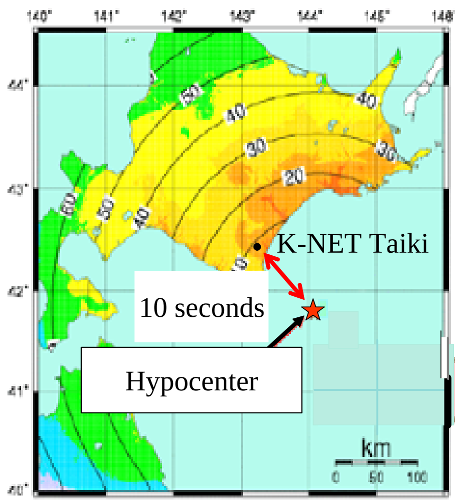

Figure 3. Scenario earthquake early warning for the 2003 Tokachi-oki EQ by JMA

The condition of an EEW was determined using the locations of the hypocenter and seismometers in the 26 September 2003 Tokachi-oki earthquake. According to the results of numerical simulation by JMA, the time between receiving the EEW and the arrival of S-wave is about 10 seconds in Taiki Town, which is located about 100 km away from the epicenter. Hence, the three-component acceleration record in K-NET Taiki Town with PGA=366.1cm/s^2 and JMA Instrumental Intensity=5.95 was used as an input seismic motion in the experiment.

The seismic response acceleration of a moving vehicle was calculated based on a vehicle response model (Maruyama and Yamazaki, 2002), and then the obtained response acceleration was applied to the driving simulators.

Three types of experiments were conducted in this study. The EEW was given neither the front vehicle nor the rear vehicle in Experiment 1 (14 pairs of drivers). The EEW was transmitted to the both vehicles in Experiment 2 (13 pairs). In Experiment 3, the EEW was given only to the front vehicle, and it was not given to the rear vehicle (14 pairs). The EEW was assumed to be transmitted by car radio, and it announced to the drivers that an earthquake has just occurred and strong motion will arrive soon.

3. RESULTS OF QUESTIONNAIRE SURVEY AFTER THE EXPERIMENTS

After the experiment, questionnaire survey was conducted to each examinee. Figure 4 shows the degree of recognition of the earthquake motion during the experiments. When the EEW was not transmitted to the drivers, about 40 % of examinees in Experiment 1 and about 70 % of examinees in Experiment 3 (rear vehicle) could not recognize the earthquake occurrence. Similar tendency was also pointed out under the actual earthquake environment (Maruyama and Yamazaki, 2006).

On the other hand, the examinees recognized the earthquake motion when the EEW was provided. If failures of road embankment or cracks of road surface are generated due to an earthquake, drivers that are unaware of the earthquake may run into the failures. The drivers that know the earthquake occurrence in advance by EEW can avoid such kind of traffic accidents. The EEW seems to be very effective in this regard.

In Experiment 3, the examinees of the front vehicle

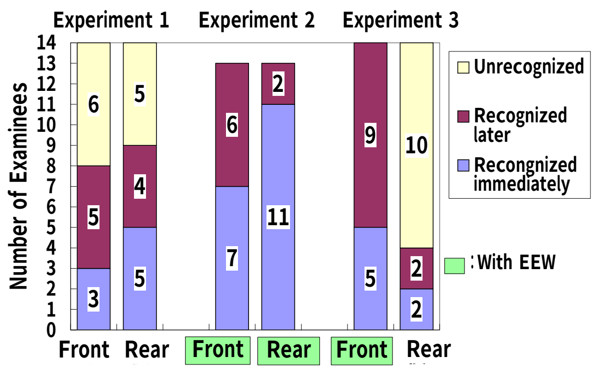

Figure 4. Degree of recognition of earthquake occurrence during the experiment

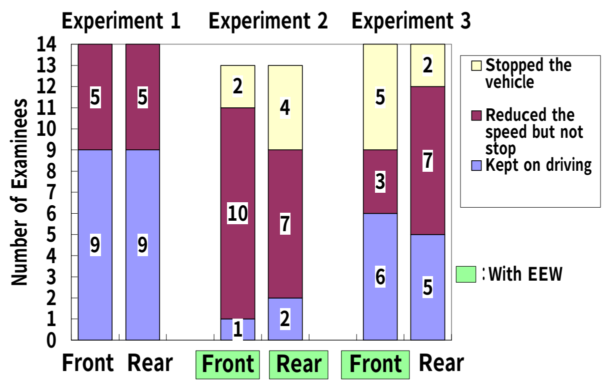

Figure 5. Reactions of the examinees during strong shaking

can recognize the earthquake occurrence owing to EEW. But the examinees of the rear vehicle may be unaware of the earthquake. The difference of earthquake recognition between the two drivers will affect drivers' behaviors during an earthquake.

Figure 5 shows the reactions of the examinees during strong seismic motion. In Experiment 1, more than half of the examinees kept on driving as usual even under strong shaking. On the contrary, many of the examinees in Experiment 2 reduced speed or stopped the car during strong shaking. Because of the EEW, the examinees in Experiment 2 recognized the earthquake. Hence, they reduced speed or stopped their vehicles to make ready for strong shaking. The results of Experiment 1 indicate that the drivers that are unaware of an earthquake may drive as usual. As for the rear vehicle in Experiment 3, less than half of the examinees kept on driving as usual though they did not recognize the earthquake. Because the examinee on the rear vehicle tried to keep the distance from the front vehicle, he reduced speed or stopped the vehicle without recognizing the earthquake.

4. RESULTS OF THE EXPERIMENTS

In the experiments, the moving speed of vehicle, the positions of brake and accelerator pedals, the angle of steering wheel and so forth were recorded to evaluate drivers' reactions during an earthquake.

Figure 6 shows the moving speeds of front vehicles in Experiments 1 and 2. The examinees in Experiment 1 drove at the speed of 80 km/h (22.2 m/s) as instructed even after main shaking because many of them did not recognize the earthquake occurrence. On the other hand, the examinees in Experiment 2 reduced the moving speed gradually after receiving the EEW. If the disorders on the road surface are generated because of strong ground shaking, the drivers with lower moving speed may avoid traffic accidents easily. According to these results, the EEW is effective for driving safety in this regard.

So far, the result of Experiment 1 when the EEW was given to neither the front vehicle nor the rear vehicle and that of Experiment 2 when the EEW was given to the both drivers were compared and discussed. If the EEW is broadcasted by TV and radio, some drivers on the expressway will receive the EEW and the others will not be informed.

Figure 7 shows the distance between the two vehicles in Experiment 3. The EEW was given only to the front vehicle in Experiment 3. The distance between the two vehicles become shorter during the EEW announcement (t = 0-5 s) in some cases. The driver on the front vehicle reduces the moving speed due to the EEW, however, the driver on the rear vehicle keeps on driving without reducing the moving speed. Two pairs of examinees out of 14 (dashed lines in Fig. 7) eventually crashed because of the information gap. In addition that, there are some cases that the distance between the two cars became too short and thought to be dangerous.

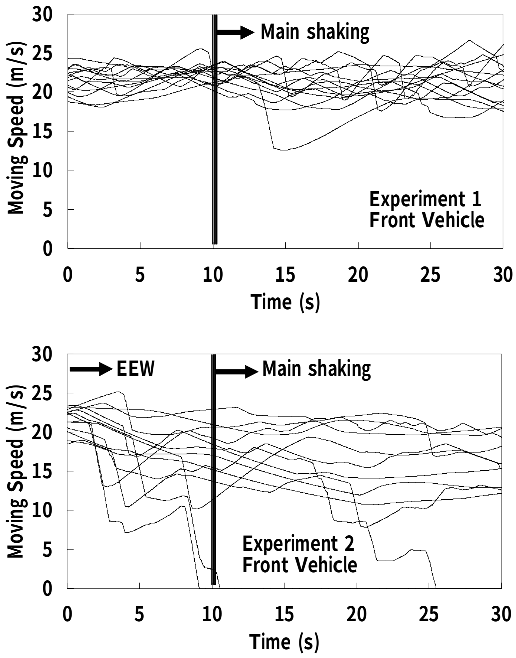

Figure 6. Comparison of moving speed in Experiments 1 and 2 (Front vehicle).

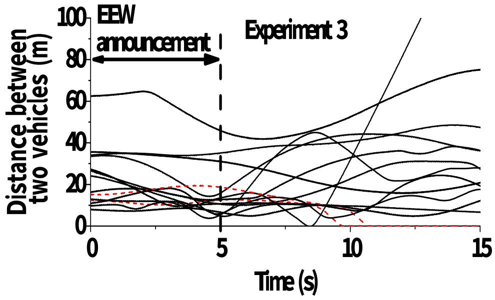

Figure 7. Distance between the two vehicles in Experiment 3

Figures 8 and 9 show examples of moving speeds of vehicles and positions of brake pedals observed in Experiments 2 and 3. When the EEW was given to the both examinees in Experiment 2 (Fig. 8), the front vehicle reduced speed gradually and the rear vehicle put on the brake in phase to keep the distance from the front vehicle.

When the EEW was given only to the front vehicle in Experiment 3 (Fig. 9), the examinee on the front vehicle put on the brake before the S-wave arrival (t = 10 s). Although the examinee on the rear vehicle tried to stop immediately, he eventually crashed to the front vehicle.

Four examinees on the front vehicle turned on hazard light before reducing the moving speeds in Experiment 3. In these cases, the rear vehicles could respond properly even though they did not receive an EEW. The intention to reduce speed of the front vehicle was conveyed to the rear vehicle by turning on hazard light. When the EEW is transmitted to general public through radio and TV, some drivers may receive the EEW and the others may not receive it at the present stage. Turning on the hazard lights by EEW

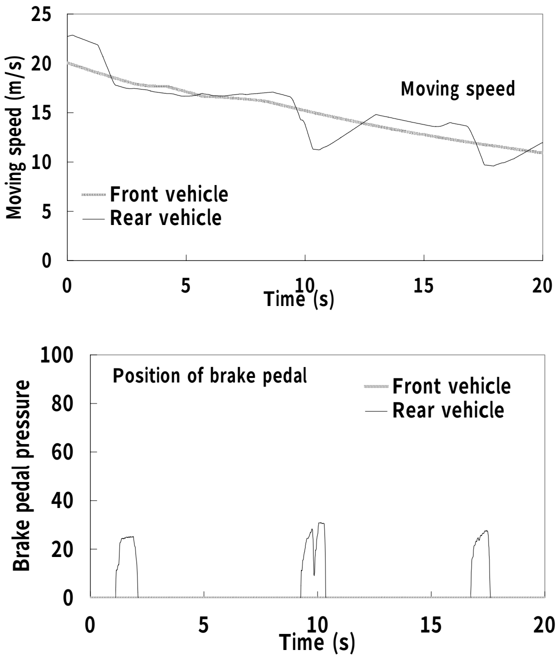

Figure 8. Examples of moving speeds and positions of brake pedals in Experiment 2

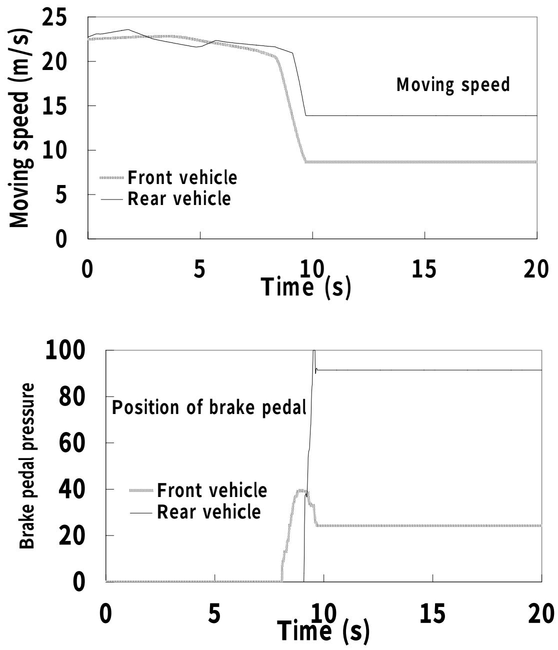

Figure 9. Examples of moving speeds and positions of brake pedals in Experiment 3

receivers is considered to be the most effective way to make the other drivers ready for an unknown hazard (a coming earthquake) on an expressway.

5. CONCLUSIONS

In this study, a series of virtual driving tests were conducted to realize the reactions of drivers under the earthquake early warning. When an EEW is given only to a part of vehicles running in close distances, the disagreement among drivers' reactions during an earthquake may cause traffic accidents. Such kind of expected events were actually occurred in the experiments using three driving simulators connected together by a server. Turning on the hazard lights by drivers that received the EEW is considered to be the effective way to make the drivers without receiving the EEW ready for unexpected hazards. To avoid accidents due to EEW from mass media, it is important to instruct drivers to turn on the hazard lights before reducing speed when receiving the EEW on an expressway.

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