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A combined method for high-speed rail seismic monitoring and early warning

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ABSTRACT

The ground motion characteristics include the strength, frequency spectrum and duration time. In China, the PGA (peak ground acceleration) is commonly used in determination of whether an earthquake warning is necessary when the high-speed train is on the rail. This method has not given an earthquake early warning time, and it only considers the strength factor of an earthquake, so the system may release an alarm for the near and small earthquakes which are no destructive. The new alarm method reconciles the timeliness and stability. It issues a P wave warning when the system receives seismic wave first, which will make the train to decelerate. Then, the system will confirm whether the P wave alarm is correct using the joint alarm result of CAV (cumulative absolute velocity) and PGA, and then take measures according to the result. The new method eliminates the interference from the near and small earthquakes, as well as the large and far earthquakes, and ensures the safety of the train when it is subjected to earthquakes. In this paper, we use seismic data to simulate the combined alarm of CAV and PGA, and then obtain the cumulative time of CAV and the time interval between CAV and PGA. Finally, we compare the new method with the double-station, earthquake monitoring alarm method which is currently used on China's high-speed rail, and find the new alarm method is better in the aspect of alarm timeliness.

1. Introduction

At present, the high-speed rail has a total mileage of more than 20,000 km in china, its operating lines account for about sixty percent of the whole world's high-speed rail operating lines, and it is the largest high-speed rail network in the world. Meanwhile, China is a country with frequent earthquakes, about 40% of its land located in the high-intensity region with the intensity above VII [1]. In order to ensure the safety of high-speed rail in the high-intensity region, Japan, France, Germany, and the South Korean have established the rail seismic monitoring and early warning system [2,3]. The early warnings are categorized into two types according to the different alarm modes: P wave warning and the seismic ground motion threshold warning [4]. The ground motion threshold warning method takes so much time to trigger warning alarms that there is insufficient time to stop trains, but it rarely generates false alarms. While the P wave warning information was released, it generally has a few seconds to tens of seconds to take corresponding measurements to control the train, but it is easy to cause false alarms under the complex vibration circumstance along the high-speed railway. At present, on the Beijing–Tianjin, Beijing–-Shanghai high-speed railways, China has constructed the earthquake monitoring early warning system on the basis of ground motion threshold alarm mode, whose principle is to set seismic monitoring sites in high-intensity region along the high-speed railway with a 20 km interval, and the alarm threshold was set to be 0.04 g (about 40 cm/s^2). In order to avoid false alarm, a car-

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control alarm is issued only when more than two adjacent monitoring sites detect the acceleration exceeding the threshold [4].

2. Development of high-speed rail seismic P wave identification technology

Rapid detection of seismic first arrival P wave and location of earthquake is required in earthquake early warning. There are a lot of methods to identify the seismic phase, but most of these methods could be poor and may lead to false identification when the seismic record has a low signal-to-noise ratio [5]. In the high-speed rail early warning, the poor or false P wave identification may lead to earthquake location deviation or false alarm. Currently, In order to facilitate system maintenance, the high-speed railway earthquake monitoring and early warning systems are all located in the substation, which means the vibrations generated by the human activities or the passing of the trains may cause false alarm of the early warning system. In order to reduce the false alarm, the domestic and foreign scholars have carried out the statistics on the P wave characteristic. In Japan, the early seismic detection and alarm systems determine the P wave by comparing 1 with the ratio of vertical amplitude to horizontal amplitude [6]. Bose et al. [7] calculated the average period *tc* and the maximum displacement *P*d within 3 s after the seismic P wave was triggered, and determined the trigger-event *tc* and *P*d, and then obtained the quality parameter *Q*. When $Q = 1$, the event is an earthquake, and signal-to-noise ratio is high; When $Q = 0.5$, it means the event maybe an earthquake with a low signal-to-noise ratio or an interference. When $Q = 0$, the event is an interference. Through the data simulation ($4 \le Ml \le 4.7$), this method can eliminate 97% false alarm caused by distant earthquake, noise, or events with poor S/N ratios, compared with the earlier used station dependent of *P*d thresholds [7]. Shinji SATO studied the difference between the train vibration and seismic wave, and found that within 2 s after the P wave was triggered, the ratio of the maximum vertical acceleration to the maximum horizontal acceleration (V/H), combined with the horizontal acceleration growth rate (B), can eliminate 97% of the interference of the passing trains [8]. But at present, there isn't an effective method to identify the single-station P wave on the high-speed railway and avoid false alarm.

3. Combined alarm method of cumulative absolute velocity (CAV) and peak ground acceleration (PGA)

It is possible to generate false alarms for the current single-station P wave warning and the seismic ground motion threshold warning based on the PGA. In order to improve the efficiency of P wave warning, the high-speed rail earthquake monitoring and early warning system can make P wave warning first; if the warning results demonstrate that the earthquake has influence on the safety of the train, the train can decelerate first, waiting for more reliable alarm signal to decide whether stop or relieve the P wave alarm. PGA is chosen as the parameter of the seismic ground motion threshold alarm; however, there is still a possibility of false alarm, so it is necessary to use a more reliable parameter to determine the influence of the earthquake on the train. The combined alarm method of CAV and PGA can effectively eliminate the interference from near and small earthquakes as well as far and large earthquakes, and can be used as a single-station alarm method to replace the PGA multiple-station alarm mode [9]. The concept of CAV was first proposed by the American EPRI (Electric Power Research Institute) [10], and the standardized CAV algorithm is:

$$CAV_{\text{Total}} = CAV_i + \int_{t_{i-1}}^{t_i} |a(\text{t})|dt \tag{1}$$

where $a(t)$ is the acceleration in the 1-s internal, among which at least one value exceed 0.025 g (about 25 cm/s^2); $i = 1, 2 \ldots n$, n represents the record length in second. Through research, it is suggested to set the alarm threshold of CAV as 0.045 g s (about 45 cm/s) in high-speed rail [9].

Setting the alarm threshold of PGA as 0.04 g (about 40 cm/s^2), alarm threshold of CAV as 0.045 g s, the earthquakes can be divided into four alarms regions according to the earthquake destruction (Fig. 1). As is shown, the 0-zone demonstrates that the earthquake has no threat to the train, and the train can keep going; 1-zone demonstrates that far and large earthquake has mild impact on the train, so a deceleration is needed; 2-zone demonstrates that near and small earthquake has mild impact on the train, so a deceleration is needed; 3-zone demonstrates that far and large earthquake has serious damage to the train, and the train needs to stop.

The combined alarm system of CAV and PGA can not only eliminate the interference from the less-destructive near and small earthquake or far and large earthquake, but also reduce the false alarm caused by single-station seismic motion threshold, because high-frequency inference like the human activity or vehicle vibration near the seismic monitoring site may exceed PGA alarm threshold value, but their vibration amplitude attenuate usually fast and duration time is not enough, so that their CAV is difficult to exceed CAV alarm threshold. Combination with P wave warning can achieve the best effect in earthquake disaster reduction.

4. Determination of the maximum cumulative time for CAV

In order to achieve the best effect in earthquake disaster reduction, the high-speed earthquake monitoring and early warning system is required to process the seismic data in real time. The real-time PGA parameter is determined by the real-time maximum acceleration given by the recorder, while the CAV, in the nuclear power design, is calculated by the whole seismic time after the earthquake. In the high-speed earthquake monitoring and early warning system, if waiting till the end of the whole earthquake event, the destruction may have occurred and the timeliness of the alarm will be greatly reduced. So it is required to set a maximum cumulative time $t_{\max}$ to calculate the CAV. If the CAV at $t_{\max}$ still not exceed 0.045 g s, this earthquake duration is

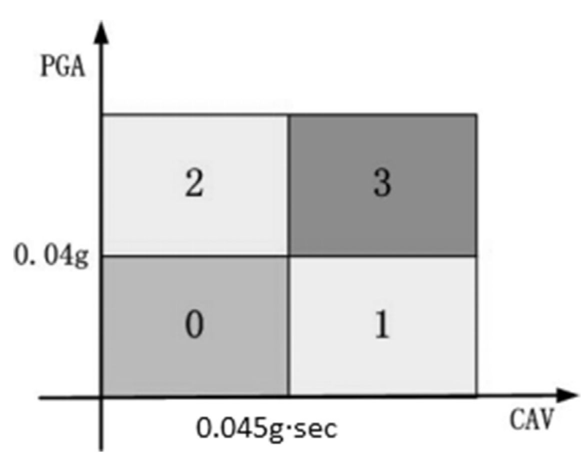

Fig. 1. Schematic diagram of the combined alarm of CAV and PGA.

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